SOUVENIR

तीसरा राष्ट्रीय सरसों सम्मेलन (एन.बी.सी. 2017)

''जलवायु–परक प्रौद्योगिकियों द्वारा तिलहन–सरसों उत्पादन में वृद्धि''

फरवरी 16–18, 2017, भा.कृ.अनु.प.–भा.कृ.अनु.सं., नई दिल्ली, भारत

3rd National Brassica Conference (NBC 2017)

"Enhancing Oilseed Brassica Production Through Climate-Smart Technologies"

February 16-18, 2017, ICAR-IARI, New Delhi, India

Unlocking secrets of the Brassica: A plethora of exciting possibilities

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ICAR- Indian Agricultural Research Institute, New Delhi
Directorate of Rapeseed Mustard Research, Bharatpur
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3rd NATIONAL BRASSICA CONFERENCE (NBC - 2017)

"Enhancing Oilseed Brassica Production Through Climate Smart Technologies "

February 16-18, 2017, ICAR-IARI, New Delhi, India

Souvenir & Abstracts

Organizers

Citation

Sujata Vasudev, D.K. Yadava, Sangita Yadav, Naveen Singh, Navinder Saini, Mukesh Dhillon, S.S. Rathore, Yashpal Vinod Kumar and P.D. Meena (2017) Souvenir: 3rd National Brassica Conference on "Enhancing Oilseed Brassica Production Through Climate Smart Technologies" organized by Society for Rapeseed Mustard Research, Bharatpur at ICAR-IARI, New Delhi, India during February 16-18, 2017. pp. 269.

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Acknowledgements

We extend our thanks to all authors and contributors

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Published by

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Printed at

Angel Printers, C-116, Naraina Industrial Area, Phase-1, New Delhi - 110 028
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3rd National Brassica Conference – 2017

"Enhancing Oilseed Brassica Production Through Climate-Smart Technologies"

ICAR-IARI, New Delhi, February 16-18, 2017

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Abstracts

Preface

After the U.S., China and Brazil, India is world's fourth largest edible oil economy. It contributes almost six per cent of global vegetable oil production; 14 per cent of vegetable oil imports and 10 per cent of edible oils. The total market size of the Indian oilseed sector is about Rs 600 billion (US$13.4 billion). In the context of national agricultural system, oilseeds occupy 13 per cent of the country's gross cropped area and 3% to gross national products and 10% value of all agricultural products. Groundnut, soybean and rapeseed-mustard are the major oilseed crops contributing approximately 80 per cent of production. The average contribution of rapeseed-mustard to the total oilseed production in India was 24.2%. Oilseed Brassicas grown in India are *B. juncea, B. rapa. B. napus* and *B. carinata. B. juncea* predominates and accounts for about 90% area under rapeseed-mustard crops. These crops are grown under diverse agro-climatic conditions.

As India is highly dependent on edible oil imports to meet its domestic demand, hence, attaining self-sufficiency in edible oil sector is crucial to reduce current deficit and to ensure edible oil security for increasing population. This necessitates a comprehensive road map to meet the challenge of bridging the widening gap of demand and production of edible oil for which a common platform is essential to bring all stakeholders under one banner. Keeping this in view t**he "Society for Rapeseed Mustard Research"** was established in December 2008 at the Directorate of Rapeseed Mustard Research, Bharatpur with the primary objectives of organizing meetings, conferences, seminars, etc. with the aim of diffusing knowledge in rapeseed-mustard research and technology development among scientists and others; endeavouring to cooperate with other scientific bodies with common interests; encouraging original investigations and scientific studies in the field of rapeseed-mustard research and publishing research work and making them available online, wherever possible. Rapeseed-mustard is expected to play a major role, however, attempts to enhance its productivity significantly are not fully successful due to their cultivation under diverse and mostly constrained ecologies. Climate change can further limit the productive potential of the crop.

It gives us immense pleasure that this souvenir containing papers from lead speakers and abstracts of research papers is brought out on the occasion of 3rd National Brassica Conference on the theme 'Enhancing Oilseed *Brassica* Production Through Climate-Smart Technologies' to provide an overview of the basic and applied research in rapeseed mustard. We sincerely hope that this conference will certainly provide a platform to prepare a roadmap for enhancing the rapeseed mustard production to meet the challenges of climate change. We are grateful to the members of the Publication Committee for their concerted efforts in compilation of this Souvenir and also to all contributors of papers and abstracts; members of all committees involved in organization and sponsors,

(K.V. PRABHU) (ARVIND KUMAR)

MESSAGES

राधा मोहन सिंह
RADHA MOHAN SINGH

कृषि एवं किसान कल्याण मंत्री
भारत सरकार
MINISTER OF AGRICULTURE
& FARMERS WELFARE
GOVERNMENT OF INDIA

14.02.2017

MESSAGE

I am happy to know that the Society for Rapeseed Mustard Research, Bharatpur is organizing the 3rd National Brassica Conference on the theme "Enhancing Oilseed Brassica Production Through Climate-Smart Technologies" during 16-18 February, 2017 at ICAR - Indian Agricultural Research Institute, New Delhi in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences, New Delhi.

Agriculture constitutes the lifeline of India, which is directly associated with 67.63% livelihood of our population. Indian Agriculture has made impressive progress over the years and phenomenal growth has been observed in oilseed production. Even after all hard work of our scientists, development departments and farmers, our edible oil imports are increasing year by year which needs special attention by all involved in research, development and production. The theme and timing of the seminar selected both are very appropriate. The deliberations during this Conference would further improve the edible oil situation in general and rapeseed mustard in particular which will help in narrowing down the gap between demand and availability of edible oils in the country. I am sure that with supportive Government policies, it will become still more relevant to accelerate spread of high yielding varietal and other improved technologies to the farmers.

The Conference, I trust, offers an opportunity for every stake holder to exchange ideas for highlighting the critical role of new crop varieties and other production technologies in providing dynamic and sustainable oilseed production.

On this occasion, I extend my greetings and felicitations to the participants and the organizers and wish the Conference all success.

Radha Mohan Singh
(RADHA MOHAN SINGH)

Office: Room No. 120, Krishi Bhawan, New Delhi-110 001 Tel.: 23383370, 23782691 Fax : 23384129

परशोत्तम रूपाला
PARSHOTTAM RUPALA

कृषि एवं किसान कल्याण और
पंचायती राज राज्य मंत्री
भारत सरकार
**Minister of State For Agriculture &
Farmers Welfare and Panchayati Raj
Government of India**

सत्यमेव जयते

February 8, 2017

MESSAGE

I am pleased to know that the Society for Rapeseed Mustard Research, Bharatpur in collaboration with Indian Council of Agricultural Research and National Academy of Agricultural Sciences is organizing the 3rd National Brassica Conference on the theme "Enhancing Oilseed Brassica Production Through Climate-Smart Technologies" during 16th – 18th February, 2017 at ICAR – Indian Agricultural Research Institute, New Delhi.

Rapeseed and mustard have been the major component among the seven edible oilseed crops grown in our country. This group of crops has progressed well in terms of area expansion and productivity enhancement, leading to more than 30% share in edible oil production in the country. Rapeseed mustard is the best suited crop under the changing climate and will definitely play a major role in improving the edible oil situation in the country. I am sure that the critical issues related to yield enhancement, faster spread of improved technologies, public-private partnership and problems being faced by the rapeseed mustard growing farmers will be addressed in detail during the three days deliberations and a roadmap will be defined which will help in ensuring edible oil security of our country.

I extend my good wishes for the success of this Conference.

(Parshottam Rupala)

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S. S. AHLUWALIA

सत्यमेव जयते

कृषि एवं किसान कल्याण और
संसदीय कार्य राज्य मंत्री
भारत सरकार
MINISTER OF STATE FOR AGRICULTURE
& FARMERS WELFARE AND
PARLIAMENTARY AFFAIRS
GOVERNMENT OF INDIA

8 FEB 2017

MESSAGE

I am happy to know that the Society for Rapeseed Mustard Research, Bharatpur and ICAR - Indian Agricultural Research Institute in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences, New Delhi are organizing the 3rd National Brassica Conference on the theme "Enhancing Oilseed Brassica Production Through Climate-Smart Technologies" during 16-18 February, 2017 at ICAR - Indian Agricultural Research Institute, New Delhi.

Since implementation of Technology Mission of Oilseeds in 1985-86, a tremendous progress has been witnessed in the edible oil crops in terms of yield enhancement and area expansion, yet India is largely dependent on edible oil imports to cater our domestic requirements. The impact of high yielding varieties and hybrids with improved production technology in boosting productivity under the uncertain and vagaries of climate is well known. Both the Central and State Governments are committed to overcome all types of challenges through various programmes and policies to increase rapeseed mustard.

I hope that the 3rd National Brassica Conference (NBC-2017) on "Enhancing Oilseed Brassica Production through Climate-Smart Technologies" will provide an excellent forum to all the participants for meaningful discussions on current issues and future challenges in rapeseed mustard production.

I convey my best wishes for the success of the Conference.

(S. S. Ahluwalia)

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भारत सरकार
MINISTER OF STATE
FOR AGRICULTURE &
FARMERS WELFARE
GOVERNMENT OF INDIA

सत्यमेव जयते

MESSAGE

I am very happy to know that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are organizing the 3rd National Brassica Conference on the theme "**Enhancing Oilseed Brassica Production Through Climate-Smart Technologies**" during **16-18 February, 2017** at **New Delhi.**

Rapeseed and mustard contribute about 30% of the edible oils production in our country. Keeping the productivity levels of around 20 q/ha at global level, this crop has great potential and there is ample scope of productivity enhancement. However, the unfavourable climatic conditions and other biotic factors pose potential threats that needs to be resolved in a scheduled time frame to make this crop more remunerative, competitive and secure, leading to enhanced income of the farmers. With the efforts of research and development agencies, combined with the hard work of our farmers, rapeseed-mustard is going to have a major say in the country's oilseed economy under the changing climatic scenario. I am sure that the important issues will find a place in the deliberations during these three days.

(Sudarshan Bhagat)

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National Academy of Agricultural Sciences

Dr. V. L. CHOPRA
Former President, NAAS

MESSAGE

I am happy to learn that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are jointly organizing the 3rd National Brassica Conference on the theme “Enhancing Oilseed Brassica Production Through Climate-Smart Technologies” during 16-18 February, 2017 in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences, New Delhi at Pusa Campus, New Delhi.

With advancements in variety and hybrid development and support of refined farming technologies, rapeseed - mustard has taken a pivotal role in Indian edible oil economy. The situation demands that a thorough review is taken for designing new initiatives and research directions for solving the problems facing this very important oilseed crop so that timely intervention can duly safeguard farmers' interest. Many recent developments, including incisive genomic tools and technologies have now become available for designing modern cultivars with high productivity combined with resilience to destabilising factors like pests, pathogens, weeds and ill-effects of climate change.

To convert the current challenges into opportunities, there is also need to address many policy issues that portend far reaching influence on the Indian oilseed economy. To achieve these goals a conference of this magnitude is ideal for bringing all stakeholders together on one platform.

I congratulate the organizers of the Conference for this initiative and hope that useful recommendations will emerge from its in-depth deliberations.

(V. L. CHOPRA)

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taas
Progress Through Science

Dr. R.S. Paroda
Founder Chairman

MESSAGE

It is a pleasure to know that the Society for Rapeseed Mustard Research, Bharatpur. ICAR-Indian Agricultural Research Institute and National Academy of Agricultural Sciences, are organizing the 3rd National Brassica Conference on "**Enhancing Oilseed Brassica Production Through Climate-Smart Technologies**" during 16-18 February, 2017 at Indian Agricultural Research Institute, New Delhi.

India is a major producer and consumer of oilseeds and to meet the domestic demand country imports edible oil worth more than 70,000 crores annually accounting for more than 50% of the total value of agricultural imports. Among the various edible oils, mustard oil occupies a prime position as a cooking medium. The importance of the Indian mustard among Brassica can be gauged from the fact that rapeseed mustard contributes nearly 24% of our total oil seed production and 90% area under Brassica crops. The climatic changes and associated abiotic and biotic stresses have emerged as new challenges. Hence, this conference is a very timely initiative.

It is hoped that the 3rd National Brassica Conference (NBC-2017) will provide an opportunity for diverse stakeholders to deliberate on current and emerging concerns for increasing mustard production and will come out with useful recommendations as Road Map to address all challenges successfully.

I convey my best wishes for the success of the Conference.

(R.S. Paroda)
Chairman, TAAS
Former Director General, ICAR and
Secretary, DARE, Govt. of India

National Academy of Agricultural Sciences

Dr. Mangala Rai
Former President, NAAS

MESSAGE

I am pleased to learn that the Society for Rapeseed-Mustard Research Bharatpur and Indian Agricultural Research Institute of ICAR and National Academy of Agricultural Sciences, New Delhi are organizing the 3rd National Brassica Conference on the theme "Enhancing Oilseed Brassica Production through Climate-Smart Technologies" during 16-18 February, 2017 in New Delhi.

The Technology Mission on Oilseeds launched during 1986 had witnessed a quantum jump in oilseeds productivity and productions in a short span of a decade despite the oilseed crops were cultivated under low input rainfed conditions. However climate change is becoming more obvious now, the climate sensitive Indian agriculture is becoming highly vulnerable. According to the South Asian Disaster Report of 2009, India ranks in the risk class level 9 on a 0 to 10 scale and the crop production is likely to be most affected in Indo-Gangetic Plains. The climate impacts on crops will vary widely in rainy and winter season. In general pulses would be more vulnerable than the cereals. Among cereals, wheat yield will be less by about 22%, almost 3 times that of barley. Similarly, in rainy season, rice will be affected more than maize and sorghum. Groundnut also stands to lose, but rapeseed-mustard would surprisingly to be least affected according to some recent projections. Adaptation, mitigation and natural resource management are basic to sustainability of crop production. Therefore, fast changing climatic conditions and crop growing situations demand a re-look on our research and development strategies and matching policies in proper perspectives.

The organization of 3rd National Brassica Conference (NBC-2017) is, therefore, timely to take stock of the situation and assess future strategic options available for an important oilseed crop of the country. I trust that the Conference will provide an excellent platform for fruitful scientific deliberations.

My best wishes for the success of the Conference.

(MANGALA RAI)

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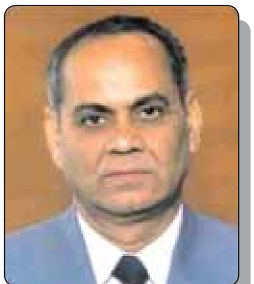
National Academy of Agricultural Sciences

Prof. Panjab Singh
President



MESSAGE

I am glad to know that the 3rd National Brassica Conference on the theme "**Enhancing Oilseed Brassica Production Through Climate-Smart Technologies**" is being organized jointly by the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute, New Delhi in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences, New Delhi at Indian Agricultural Research Institute, New Delhi during 16-18 February, 2017.

In the past decades, research and development efforts have played an important role in improving the national oilseed production but still it is far below to meet our total demand. In the present scenario of higher demand for vegetable oils and climate uncertainties, the challenges confronting the oilseed sector are greater than ever before. In this regard, several initiatives have been taken by the Government of India and National Agricultural Research System to boost the oilseed production. However, issues concerning emerging climate related threats and scientific advancement pertaining to oilseed crops in general and rapeseed-mustard in particular still remains to be addressed systematically.

I hope that the National Brassica Conference-2017 is an appropriate platform for the delegates, scientists and policymakers to discuss on the researchable issues and to evolve a strategic plan with concrete recommendations with a plan of action to address the oilseed production in context of country's economy.

I wish the organizers the Conference a great success.

(Panjab Singh)

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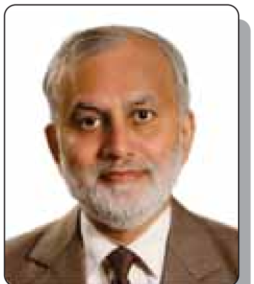

MESSAGE

National Academy of Agricultural Sciences has desired the Professional Associations of Agricultural Sciences (PAAS) to organize a symposium on "Climate Smart Agriculture", connecting to the specialized area of society before 13th Agriculture Science Congress scheduled to be held at Bengaluru from February 21-24, 2017. It is my pleasure to learn that Society for Rapeseed-Mustard Research (SRMR), Bharatpur is organizing **3rd National *Brassica* Conference** on **'Enhancing Oilseed *Brassica* Production through Climate-Smart Technologies'** at the ICAR-IARI, New Delhi during February 16-18, 2017, in collaboration with ICAR- Indian Agricultural Research Institute and National Academy of Agricultural Sciences, New Delhi.

The National Conference shall deliberate on major themes viz., **Innovative approaches to rapeseed-mustard breeding; Climate ready resource-use efficient production technology; Climate impact mitigation strategies for crop Protection and Trading policies and Innovative approaches for technology dissemination etc.** The deliberations emanating from the conference would provide the much needed impetus to enhance the productivity of oilseeds.

India is the second largest importer of edible oilseeds, after China and the country has to spend huge amount annually to augment the domestic supplies. Thus, attaining self-sufficiency in edible oil sector is crucial for reducing the deficit and ensuring supply to the burgeoning population. This necessitates the development of road-map to meet the challenge under climate adversities and bridging the widening gap of demand and supply of edible oils. Rapeseed-Mustard, being a potential crop has the capability to sustain and improve farmer's income under diverse and mostly constrained ecologies.

The organization of the conference is expected to meet the aspirations of various stakeholders by providing stimulating platform for discussing key issues related to Climate Smart Oilseed Brassica technologies and policies.

I convey my best wishes for the grand success of the Conference.

(S. AYYAPPAN)

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त्रिलोचन महापात्र, पीएच.डी.
एफ एन ए, एफ एन ए एस सी, एफ एन ए ए एस
सचिव एवं महानिदेशक

TRILOCHAN MOHAPATRA, Ph.D.
FNA, FNASc, FNAAS
SECRETARY & DIRECTOR GENERAL

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली 110 001

GOVERNMENT OF INDIA
DEPARTMENT OF AGRICULTURAL RESEARCH & EDUCATION
AND
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
MINISTRY OF AGRICULTURE AND FARMERS WELFARE
KRISHI BHAVAN, NEW DELHI 110 001
Tel.: 23382629; 23386711 Fax: 91-11-23384773
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MESSAGE

I am happy to know that the Society for Rapeseed Mustard Research, Bharatpur and Indian Agricultural Research Institute, New Delhi are jointly organizing the 3rd National Brassica Conference on the theme "Enhancing Oilseed Brassica Production through Climate-Smart Technologies" during 16-18 February, 2017 at New Delhi.

Technology Mission of Oilseeds and Pulses, ever since 1986, has resulted in a quantum jump in area, production and productivity of edible oilseed crops in the country. Among the edible oilseeds, rapeseed-mustard ranks second in production and contributes to more than 30% of edible oil production in the country. To overcome the challenges being faced by the crop owing to climatic variability and associated impacts on crop growth and production, it becomes imperative that the issues should be addressed strategically involving both public and private sector organizations to bridge the R&D gaps.

I am sure, the deliberations in this Conference, particularly on the issues pertaining to innovative approaches for genetic enhancement and improved crop production and protection technologies under changing climate, quality enhancement and public-private partnership will help in developing a roadmap for ensuring oilseed security of the country.

I wish the Conference a great success.

(T. MOHAPATRA)

Dated the 9th February, 2017
New Delhi

कृषि वैज्ञानिक चयन मंडल
(भारतीय कृषि अनुसंधान परिषद)
कृषि अनुसंधान भवन–I, पूसा, नई दिल्ली 110 012

AGRICULTURAL SCIENTISTS RECRUITMENT BOARD
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Dr GURBACHAN SINGH
CHAIRMAN

MESSAGE

I am indeed very happy to know that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are organizing the 3rd National Brassica Conference on the theme "**Enhancing Oilseed Brassica Production Through Climate-Smart Technologies**" during 16-18 February, 2017 in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences at Pusa Campus, New Delhi.

The country spends over rupees 60,000 crores annually to augment domestic edible oil requirements. Thus, attaining self-sufficiency in edible oil sector is crucial for reducing current account deficit in view of increasing population. Rapeseed-mustard is expected to play a major role in bridging the widening gap of demand and production of edible oils. However, attempts to enhance productive potential of the crop significantly are not fully successful due to their cultivation under diverse and constrained ecologies. It is necessary that key issues related to 'Climate-Smart Oilseed Brassica production' in all its facets; including socio-economic, empowerment of marginal farmers through technology development and policy initiatives for sustainable farming, and natural resource management in tune with global climate change are deliberated among all the stakeholders.

I am sure that this Conference will provide opportunities to discuss emerging issues related to assured oilseed supply for oil security of the country.

I wish a grand success for this Conference.

(GURBACHAN SINGH)

प्रो० आर. आर. हंचिनाल
अध्यक्ष
पौधा किस्म और कृषक अधिकार संरक्षण
प्राधिकरण, भारत सरकार
एन.ए.एस.सी. काम्प्लैक्स, डीपीएस मार्ग,
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Prof. R.R. Hanchinal
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Dated: 8th February, 2017

MESSAGE

I am happy to learn that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are organizing the 3rd National Brassica Conference on the theme "**Enhancing Oilseed Brassica Production Through Climate-Smart Technologies**" during 16-18 February, 2017 in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences, New Delhi at Pusa Campus, New Delhi.

Since the implementation of Technology Mission of Oilseeds and Pulses in the Country, the National Agricultural Research System has played significant role in enhancing the production and productivity of edible oilseed crops by developing high yielding varieties, ensuring the supply of breeder seed and transferring the technologies to farmers' fields. With the changing climate and global scenario in terms of technological advancements and global oilseed trade, it is appropriate that this National Conference will provide an excellent opportunity to the rapeseed-mustard researchers, technologists and policymakers to discuss the most important issues being faced by the farmers presently and in the years to come.

I am confident that the National Brassica Conference will provide the needed opportunities for interaction on the development of technologies and formulation of policy issues for enhancing the productivity and production in rapeseed-mustard.

I wish the Conference a grand success.

(R.R. HANCHINAL)

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सत्यमेव जयते

भारत सरकार
कृषि एवं किसान कल्याण मंत्रालय
कृषि अनुसंधान एवं शिक्षा विभाग
कृषि भवन, नई दिल्ली-110001
GOVERNMENT OF INDIA
MINISTRY OF AGRICULTURE AND FARMER'S WELFARE
DEPARTMENT OF AGRICULTURAL RESEARCH AND EDUCATION
KRISHI BHAWAN, NEW DELHI-110001

MESSAGE

I am glad to learn that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are organizing the 3rd National Brassica Conference on the theme "Enhancing Oilseed Brassica Production Through Climate-Smart Technologies" during 16-18 February, 2017 in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences, New Delhi at Pusa Campus, New Delhi.

The country has made significant progress in agricultural production and productivity over the past 3-4 decades along with oilseed crops. However, continuous research and developmental efforts are required to ensure oil and nutritional security on a sustainable basis. The ever increasing population coupled with emerging issues of sustainability and the increasing globalization of the economy is posing fresh challenges. The issues related to oilseed production and trade needs to be addressed within the global framework.

I sincerely hope that these rapeseed-mustard related issues will be discussed and deliberated during the Conference. I take this opportunity to wish the Conference a grand success.

(Chhabilendra Roul)

डॉ. जीत सिंह सन्धू
उपमहानिदेशक (फसल विज्ञान)

Dr. Jeet Singh Sandhu
Deputy Director General
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भाकृअनुप
ICAR

भारतीय कृषि अनुसंधान परिषद्
कृषि भवन, डा. राजेन्द्र प्रसाद मार्ग, नई दिल्ली - 110001

INDIAN COUNCIL OF AGRICULTURAL RESEARCH
KRISHI BHAWAN, DR. RAJENDRA PRASAD ROAD, NEW DELHI-110001

MESSAGE

I am extremely happy that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are organizing the 3rd National Brassica Conference on the theme "**Enhancing Oilseed Brassica Production Through Climate-Smart Technologies**" during 16-18 February, 2017 in collaboration with the Indian Council of Agricultural Research (ICAR) and National Academy of Agricultural Sciences at Pusa Campus, New Delhi.

Indian Agriculture has grown impressively in terms of oilseed productivity and production after the implementation of Technology Mission on Oilseeds and Pulses and the NARS has played a critical role in this growth. The widening gap between the demand of edible oils and its domestic availability is leading to imports of huge quantity of edible oils, which incurs over Rs. 60,000 crores on the foreign exchequer. Hence, it becomes imperative to have further insights into the researchable issues of rapeseed mustard for enhanced productivity in light of changing climate and competition with contemporary crops. The researchable issues pertaining to the genetic improvement, input management for higher cost- benefit ratio and policies are required to be deliberated to devise a pragmatic roadmap and possible solutions.

It is expected that deliberations in the Conference will culminate in formulating concrete recommendations and a plan of action to address the entire gamut of issues emerging under changing climate scenario.

I convey my best wishes for a great success of this Conference.

(JS SANDHU)

New Delhi

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क. अलगुसुन्दरम
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Deputy Director General (Engineering)

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INDIAN COUNCIL OF AGRICULTURAL RESEARCH
KRISHI ANUSANDHAN BHAVAN-II,
PUSA, NEW DELHI-110 012

MESSAGE

I am happy to learn that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are organizing the 3rd National Brassica Conference on the theme **"Enhancing Oilseed Brassica Production Through Climate-Smart Technologies"** during 16-18 February, 2017 in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences, New Delhi at Pusa Campus, New Delhi.

Since independence, India has made significant progress in agriculture. The genetic advancement in this crop along with the development of location-specific production technologies has been tremendous and impressive. However, production and productivity of oilseeds, including rapeseed-mustard has been challenged by many inherent as well as external factors, in the wake of degrading resources and changing climate. Hence, these issues need to be addressed through various technological interventions for sustainable increase in rapeseed-mustard productivity and farmers' income in order to achieve national edible oil security and development goals under changing climate scenario.

I hope the National Brassica Conference (NBC-2017) will provide an opportunity to delegates, scientists and policymakers to reflect on this important theme **"Enhancing Oilseed Brassica Production Through Climate-Smart Technologies"** and evolve a strategy to address the various issues confronting the oilseed sector.

I wish the Conference a grand success.

9/2/17

K. Alagusundaram

CENTRE FOR GENETIC MANIPULATION OF CROP PLANTS (CGMCP)
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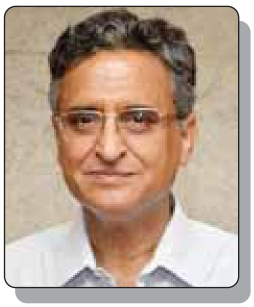

MESSAGE

Brassica crops are contributing in a major way to global edible oil production. Productivity in rapeseed has increased significantly in Europe, Canada and China due to extensive deployment of hybrids. Mustard is most important oil seed crop of India. It is well adapted to dry land agriculture and therefore of great value to the farmers in these areas.

Currently intensive work is being carried in our country on genetics and genomics of mustard. We need both productivity enhancement and protection. The current meeting is very timely as it will bring all stake holders in mustard breeding together to analyze the progress made on technology development and its demonstration in the farmer's field.

Deepak Pental

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ICAR - INDIAN AGRICULTURAL RESEARCH INSTITUTE
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MESSAGE

I am extremely happy that the Society for Rapeseed Mustard Research, Bharatpur and ICAR-Indian Agricultural Research Institute are organizing the 3rd National Brassica Conference on the theme “Enhancing Oilseed Brassica Production Through Climate-Smart Technologies” during 16-18 February, 2017 in collaboration with the Indian Council of Agricultural Research and National Academy of Agricultural Sciences at ICAR-Indian Agricultural Research Institute, New Delhi.

The importance of oilseed as the energy provider is well known. Rapeseed mustard plays a pivotal role in our oilseed economy. The high yielding varieties and hybrid development, input responsive technologies, disease and pest management technologies and better economic policies have helped in enhancing the oilseed production in the country.

In order to meet the challenges Indian scientists, policy planners in the public and private sectors need to join hands to formulate a strong and sustainable oilseed research programme on Brassicas. I am confident that the National Brassica Conference (NBC-2017) will provide the necessary platform for the same.

I extend my warm wishes to all the delegates for very productive deliberations during the Conference.

(RAVINDER KAUR)

LEAD LECTURES

Enhancing production and productivity of oilseed *Brassica* in India: Research needs for 21st century

P.R. Kumar
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- India is one of the largest cultivators of oilseed crop.
- An exceptional increase from 6.2 kg/year per capita consumption of edible oils in 1986-87 (under Technology Mission on Oilseeds, to make India nearly self-reliant) to 14.2 kg/year during 2012-13 has been achieved.
- Rapeseed-mustard, a crop commodity, commonly referred to as *Sarson*, is the third most important source of edible oil after soybean and oil palm.
- In India, it is an important cooking medium and dietary fat of the majority of northern, north-western, central, eastern and north-eastern states.
- It is the most common medium of pickling and food preservation.
- Oilseed production is facing challenges due to biotic and abiotic stresses, deteriorating natural resources, climate change and fragmented land holdings.
- Projected annual demand of total vegetable oils by 2025 is 27.0 mt, while for rapeseed-mustard, it is 14.03 mt to meet enhanced per capita consumption of 16.98 kg/year.
- On the other hand domestic production of edible oils has remained almost static during last five years, hence it is challenging to achieve the goal.
- For achieving projected demand, both vertical and horizontal growth approaches would be required.
- Heterosis breeding should be the major focus.
- Identification of trait specific germplasms, pre-breeding and genetic enhancement, gene pyramiding through marker assisted breeding, allele mining, proteomics etc. would facilitate better exploitation of the available genepools in order to overcome the production constraints.
- For horizontal growth narrowing the yield gaps and bringing additional area under cultivation are viable approaches.
- An estimated area of 2.00 mha could be brought under rapeseed-mustard cultivation from Eastern Uttar Pradesh, Bihar, West Bengal, NEH States, Asom, Madhya Pradesh, Jharkhand, Odisha and Chattisgarh under the rice-fallow cropping system.
- Non traditional areas such as Karnataka, Vidarbha region of Maharashtra, Andhra Pradesh and Tamilnadu could contribute upto 1.0 mha area for cultivation of this crop.
- This paper would deal with immediate research needs for conventional breeding with emphasis on sustainability, exploitation of available genetic variability in complementation with genomic resources and genetic engineering.

Oilseed technologies towards self sufficiency in changing climate scenario

Arvind Kumar

Vice-Chancellor, Rani Lakshmi Bai Central Agricultural University, Jhansi

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1. Preamble

Vegetable oils are critical for nutrition, energy and economy of the country and in global commodity supplies. Self¬ sufficiency in vegetable oil requirement is envisioned to be achieved through relevant technological back- stopping and integration. The oilseeds sector has been vibrant and dynamic of world agriculture growing at 4.1 % production per annum in the last three decades surpassing the growth of agriculture including livestock products. The demand-supply gap will widen in near future due to rapid increase in demand exceeding the moderate increase in supplies. The growth in vegetable oil supplies is constrained due to their cultivation under shrinking resource base, input supplies and uncertain profitability, while the demand increases at an increasing rate due to rise in per capita income and improved standard of living. The per capita demand for Oil crops at the global level is expected to increase rapidly than that of cereals due to the diversion of vegetable oils for energy and non-food uses. The projections of world feed use of cereals & oilcakes production towards the livestock component clearly indicates that it has increased four times by 2010 (240 million tons) over 1980 and would touch 400 million tons by 2050. The shift towards more balanced feed rations in the recent past puts enormous pressure on the use of protein rich oilcakes. Of all the arable crops, markets for oilseed commodities are set to undergo the greatest expansion wherein global oilseed production is likely to double the level observed in the last two decades. The per capita consumption of vegetable oils is expected to increase by 60% in developing countries through the first half of the century; in South Asia, this consumption is projected to be almost double (FAO, 2006). The global demand for vegetable oil for substituting fossil fuel will grow steeply to meet the Inter-Governmental Panel on Climate Change (IPCC) guidelines.

Three decades ago, consumption of oil crop products (4.9 kg/person/ year. In oil equivalent) supplied only 136 kcal/person/day, or 6.5% of the total availability of 2110 K calories in the developing countries. By 1999/01, per capita consumption had grown to 10.4 kg contributing 272 kcal to total food supplies, or 10 per cent of the total which itself had risen to 2650 kcal.

Growing contribution of vegetable oils to food supplies and food security

World production, consumption and trade in vegetable oils have been increasingly dominated by a small number of crops viz., oil palm, soybeans and rapeseed providing 82% of the total increment in world oil crop production since 1990 (in oil equivalent) with oil palm contributing to the major chunk of increment. Vegetable oils provide the much needed food security measured as meeting calorie requirements in poverty assessments. Rapid growth of food demand in the developing countries, in conjunction with the high calorie content of oil products, has contributed to the increases achieved in calorie consumption in these countries. One out of every four calories added to the consumption of the developing countries over this period originated in this group of products. In future, vegetable oils are likely to retain, and indeed strengthen, their primacy as major contributors to increases in food consumption of the developing countries.

I am alarmed at the lopsided nutritional intake in our country. The fat consumption increased from 31.4 to 41.6 and from 42 to 52.5 g per person in rural and urban India respectively between 1993-94 and 2012-13. On the contrary, protein consumption declined from 60.2 to 56.5 and from 57.2 to 55.7 g per person in rural and urban India, respectively for the aforesaid periods. To make matter worse, the per person Kcal intake has declined from 2153 to 2099 and from 2071 to 2058 for the period 2011-12 vis-a-vis 1993-94. Almost 70 and 80 per cent of the urban and rural India are not consuming the government recommended 2400 calories Kcal per day worth of nutrition, a situation that has very harmful health implications apart from its sheer inhumanity. The Kcal consumption of poorest 10 per cent of the rural and urban population is 1724 and 1679 respectively while the Kcal consumption of the richest 10 per cent in the rural and urban India is 2531 and 2518. Although the share of fruits and vegetables and other milk and live stock based products have increased, the overall nutrition basket is distorted with serious imbalance on the fat and protein front. The repercussion of such imbalance is irreversible and has an adverse effect on the health of the nation.

India occupies a prominent place in global oilseeds scenario with 12-15 per cent of area, 6-7 per cent of vegetable oil production, and 9-10 per cent of the total edible oil consumption and 13.6 per cent of vegetable oil imports. In India, oilseeds account for 13 per cent of the gross cropped area, three per cent of the gross national product and 10 per cent of the value of all agricultural products. Vegetable oils are essential requirements for the nutritional security of our people in India. India has rich diversity of nine annual oilseed crops on account of diverse agro-ecological conditions. Despite having the largest area under oilseeds in the world (28.53 m ha during 2013-14), India imported about 53 per cent of total oil requirement (11.06 million tons) at an exchequer of Rs.56907 crores (2013-14) which has further increase to more than Rs. 68,000 crores during 2015-16.

2. Production scenario

India grows oilseeds on an area of 25.8 million hectares, with production of 27.5 million tons and productivity of 1060 kg per hectare (quinquennium ending 2014-15). The average yields of most of the oilseeds with castor as an exception vis-à-vis world are invariably low (Table 1) since they are confined to resource poor farmers in nutrient starved soils with small and fragmented land holdings primarily under rainfed ecosystem (72.8 per cent).

Table1. Oilseeds productivity (kg/ ha) in India vis-à-vis World

Crop	India	World	Country with highest average productivity
Groundnut	996	1676	4699 (USA)
Rapeseed-Mustard	1262	1873	3690 (Germany)
Soybean	1353	2374	2783(Paraguay)
Sunflower	651	1482	2494 (China)
Sesame	402	518	1315 (Egypt)
Safflower	590	961	1489 (Mexico)
Castor	1592	1162	1455 (India)
Linseed	503	752	1358 (Canada)
Oil palm fruit	12380	14323	21901 (Malaysia)

The production scenario of vegetable oilseed sector in the country can be categorized into four periods, viz., i) Post Independence (1950 - 1966), ii) Coordinated Research Program (1967 - 1985), iii) Focused approach through Technology Mission (1986 - 1996) and iv) Post-Mission (1996-97 to till date) periods.

I. Post Independence Period

This period evidenced area expansion by 32 per cent and production increase by 34 per cent. The growth rate of productivity was 0.07 per cent (Fig 1).

II. Coordinated Research Program Period (Pre-TMO)

The establishment of the All India Coordinated Research Project on Oilseeds (AICORPO) in 1967 witnessed massive structural reforms in the national network in oilseeds. This period heralded for the development, verification and adoption of location specific technologies for increased productivity, especially the new varieties and hybrids. The compound annual growth rates registered during the period 1967-68 to 1986-87 was 1.21, 2.41 and 1.19 per cent for area, production and productivity, respectively (Fig. 1). The period also witnessed release of 153 varieties of Oilseeds.

III. Focused approach through Technology Mission on Oilseeds

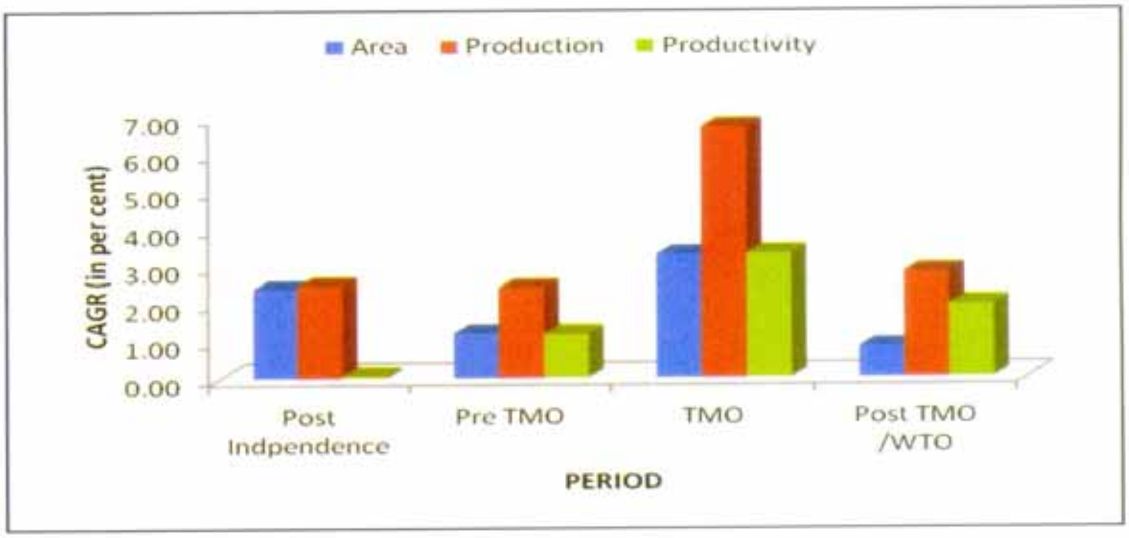
Technology Mission on Oilseeds was initiated in May, 1986 with very ambitious objectives of (a) self-reliance in edible oils by 1990 (b) reduction in imports to almost zero by 1990, and (c) raise oilseed production to l8.0 million tons by 1989-90 and 26.0 million tons of oilseeds and 8.0 million tons of vegetable oil by 2000 AD. Thrust was given on the main oilseed crops in selected 180 districts in 17 states which contribute the maximum quantity of oilseeds to the nation. The mission started functioning as a consortium of concerned Govt. departments, and adopted a four-pronged strategy through Mini-Missions I, II, III and IV.

The Technology Mission on Oil seeds (TMO) in 1986, resulted in the country's oilseed production surpassing the Seventh Five- Year Plan target of 18 million tons, with an impressive annual growth rate of nearly 6 per cent in the short - run. The imports declined drastically and the self sufficiency was above 90 per cent and this period was popularly referred to as 'Yellow Revolution". The growth rate in the per capita edible oil consumption during this period was 3.66 per cent with an average per capita consumption of 6 kg per annum. The increase in the per capita consumption vis-à-vis the previous period was 54 per cent.

The country witnessed a quantum jump in oilseeds production from 10.83 million tons (1985-86) to 24.75 million tons (1998¬99) through effective coordination among different Ministries, Departments and Organizations like ICAR and SAUs. The average productivity of all annual oilseed crops, enhanced from 570 to 926 kg/ha, thus registering a 62 per cent increase during this period. This golden era witnessed the release of 200 varieties and hybrids and performance of improved crop technologies under real farm situations, leading to significant improvements both in yield and profits to the farmers. As a result, India achieved a status of 'self sufficient and net exporter' during early nineties, rising from the 'net importer' state. At the same time, the imports declined from Rs. 700 crore in 1985-86 to Rs.300 crore in 1995-96.

IV. Post Mission Period

This period witnessed the operationalization of GATT/ WTO under which the Government's economic policy allowed greater freedom to the open market through open general licensing (OGL) and encouraged healthy competition and self regulation rather than protection and control. Controls and regulations thus got relaxed resulting in a highly competitive market dominated by both domestic and multinational players. Further, the increasing per capita income led to enhanced consumption of edible oils. The gap between the domestic production and the requirement became widened at an alarming rate. This has impacted the domestic edible oil sector. This completely eroded the gains that the country had achieved during the TMO period (Fig. I). In addition, the increasing biotic and abiotic stresses, strong domestic market and non-market forces led to a sticky domestic oilseeds production and profitability.



Post independence = 1950-51 to 1965-66; Pre TMO = 1966-67 to 1985-86; TMO = 1986-87 to 1995-96; Post TMO = 1996-97 to 2013-14

Fig 1. Compound Annual Growth Rates (CAGR) of annual oilseeds during different periods

It is appropriate to mention at this juncture that performance of oilseeds on the domestic front during the last two decades has been commendable despite the vagaries of weather conditions, the global price aberrations, the competition meted out from the competing crops and the ever increasing domestic demand. The growth rate of nine edible oils during 2000-01 to 2013-14 vis-à-Vis 1990-1991 to 1999-2000 (Figure 2) has provided a fillip for consolidation and revitalization of the oilseed economy.

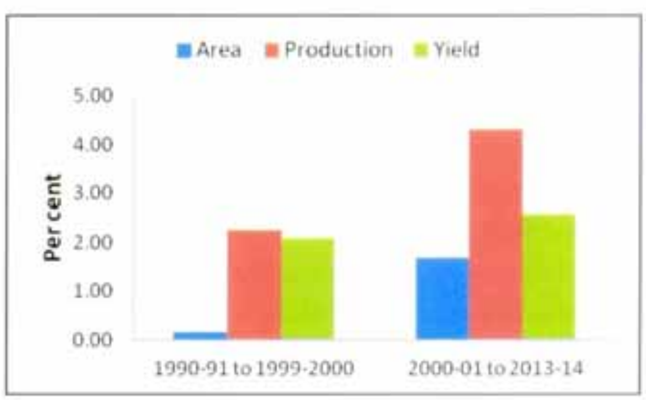


Fig 2. Compound growth rates of annual oilseed crops in India

Although enhanced growth rates of five per cent were evidenced on the domestic availability of edible oils for the decade ending 2013-14, it could not match the rate of growth of imports of edible oils which was 6.99% and the per capita consumption of edible oils that grew at a rate of 5.65%.

The trends in vegetable oils production, the imports, per capita consumption and the self sufficiency over the years are detailed in Table 2. The table suggests that self sufficiency is 50 per cent for the last five years thus necessitating an equal proportion through imports to meet the country's requirements. This is a huge challenge to the nation for enhancing the domestic production of vegetable oils to offset the drain on the nation's exchequer.

Table 2. Domestic production, imports, *per capita* consumption and self-sufficiency in edible oils in India

Year	Edible Oils (Lakh tons)	Imports (lakh tones)	Per capita Consumption)	Self sufficiency (%)
1986-87	38.7	14.7	6.2	72
1994-95	71.9	3.5	7.3	95
2002-03	51.5	43.6	8.8	53
2006-07	80.0	42.7	11.2	65
2012-13	92.8	103.8	13.9	47
2013-14	98.6	110.62	14.0	47

3. DEMAND, IMPORT AND EXPORT SCENARIO

I. Demand Projections

The domestic demand for vegetable oils and fats has also been rising rapidly at an increasing rate due to increase in per capita income, changing life style and increase in standard of living. Thus, annual demand is increasing at the rate of five per cent while our domestic output has been increasing at just about two per cent.

The demand for vegetable oils is both income and price elastic. Demand for food grains is constant and stable and can suffice to meet the population growth, whereas demand for vegetable oil increases with increase in population, increase in standard of living (income) and increased use for industrial, pharmaceutical, nutraceutical, cosmetics purposes (Fig. 3).

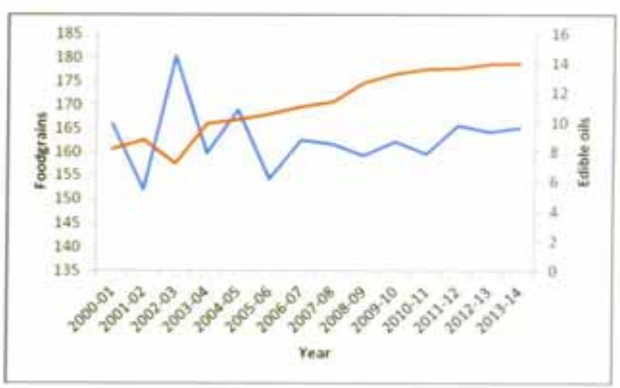


Fig 3. Per capita net availability of food grains and edible oils (kg / annum)

This has resulted in dependency on imports to meet the additional requirement. The per capita consumption of edible oils registered a compound growth rate of 5.51 per cent while the value of imports shot off to a whopping 17.62 per cent growth rate during the last fifteen years.

Taking into consideration a host of factors viz., domestic production, the import dependency, the trade buoyancy, the pattern of per capita consumption, the changes in dietary standards, the growing trend of out-of-house consumption, the rising demand for vegetable oils for industrial uses and the production of biofuel; the projections have been made for the Indian vegetable oilseeds. The projections are based on the assumptions that the per capita consumption would be increasing at 40, 45, 50 and 55 per cent above the prescribed consumption levels during 2020, 2030, 2040 and 2050 respectively. The estimated per capita consumption is accordingly placed at 15.33, 15.88, 16.43 and 16.97 kg/annum for the year 2020, 2030, 2040 and 2050, respectively.

A newer dimension of vegetable oil requirement for industrial use is estimated to grow by 15 per cent in 2020, 20 per cent in 2030 and 25 per cent post 2040, thus requiring around 3.57, 6.34, 8.88 and 10.65 million tons in 2020, 2030, 2040 and 2050, respectively. The Indian trade industry therefore, predicts much greater expansion. The total vegetable oil requirement is thus estimated at 23.81, 29.05, 34.35 and 39.16 million tons during 2020, 2030, 2040 and 2050, respectively which is a gigantic task for the country to increase its domestic production. The contribution of vegetable oil availability from secondary sources including arboreal species is estimated at 5.05, 5.89, 6.85 and 7.18 million tons during 2020, 2030, 2040 and 2050, respectively. Thus, the total domestic vegetable oilseeds requirement from nine annual oilseed crops is estimated at 50.38, 63.84, 79.66 and 92.98 million tons by 2020, 2030, 2040 and 2050, respectively. The projected crop-wise production of major oilseeds and oils in India is given below:

Projected crop-wise production of oilseeds and oils in India (in million tones)

Crop	2020		2030		2040		2050	
	Seed	Oil	Seed	Oil	Seed	Oil	Seed	Oil
Soybean	18.4	2.9	27.5	4.0	37.2	5.5	46.8	6.7
Rapeseed-Mustard	13.4	5.4	14.3	5.7	16.1	6.5	16.4	6.6
Groundnut	14.8	3.5	17.8	3.9	21.6	4.3	24.6	4.9
Total Nine annual oilseeds	50.4	13.3	63.7	15.3	79.6	18.2	93.0	20.4
Oil palm	8.5*	1.9	30.0*	7.2	39.6*	9.9	42.0*	14.0
Total oilseeds production	58.9		93.7		119.2		135.0	
Secondary sources	5.0		5.9		6.8		7.2	
Total vegetable oil production	20.2		28.4		34.9		41.6	

II. Export Import Scenario

After China, India is the world's largest importer of vegetable oil. Besides meeting the shortfall in production, to check the inflation, state owned trading companies started increasing their overseas purchases. To aid the process and for consumer protection against price rise, in the year 2005, import duty was raised on crude palm oil/crude palmolein from 65 per cent to 80 per cent and on refined palm oil/ RBD palmolein from 75 per cent to 90 per cent. Subsequently, in August 2006, the import duty was reduced on crude palm oil/ crude palmolein from 80 per cent to 70 per cent and on refined palm oil/ RBD palmolein from 90 per cent to 80 per cent. In the year 2007, the custom duty on crude and refined palm oil/ palmolein was further reduced to 45 per cent and 52.5 per cent, respectively. The custom duty on crude as well as refined sunflower oil was further reduced to 40 per cent and 50 per cent, respectively. In 2008, the custom duty on all major crude and refined oils was reduced to 'Nil' and 7.5 per cent, respectively. In December, 2014, the customs duty on crude and refined vegetable oils had been hiked to 7.5 and 15 per cent respectively.

As discussed earlier, dependency on imports has been on the rise to cater the domestic consumption. The cost towards imports of vegetable oils during 2014-15 is Rs. 59094.33/- crores. Palm oil constitutes to the major chunk of the import bill. The commodity-wise imports are detailed in Table 2.

Table 2: import of vegetable oils in India (Rs. In crore)

Year	Soybean	Groundnut	Olive	Palm oil and its fraction,	Sunflower seed, safflower or cotton seed oil and their fraction	Coconut (copra), palm kernel or babassu oil and fractions	Rape colza/ mustard oil and its fractions	Other fixed vegetable fats and oils	Total imports of vegetable oils
2000-01	903.89	0.25	8.20	4071.53	987.13	84.09	86.62	15.52	6157.23
2001-02	2273.12	0.00	12.79	3755.22	295.43	114.29	37.88	15.49	6504.27
2002-03	2626.53	0.01	12.52	5892.58	101.76	147.71	2.85	10.12	8794.10
2003-04	2632.40	0.04	15.27	8418.42	304.95	317.09	0.06	15.66	11703.90
2004-05	2955.01	0.07	15.50	7691.27	109.87	310.01	0.04	20.32	11102.09
2005-06	38.99.91	0.11	23.21	4563.41	184.68	306.21	0.16	25.08	9002.76
2006-07	3103.68	0.04	24.56	5629.14	423.05	375.03	0.19	24.80	9580.53
2007-08	2748.25	0.03	35.07	6712.07	255.14	568.05	0.21	35.78	10356.27
2008-09	1871.94	0.27	49.15	11864.59	1253.54	794.01	40.53	38.23	15912.35
2009-10	4117.35	0.02	59.62	19112.43	2169.21	913.49	182.69	59.67	26614.59
2010-11	4899.34	0.34	77.65	20946.24	3066.19	911.81	3.66	60.91	29966.80
2011-12	5444.23	1.49	116.83	34529.71	4966.50	974.11	278.10	60.91	46431.55
2012-13	7611.61	1.09	178.15	43926.14	7738.16	1215.70	558.82	139.21	61384.94
2013-14	8308.08	1.84	221.91	39355.38	6986.29	1460.99	447.38	106.54	56906.99

On the export front, the oilseeds, oils and the oil meals have immensely contributed to the Indian economy with export earnings of Rs.27174 crores (2012-13). Oil meals constitute to the bulk of exports (58 per cent) while sesame and groundnut seeds and castor oil are other important commodities being exported

The details of the exports (value) for important oilseed commodities that are consistently traded from the year 2000 are presented in Table 3. (The information in tables, however, does not include the secondary sources of oils and from seeds of other annual oilseeds).

Way Forward

The country has to devise a multi pronged approach for addressing the issues in oilseeds and make the Indian oilseeds sector more vibrant and dynamic.

It is important that the productivity of all annual oilseed crops need to be enhanced substantially considering the existing production. This requires exploitation of the power of technology that is available in the country. These interventions are to be addressed based on the demand driven approach and hence most of the technologies that have emanated from the National Agricultural Research System (NARS) system that includes universities and research institutes have direct bearing for the respective agro-ecological regions where oilseeds are cultivated. On this aspect, I primarily foresee a huge opportunity for all the stakeholders to have access to the technologies available within the NARS/ ICAR to give a fillip to the oilseeds production through various interventions including cluster based approach considering the size and fragmented holdings so that economies of scale operate at the farm level.

Table 3: Export from selected oilseeds, oil and oil meals (Rs. Crore)

Year	Sesame seed	Niger seed	Groundnut	Oil Meals	Castor Oil	Total
2001-02	562.23	47.85	250.94	2262.93	625.94	3749.89
2002-03	372.89	77.99	178.30	1487.35	609.81	2726.34
2003-04	708.90	45.41	179.11	3249.89	656.06	4839.37
2004-05	708.95	64.74	547.02	3177.60	1077.98	5576.29
2005-06	746.60	60.25	513.69	4875.01	939.74	7135.29
2006-07	939.58	66.87	798.46	5504.32	1090.11	8399.34
2007-08	1642.29	90.23	1054.08	8140.55	1275.72	12202.87
2008-09	1494.26	64.23	1239.01	10269.24	2128.72	15195.46
2009-10	1494.10	24.23	1425.93	7831.79	2179.27	12955.32
2010-11	2194.44	41.14	2099.77	10845.91	2851.67	18032.93
2011-12	2641.66	117.29	5246.65	11796.46	4571.67	24373.73
2012-13	2881.14	90	4065.59	15821.69	4314.78	27173.20
2013-14	3583.46	113.61	3187.66	17070.13	4364.33	28319.19
2014-15	4717.77	108.23	4675.38	8128.60	4710.18	22340.16

Technology transfer for Good agricultural practices: It is proven that the oilseeds production system in the country is operating on low levels of efficiency primarily due to non adoption of technology practices. The farm level productivity of oilseed crops can be substantially enhanced by resorting to adoption of the Good agricultural Practices.

Establishment of seed banks: It is an established fact that for the oilseed crops in general, the seed replacement rate is pretty dismal. Making available the quality seed at the right time to the farmer can enhance the productivity. To make available the quality HYV/ Hybrid seeds of oilseed crops, it is important that creation of seed banks on cluster approach through KVK/ NGO/ private seed industry can pave way for increasing the productivity.

Focus on micronutrient application: The oilseeds respond very well to micronutrients. The role of sulphur and boron are striking examples that come to my mind that has a positive effect on the oil content. The application of sulphur through gypsum and boron resulted to enhanced oil content that led to farmers being offered a premium price during disposal of the produce. It is important that the specific recommendations on the micronutrient front for the respective oilseed crops should be translated to the farming community.

Expansion to Rice fallows: Immediate attention has to be bestowed towards expansion of oilseeds to paddy fallows in various agro- ecological regions of the country. This can play a pivotal role in contributing to the national oilseeds kitty. Oilseeds have a comparative advantage in rice fallows due to higher productivity potential and ease of production vis-à-vis paddy and other water loving crops.

Public Private Partnerships: There is enormous potential for PPP in oilseeds on the production and marketing aspects. On the production front, the industry can play a role in providing technical backstopping besides input marketing, while on the other hand, the direct linkage between the oilseed farmer and the industry on the output marketing is a WIN WIN situation.

Digital Agriculture for information dissemination: The role of lCT has not been explored in agriculture. The tools of ICT are to be explored on POP's / price information to the farmers or through KVK's for making available the pertinent information. An important ICT technology that holds high promise is the weather based advisory service to the farming community. This can help the farmers in taking appropriate decisions on the management of oilseed crops.

Crop ecological Zoning for enhancing exports: A few of the oilseed crops viz., Sesame, HPS Groundnut have immense export potential. The country has a comparative advantage for export of the above commodities. It is important to carve out niche areas in select agro-ecological regions between farmers on a cluster mode with industry on "tie up" mode for increasing the volume of exports. This holds high promise for bold seeded pesticide free sesame, hand picked selection (HPS) table purpose aflatoxin free groundnut and high oleic sunflower and safflower. This can ensure enhanced profitability both to the farmers and the industry.

Focused approach in select agro-ecological regions: It is pertinent to note that a few districts contribute to majority of the area under the respective oilseed crops. It is important to dovetail all the potentially viable technologies in these areas for enhancing the oilseeds productivity. The frontline demonstrations conducted across the nine annual oilseed crops have indicated the potential for increased productivity. Special emphasis has to be laid in these areas for harnessing the potentially viable technologies.

Technology access in nontraditional areas: Focus on spread of oilseed technologies to non traditional area viz., Orissa, West Bengal and Chhattisgarh in the Eastern Grid and in Indo-Gangetic Region of Punjab, Haryana, Western Uttar Pradesh and Bihar ably supported with buy back arrangements can play a vital role for increasing the productivity of oilseeds in the country. The agro ecological situations in the above regions provide a highly conducive environment for oilseeds. Hence, providing necessary input supply, technology, market and processing facilities in these areas can help realize quantum jump in productivity with ease.

Crop Diversification in select target domains: An important intervention is introducing oilseeds technology in Rabi season under the tail end canal irrigation system. The potential economic and ecological benefits are tremendous to the oilseed farmers since the management of oilseeds in these regions hold high promise.

Focus on Natural Resource Management: With the current practices of crop cultivation under sub-optimal management, especially without balanced nutrient replenishment, significant soil nutrient mining is perpetual. Addressing the imbalance in soil nutrients can provide rich dividends. Declining per capita arable land and extending oilseeds cultivation to poor and

marginal soils result in low productivity. Moreover, productivity of oilseed crops is limited owing to their cultivation under rain fed conditions. Currently only 28 per cent of area is irrigated under oilseeds. Water requirement in oilseeds is, therefore, a key factor for ensuring higher yields. With dwindling water resources both in quantity and quality, water for irrigation will be costly and face severe competition from different enterprises within agriculture sector. Watershed management with appropriate rainwater harvesting both in situ with proper disposal and storage farm ponds provides excellent opportunity to mitigate the expected dual problems of long droughts and floods with advantage. Site specific land configuration and management for effective soil and moisture conservation and its economic use can operationalize the drought mitigation strategy. Enhancing drought tolerance in oilseed crops is therefore, a priority with associated practices to improve profitability through achieving 'more crops (oil) per drop' of water, Resource use efficiency and preferential edge over other competing crops.
Exploiting nutrient interactions as per the soil test and crop response results in higher efficiency and reduced cost. Organic manures are central in the integrated nutrient management (INM) of oilseeds under rain fed situation along with other components such as secondary and micronutrients, like use of sulphur bio-inoculants, crop residues, etc. Precision crop management with conservation agricultural practices and customized fertilizer application schedules would usher higher efficiency and profitability. Emphasis on integrated natural resource management in oilseeds should, therefore, be our high priority.

Innovative Transfer of Technology: Concerted efforts are urgently needed for the dissemination of technologies and novel approaches on a participatory mode are to be strengthened for effective delivery mechanism by show-casing the potential technologies/products. The Farmer-Institution-Industry linkage mechanism should be strengthened for increasing the farm level productivity which is mutually beneficial to the stakeholders. The power of Information and Communication Technology (ICT) tools should be harnessed on a dynamic and interactive mode for reducing the asymmetry in information. Harnessing the potential of farm level students (diploma and degree holders) at the rural areas through devising appropriate outsourcing mechanisms go a long way in up scaling innovation for a greater impact besides retaining the rural youth with the agricultural sector.

Public Private Partnership for value addition: Profitability of oilseeds solely from the primary products like seed and oil will not be sustainable. Besides the primary product oil, oilseed crops provide immense scope for diversified uses with high value specialty products and derivatives. From the vegetable oil consumption point of view either for edible or for fuel purpose, the situation is envisaged towards valuing oil for its intrinsic value for calorie or for desired fatty acid that is beyond the realm of individual crop as perceived now. Designer oils with requisite blends can meet the expectation and to that extent individual oilseed crop's potential would be seen for the yield of oil or the desired fatty acid and not as oil from specific crop. Harnessing the omega 3 in linseed for enriched eggs through feed mechanisms, Canola rapeseed oil, fortification of soya protein, quality linseed fiber production, zero ricin castor and higher order derivates in castor are a few possibilities that come to my mind. High oleic acid oils have a premium market globally. On this front, collaborative research programmes on specific oilseed crops for high oleic varieties / hybrids can able the country to enhance the exports.

PPP on crop production/improvement: Many stakeholders are not aware of the possibilities of technology(s) that can be accessed to them from ICAR / NARS through technology licensing. The private players to utilize the opportunity of accessing the technology(s) and play a key role in enhancing the productivity of oilseeds.

The few practical approaches suggested above would not only rejuvenate the oilseed sector spectrum but also will help in promoting profitability of farmer, the principal stakeholder, to enhance the oilseed area and production to shrink the vegetable oil import bill. The most imminent factor that would be forthcoming is the linkages that are farmer centric and networking between the public and private sector for fostering the vegetable oils production to strive towards self sufficiency and create the mantra of MADE IN INDIA vegetable oils.

CONCLUSION

Increased availability of vegetable oils warrants the highest commitment of all the stakeholders. There is an urgent requirement to launch a special mission on oilseeds with greater accountability and commitment to boost the domestic production of vegetable oils in the country and thus minimize the dependency on imports. The involvement of all stakeholders with the oilseeds farmer at the centre stage should be perpetual while formulating the special mission. The emphasis of the mission should be to identify immediate actionable outputs to be translated to outcomes through convergence from micro-meso-macro levels for providing a fillip to the national vegetable oilseeds basket. This may be treated as a high priority agenda at the national level.

Pangenomics for crop improvement

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Since the sequencing of the first plant genome (Arabidopsis Genome Initiative., 2000), comparative genomic studies of plants often focus on single nucleotide polymorphisms (SNPs) between individuals, as these can be relatively easily identified and assayed across populations (Gore *et al*., 2009; McNally *et al.*, 2009). However, there has been an increasing awareness that a single reference genome is insufficient to capture the genomic diversity we observe in nature due to a considerable amount of structural variation including copy number variants (CNVs) and presence absence variants (PAVs), which alter the total amount of genomic sequence found in individuals (Saxena *et al*., 2014). CNVs are sequences which are present in a different number of copies between individuals and encompass duplications, insertions and deletions (Saxena *et al.*, 2014). PAVs are sequences that are present in one genome and absent in another and can therefore be considered to be extreme form CNVs, where the sequence is completely missing from one or more individuals. The existence of CNVs and PAVs, even between individuals belonging the same species, has been extensively documented in plants (Cao et al., 2011; Golicz et al., 2012). Future genome editing applications for crop improvement, requires the entire gene content of the edited individual to identify potential targets, and in order to capture the entire genomic sequence present within the species, including the complete gene set, the pangenome needs to be sequenced.

The concept of the pangenome was introduced by (Tettelin *et al*., 2005) who described the production of the first ever pangenome; for a bacterial species; *Streptococcus agalactiae.* Since then, the concept of the pangenome has become increasingly popular with numerous examples available for bacteria and other microorganisms. Recently, pangenomic studies of higher organisms have emerged including in maize, soybean, *Brassica rapa* and rice.

Pangenome genes can be divided into two groups: the core genes, which are present in all of the individuals, and the variable genes, also known as accessory or dispensable genes which are present in some, but not all, individuals. The core and variable genes could be interpreted to represent 'the essence and the diversity of the species', respectively.

Pangenome analysis

The analysis of pangenomes can answer three important questions which may help characterize the species: (I) What is the size of the core genome, in other words how many genes/gene families are present in all the individuals? (II) What is the size of the pangenome; how many genes/gene families are present within the species? (III) With the addition of each new individual, how many genes/gene families will be added to the pangenome? The analysis of the core genome size, the pangenome size and the number of new genes added can be conducted on two levels; individual genes and whole gene families.

Factors which influence pangenome analysis include:

(I) Assembly quality – assembly quality is a very important factor in pangenome analysis studies. The quality of the assembly, its total size, completeness and fragmentation level often translate to the quality of the annotation.

(II) Annotation quality – accurate annotation, especially of large eukaryotic genomes is a challenging task.
(III) Orthologous gene detection – classically, orthologous gene detection aims to identify functionally equivalent genes across individuals of different species. In pangenome studies, orthologous gene detection is employed to find functionally equivalent genes across individuals of the same species, which allows identification of core and variable gene families.
(IV) Selection of appropriate samples – the selection of appropriate individuals which capture the majority of diversity within a species is crucial to successful pangenome study design. The selection of a small number of closely related individuals will result in significant underestimation of the pangenome size. On the other hand the selection of diverse individuals gives more realistic estimates.

Pangenomic studies in plants

The knowledge of plant pangenomes is built upon numerous studies of structural variants, especially CNVs and PAVs. In one of the early studies of *A. thaliana* structural variants, comparison of two divergent ecotypes relative to the reference genome found 3.4 Mb of sequence to be extremely dissimilar, deleted, or duplicated(Ossowski et al., 2008). Subsequently, sequencing of eighteen *A. thaliana* genomes revealed that between 2.1 and 3.7 Mbp of sequence present in the reference was missing in these accessions. On average, there were 319 novel genes or gene fragments reported per accession. An even broader survey of 80 accessions suggested that relative to the reference sequence, 10% of the genes were absent in one or more accessions, averaging 444 genes per accession. In another survey of 80 accessions, over 4200 genes had premature stop codons, suggesting a large number of genes with altered functions (Cao et al., 2011). Overall, genes displaying presence/absence variation were found to be shorter, have fewer paralogues and were younger in age than conserved core genes.

A resequencing project of 17 wild and 14 cultivated soybean genomes revealed that 10% of reference genome genes had SNPs likely to have large functional impact (Lam et al., 2010). Additionally, comparison of assembled sequence between the wild soybean genome and the reference genome revealed 4,444 and 1,148 PAVs (>500 bp) that were absent in the reference and the wild soybean genomes. Another study found that CNVs in four diverse soybean genotypes overlapped almost 700 genes, and PAV calls overlapped 133 genes. A *de novo* assembly of 7 diverse accessions of wild relative of cultivated soybean found that 80% of the pangenome was present in all accessions, the remainder was variable and displayed greater sequence variation than the core genome.

Comparison of a 2.3 Mbp homologous region on rice chromosome 4, revealed that two rice accessions *Oryzasativa* ssp. *japonica* and ssp. *indica* differed by 27 genes in this region, with gene density higher in *japonica*. Another study comparing ssp *japonica* and *indica* found 641 CNVs between the genomes. The CNVs ranged in size from 1.1 Kb to 180.7 Kb, and amassed to approximately 7.6 Mb of sequence. Comparison of two rice accessions estimated that at least 10% of the genes displayed either presence/absence variation (5.2%) or were 'asymmetrically located between genomes' (4.7%). A pangenome study of three divergent rice lines found that 92% of the genes were core and the remaining variable. The variable genes being shorter, with fewer exons per gene (Schatz et al., 2014).

Early studies in maize suggested that 20% of genomic segments are not shared between the two maize lines B73 and Mo17 (Morgante et al., 2005). Another comparison of these lines uncovered ~3,800 CNV or PAV sequences between these two maize genomes (Springer et al., 2009). Hundreds of intact, expressed genes were present in the B73, but absent from the Mo17 genome (Springer et al., 2009). When six inbred lines were compared to the B73 reference it was discovered that 296 genes present in B73 were missing from at least one of the six inbred lines. Additionally, 570 genes were found to be absent from B73 (Lai et al., 2010). A survey of 27 lines revealed that the reference genome B73 may only capture ~70% low copy fraction of the entire pangenome (Gore et al., 2009), while a study of 503 diverse maize inbred lines identified 8681 representative transcript assemblies which were not present in the reference B73.

In humans, associations between CNVs, PAVs and health and disease have been found. In plants much less is known about the association of CNVs and PAVs with phenotype, however several examples are available. Known biological processes influenced by CNVs/PAVs are metabolite production, flowering time, submergence tolerance, phosphorus uptake and biotic stress response. Opium poppy contains a 10 gene cluster which displays PAV, being only present in plants producing noscapine and antitumor alkaloid. Investigation of wheat genes that influence flowering by changing photoperiod response (*Ppd-B1* alleles) or vernalization requirement (*Vrn-A1* alleles) revealed that both of those genes display CNV.

In rice, the *Sub1A gene is involved in submergence tolerance and is absent in* varieties which are not submergence tolerant(Schatz et al., 2014). Also in rice, a gene encoding a protein kinase *Pstol1* is associated with P-uptake efficiency, and the gene is absent in varieties, which are intolerant to phosphorus starvation. In addition, biotic stress response genes demonstrate presence absence variation in a range of species.

Partial redundancy of function between gene family members together with high CNVs/PAVs which affect different lines may contribute to heterosis. Considering genes influenced CNVs/PAVs which belong to gene families, each gene in the family can be seen as a ‘functional block’ that provides partial to complete functionality for the gene family. The loss of one gene family member may result in a small effect on phenotype since other family members will be able to compensate for the lost functionality. However, the additive effect of many gene families with members affected by CNV/PAV could result in decreased vigour. This effect could be alleviated in hybrids, resulting in substantial hybrid vigour. On the other hand, it is also possible that unique genes displaying PAV are contributing to heterosis on a single gene rather than gene family level. Considering this, abundance of CNVs/PAVs in the entire population used for breeding may limit potential for improvement.

We have applied the iterative assembly approach (Golicz et al., 2015)to produce pangenomes for several important crops species including *Brassica napus* canola, *B. oleracea*(Golicz et al., 2016)and bread wheat (Montenegro et al., 2017)and the analysis of gene content identified numerous variable genes which may play a role in the agronomic performance of these important crops. Knowledge of the core and variable gene content will facilitate the production of improved varieties both by conventional marker assisted breeding and through advanced genome editing technologies.

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Current status of *Brassica rapa* research in Korea

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According to the APG (Angiosperm phylogeny Group) Ⅲ system (http://www.mobot.org/MOBOT/research/APweb/), the Brassicaceae is a family of flowering plants belonging to order Brassicales. Worldwide, 338 plant genera and approximately 3,700 plant species belong to the Brassicaceae family. The *Brassica rapa* (2n = 20, AA) is one of the six economically important cultivated *Brassica* species of U's triangle. The *B. rapa*subspecies have wide genetic and morphological diversity which grown as leafy vegetables, vegetable oils, turnip greens, turnip roots, turnip tops and as a fodder crop.

Among *Brassica* species, *B. rapa* spp. *pekinensis* (Chinese cabbage) has been cultivated in Korea since the 13th century after it was introduced from China. Chinese cabbage is one of the major vegetables mainly used to prepare *kimchi*, one of the traditional Korean dishes of fermented vegetable. In addition to being the major ingredient in the Korean traditional food Kimchi, Chinese cabbage is widely used in the general Asian cuisines of Korea, China, and Japan in dishes such as Namul (vegetable dishes such as Saengchae, which is made with uncooked raw vegetables, and Sukchae, which is made with boiled, steamed, or stir-fried vegetables), stir-fries, salads, vegetable wraps, stews, and soups. However, the name Chinese cabbage is applied to a wide range of types and it is quite difficultto categorize them systematically. Various scholars and institutions in Korea and abroad use different scientific names for Chinese cabbage, which causes confusion in the scientific literature. This confusion makes it challenging to establish and manage databases, and may introduce errors in research results.So, recently, we organized the scientific names of Chinese cabbage accordingInternational Code of Nomenclature for algae, fungi, and plants (ICN) (McNeill et al., 2012) and the International Code of Nomenclature for Cultivated Plants (ICNCP) (Brickell at al., 2009). We found that the subspecies name '*Brassica rapa* subsp. *pekinensis* (Lour.) Rupr.was suitable asthe scientific name for Chinese cabbage, and we classified *B.rapa*var. *glabra* Regel. as its alternative name.

Since the Chinese cabbage is the economically important crops in Korea, the breeding and research efforts on Chinese cabbage was focused to develop the F1 hybrids cultivars which have economically important traits. In Korea, since F1 hybrid breeding using self-incompatibility was initiated by Dr. U in the 1950s, almost all of the cultivars currently used for economical production are F1 hybrids. Hundreds of cultivars have been bred and most of them were early or medium maturing types. The early maturation property is important to fit cultivation patterns inKorea where summer and winter are severely hot or cold. Many cultivars have been developed for various cultivation patterns as cultivars for spring, summer, autumn and over-wintering cultivation. Recently, breeders released several cultivars which had the specific functional traits or components, as Wawatsai, Red Chinese cabbage, beta-carotene rich Chinese cabbage, etc.

As basic genetic and diversity research of Chinese cabbage germplasm, we collected over 11,000 acessions of Brassicas from world. From these collected germplasm, we developed a set of fixed inbred lines specified to *Brassica rapa* subsp. *pekinensis*. We investigated the genetic diversity and population structure of 238 fixed lines of leafy *B. Rapa* with 45new simple sequence repeat markers and 109 new NGS (next-generation sequencing)-generated single nucleotide polymorphism markers evenly distributed throughout the *B. Rapa* genome. Phylogenetic analysis classified the vegetable fixed lines into four subgroups, with the three oil types forming a separate and relatively distant cluster. A model-based population structure analysis identified four sub populations corresponding to geographical origins and morphological traits, and revealed extensive allelic admixture. In particular, the Chinese cabbage cluster was subdivided into three groups and showed considerable correlation with leaf- and heading-related traits (leaf and heading shape). The vegetable *B. Rapa* fixed lines successfully developed in our study could be valuable materials for establishing a multinational *Brassica rapa* diversity resource. Understanding the genetic diversity and population structure was useful for utilization of the representative genetic variation and further genomic analysis.

As basic genetic and genomic research of Chinese cabbage, we also developed the mapping population using Chiifu-401-42 and Kenshin, as the recombinant inbred mapping population (named CKRI) and double haploid mapping population (named CKDH). Using these mapping populations, we constructed reference genetic map for sequencing project, and additionally try to QTL analysis. Transgressive segregations were observed for most of the traits. A total of 158 QTLs conferring 23 traits, and 80 QTLs belongs to 14 morphological trais were detected in DH and RIL population during several years' field trials, respectively.

By comparative genetic map and QTLs between two populations, 23 common QTLs (robust-QTLs) associated with 12 traits were detected with common loci between DH and RIL population and compared with previous studies. We also identified evolutionally conserved crucifer genetic blocks associated to the traits. Two blocks (F, E), 5 blocks (R, J&U, F, E) were corresponding to color, leaf morphology in majorly 2 (A3, A7), and 4 linkage group (A2, A3, A5, A9) by syntenic analysis between *A. thaliana* and *B. rapa* genome.

B. rapa including Chinese cabbage is the smallest genome (529Mbp) and an ideal candidate genome as a reference, compared to *B. nigra* (BB, 632Mbp) and *B. oleracea* (CC, 696Mbp). *Brassica rapa* genome sequencing has been initiated by The *B. rapa* Genome Sequencing Project Consortium (BrGSPC) using *B. rapa* spp. *pekinensis* accession Chiifu-401-42. The BrGSPC published the whole genome sequence of mesopolyploid species of *B. Rapa* accession Chiifu-401-42 in *Nature Genetics* (2011) with 283.8 Mbp of assembled sequence which 1.97 Mbp of N50 and covered > 98% of gene space. Totally 41,174 protein coding genes were annotated through the *B. rapa* genome which has undergone genome triplication. To improve the breeding quality, we have identified ~2.3 million single nucleotide polymorphisms (SNPs) from 201 diverse inbred lines by deep re-sequencing using illumine Hiseq 2000.

Also re-sequencing the genome of 9 elite lines with nearly 20 fold coverage and other 192 with 3 to 5 fold coverage helped to generate the high dense genome-wide genetic map with respect to characterize the population structure of morphotypes. Further we analyzed nucleotide variation diversity, linkage disequilibrium and recombination rates throughout the genome to discover the genomic patterns of Chinese cabbage and non-Chinese cabbage lines.

Using the whole genome sequence (WGS) of *B. rapa*, we have done genome-widely analysis of several important gene families as Aux/IAA Family Genes, LRR-RLK (*BrLK*) genes, FOX gene families, etc. In the case of Auxins/IAA gene families, we identified 55 Aux/IAA genes in B. rapa using four conserved motifs of Aux/IAA family(PF02309). Chromosomal mapping of the B. rapa Aux/IAA (BrIAA) genes facilitated understanding cluster rearrangement of the crucifer building blocks in the genome. Phylogenetic analysis of BrIAA with Arabidopsis thaliana, Oryza sativa and Zea mays identified 51 sister pairs including 15 same species (BrIAA—BrIAA) and 36 cross species (BrIAA—AtIAA) IAAgenes. Among the 55 BrIAA genes, expression of 43 and 45 genes were verified using GenebankB. rapa ESTs and in home developed microarray data from mature leaves of Chiifu andRcBr lines. Despite their huge morphological difference, tissue specific expression analysis ofBrIAA genes between the parental lines Chiifu and RcBr showed that the genes followed a similar pattern of expression during leaf development and a different pattern during bud, flower and siliqua development stages. The response of the BrIAA genes to abiotic and auxin stress at different time intervals revealed their involvement in stress response. Single Nucleotide Polymorphisms between IAA genes of reference genome Chiifu and RcBr were focused and identified. Our study examined the scope of conservation and divergence of Aux/IAA genes and their structures in *B. rapa*.

The LRR-RLK and F-box proteins regulate diverse functions related to plant growth, development and responses to stresses. In general both these gene families are involved in post translation modifications, LRR-RLK's in phosphorylation and F-box's in ubiquitination so due to its biological importance we have identified and analyzed both these gene families in the genome of Chinese cabbage. Totally we have identified 571 and 303 number of *Brassica rapa LRR-RLK* (*BrLRR-RLK*s), *Brassica rapa* F-box (*BrFBX*) genes in genome-wide and the chromosome mapping of these genes shown uneven distribution on the chromosomes. In addition we have identified 25 motifs in each protein of these two gene families that allowed to predict various types of functional domains that are conserved in specific to the family. The gene expression analysis for both these gene families in different vegetative and reproductive organs revealed their tissue specific expression. More over the abiotic stress (cold, drought and salt) microarray expression for genes of these gene family, have expressional variations among all the three stresses and the biochemical analysis for few LRR-RLK's have showed dual kinase activity. This study provides comprehensive results for the *BrLRR-RLK*s, *BrFBX*genes revealing expansion of the gene family through gene duplication events, structural similarities and variations among the genes, and potential functional roles according to gene ontology, transcriptome profiling, abiotic stress expression and phosphorylation activity for LRR-RLKs.

Genome wide association studies (GWAS) are widely used to analyze the common variations in QTLs among diverse germplasm. GWAS is achieved by associating genetic variations to phenotypic diversity for both plant and animal species that are completely sequenced.

In this study we choose *Brassica rapa* a model diploid (2n = 20, AA) plant with large genetic variability and re-sequenced the genome of 171 inbred lines including 9 elite lines with 10 to 54 fold coverage using illumina paired-end sequencing library. The populations were genotyped for SNPs and discovered 3.8 million SNPs throughout the genome with 549,016 SNPs on protein coding region. These SNPs were utilized to construct genetic markers for several important traits in *B. rapa.*For application of GWAS, we focused to morphological traits and other economically important traits.

We performed association study for 22 different morphological traits using the SNPs of 145 Chinese cabbage accessions and the candidate genes were identified. Traits like plant height, head color, leaf length, head forming leaf overlap and petiole width evidenced good association in our analysis. Several previously analyzed QTLs were tightly linked with GWAS results. Plant height associated traits loci’s were identified with known genes such as NADK gene. This study provides the fundamental resource for Chinese cabbage as well as other brassica genetics research and breeding, and establishes that an approach integrating next-generation genome sequencing and GWAS can be a powerful complementary strategy to study a complex trait in *B. rapa*.

A reverse breeding approach for alien gene introgression from *Diplotaxis erucoides* into *Brassica juncea*

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Crop species have experienced domestication bottlenecks. As a result, genes governing many important traits present in the progenitor species are not found in crop species. It is well known that wild related species of crops are a treasure-trove of useful genes for various biotic and abiotic stress tolerances, and for quality and nutritional traits. A number of useful genes transferred from wild related species have proved extremely useful in protecting major crops such as wheat, rice, maize, potato, tomato, sunflower, lettuce, chickpea against major pests, pathogens or abiotic stresses like salinity, flooding etc. (Hajjar and Hodgkin, 2007; Dwivedi *et al*. 2008). The role of wild species in crop improvement is best illustrated in sugarcane where hybridization of noble canes (*Saccharum officinarum*) with *S. spontaneum* gave superior hybrids, which have completely replaced noble canes. Recognizing the importance of wild species for crop improvement, special efforts have been made worldwide to collect and conserve wild species of crops, and a significant number of species have been gathered and maintained in national and international gene banks. However, utilization of wild species in crop breeding has been very limited.

Brassica crops (oilseed and vegetable) suffer from several major pests and diseases that include aphids, *Alternaria* black spot, *Sclerotinia* rot, white rust and the root parasite *Orobanche*. No reliable source of resistance is available among the cultivated species for most of these traits. However, wild related species have been found to show resistance to some of these pests and pathogens. For instance, our lab has identified a number of potential donors for tolerance to *Alternaria brassicae* (Sharma *et al*. 2002). While wild Brassica species have been well exploited to transfer genes for cytoplasmic male sterility and fertility restoration (Prakash *et al*. 2009), there are few reports of successful transfer of genes for disease/pest tolerance from wild species into crop Brassicas. We have been working to transfer genes for *Alternaria* tolerance from the wild species *Diplotaxis erucoides* and *Sinapis alba*.

A number of factors such as incompatibility, hybrid sterility, poor pairing between chromosomes of the wild and cultivated species, aneuploidy etc. impedes gene transfer from wild species. Techniques such as bud pollination, embryo rescue, somatic hybridization, pollen irradiation etc. have been devised to facilitate interspecific hybridization and alien gene transfer. Nevertheless, alien gene introgression is a slow and tedious process. In almost all cases, the backcross progenies derived from interspecific hybridization are screened for the trait of interest to identify the individuals carrying the alien gene. If the trait is governed by multiple genes or the trait manifests under special conditions (e.g. disease, pest or salinity or drought tolerance), evaluating a large number of lines becomes difficult. It is now well known that wild species often harbor QTLs of agronomic significance that do not manifest in the wild species but relevant in the crop species genetic background. Progenies carrying such introgression could be lost when early generation progenies are screened for disease or pest tolerance. Therefore, methods for early and efficient detection of introgressions without phenotyping of progenies are urgently required.

Use of molecular markers has the potential to efficiently identify individuals carrying alien gene introgressions. So far, molecular markers have been used to tag the foreign gene after the introgression has been confirmed though trait testing. Later, the linked molecular markers are used for deployment of alien gene(s) into popular varieties. In this study we demonstrate implementation of a reverse breeding approach for gene introgression from *D. erucoides* into *Brassica juncea.*

Molecular information is often lacking for the donor wild species. Further, popular markers such as SSR, SCAR and STS developed for crop species generally fail to work in wild species. Similarly, markers derived from NGS data of crop species (EST-SSR, SNP) do not either amplify or show polymorphism. Therefore, the choice of molecular markers for tracking introgression is a major issue that needs to be addressed. In order to develop wild-species-specific markers, we have used Ion Torrent genome sequencing platform to obtain low coverage sequencing of *D. erucoides* genome. From an initial 72 million single end reads, we recovered 70 million quality reads. These reads were compared with sequences in the Brassica database and those showing match were removed. Further, sequences matching the organelle genomes of *B. juncea*/*B. oleracea* were also excluded. The remaining 15 million reads were assembled which yielded 3895 contigs of >500 bp with N50 value of 1265. These contigs were used to design STS primers. A total 101 STS primers were designed and tested in *D. erucoides* and *B. juncea.* Most of the primers failed to give any amplicon in *B. juncea* but a very high frequency (89/101) of primers gave unique amplicons in *D. erucoides* suggesting that the strategy used is very efficient in finding markers suitable for tracking gene introgressions.

We derived advanced backcross populations from the cross between amphidiploid (*D. erucoides* x *B. rapa*) and *B. juncea.* We tested 90 BC_2F_{2-4} progenies picked at random for D. erucoides gene introgression using molecular markers. We prepared nine DNA bulks by mixing equal quantity of DNA from 10 different plants. When these bulks were screened with 31 *D. erucoides* specific STS markers, as many as 17 markers were detected in one or more bulks. Further, individual plants of the bulk were tested with the markers showing amplification in the respective bulk. This revealed a total 22 plants (out of 90) showing alien gene introgression. To further validate the utility of markers for identifying gene introgressions, a set of 22 backcross progenies showing distinct phenotypes derived from *D. erucoides* such as trichomes on leaf margin, glossy leaf, pale yellow flower etc. were screened with 59 STS markers. Eight primers showed *D. erucoides*-specific amplicons in eight plants confirming the alien introgression. One of the markers ESST70 showed amplicons in six of the nine plants with glossy leaf trait suggesting its association with the trait.

We have tested the progenies for A. brassicae tolerance by both artificial challenge and by growing under disease hot spot conditions at Pantnagar. The wild species *D. erucoides* and the amphidiploid (*D. erucoides* X *B. rapa*) show complete resistance and some of the progenies showing high resistance comparable to the wild species have been identified. These resistant lines are being screened with molecular markers to find the introgressed gene(s).

Thus, this study demonstrates for the first time that reverse breeding could be implemented to transfer genes from the wild species and NGS sequencing could be efficiently used to develop markers for reverse breeding. The cost of genome survey sequencing will be more than compensated by the savings that will accrue on procuring primers. Further, the markers will not only allow efficient tracking of introgression but also will provide clue to targeted phenotyping as nature of genes transferred could be predicted from gene ontology analysis.

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Crop architectural breeding in *Brassica* oilseeds

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There is a growing interest in architectural modification in crop Brassica species as a mean to enhance crop productivity. Crop architecture is commonly defined as a set of features delineating the shape, size, geometry and external structure of a plant (Ross 1981). Although, plant architecture is strongly influenced by agronomic practices and the prevailing environmental conditions, breeding can modify the structure of each individual plant as well as their responses to a change in canopy density. Changed architecture is important as it can alter plant growth, dry matter accumulation and metabolite partitioning. It can also impact light interception. The existing canopy architecture in crop Brassicas is primarily defined by their indeterminate growth habit. This growth habit is expressed through the production of new orders of branches from buds located at the axils of the top leaves of the branches of the previous order. Indeterminate growth habit is a wild type characteristic, conferring plants with ability to extend duration of the reproductive growth and maximizing chances of procreation under adverse climatic conditions. Under commercial agriculture, especially under stressed ecologies, it may compensate for large variations in the plant stand by producing additional vegetative and reproductive organs to achieve an acceptable seed production when the first reproductive organs aborted or were damaged. This kind of growth habit can be physiologically inefficient, as this endows plants with physiological ability to prolong their vegetative phase after the onset of flowering, causing competition between the vegetative and the reproductive growth for assimilates from a common metabolic pool. Such a situation leads to low or unstable harvest index and as a consequence low or unstable seed yields. Most common manifestation of this phenomenon in Brassicas is the wasted growth in terms of tip sterility. The second physiological implication is the potentially long cycle and late ripening due to the prolonged vegetative phase. Another important fact of crop Brassicas is that the pod walls are able to photosynthesize and feed the developing grains. At harvest, the pod walls contribute a large proportion. Because of this characteristic, the architecture of the reproductive organs is also important. Although most crop architectural modifications lead to reduced biomass production, these allow increased productivity through enhanced biomass partitioning to developing seed sinks. Main reason to genetically modify plant architecture is to maximize and stabilize seed yield. The second agronomic reason is to make the plant cycle best suited to the climatic conditions of a given environment, i.e. to flower when there are low risks of temperature and water stress, and to secure crop maturation. Crop architecture has been described and optimised in cereal crops. However, same is yet to be adequately defined for crop Brassicas. However, most architectural breeding approaches may combine physiological and genetic traits involving plant canopy. Most of the crop architectural traits are generally more heritable than the seed yield and, as most of the times; these are under a mono- or oligogenic control. The selection on architectural traits can be thus being more effective than the direct selection on the seed yield and its components. Three plant characteristics: roots, plant canopy and pods can be the targets for architectural modifications.

Determinate growth habit

The determinate growth habit is a remarkable architectural modification in crop Brassicas. The word ’determinate’ covers different situations. In crop Brassicas, the determinate growth habit is expressed by the floral stage of the stems. This may then induce the production of branches at different locations along the stems. As a result, the vegetative stage may sometimes become longer than in the indeterminate. Crop Brassicas are naturally indeterminate. This growth habit tends to accentuate intra-plant competition for resources within the plant canopy, leading to unfilled seeds, immature pods and tip sterility. The determinate genotypes have been bred in all the three crop Brassica species, by exploiting allelic variation for the gene *TFL1*. TFL-1 is a key regulator of vegetative growth as well as inflorescence architecture of the plants as studied and discussed in *Arabidopsis* research. Plants with determinate plant growth habit were first identified in progenies of resynthesized *B. juncea* as a *de novo* variation (Kaur and Banga 2015). F_1 plants, developed from crosses of determinate mustard with natural indeterminate genotypes were indeterminate, indicating the dominance of indeterminacy. F_2 segregation revealed monogenic recessive inheritance in majority of the progenies studied. Some F_2 progenies, however, showed a good fit with 13:3 ratio of digenic recessive epistasis. Gene for determinacy (Sdt_1) was mapped to the linkage group 15 of *B. juncea*. We also cloned and sequenced the gene for further analysis. We have primarily detected three paralogues of TFL-1 based upon the sequence analyses. BLAST results with whole genome and in house transcriptome of *B. nigra* and *B. rapa.* One of these three showed 99% similarity *B. rapa* , it was designated as AA and could be localized to chromosome A10. Other two paralogues showed maximum identity with *B. nigra*. These were designated as BB and B'B'. Of these, one showed maximum similarity with the existing *Brassica nigra* sequences whereas the second one was much closer to *Arabidopsis* sequences. These could be localized to two chromosomes of *B. nigra*. The nucleotide sequences of both DT and IDT genotypes carrying B or B' were aligned separately using MULTALIN program and possible SNPs were identified. SNP identified in the sequences carrying B homologues. "A" was the diagnostic SNP (A/T) that discriminated all DT lines from IDT lines with "T". The trait has since been transferred to *B.napus* as well.

Agronomic consequences of the determinate growth

Because of its impact on the growth, a lot of effort has been devoted to the analysis of the impact of this growth on the yield. Determinate progenies showed significant variation for plant height, flowering time and productivity. There appeared to be no adverse association in terms of lower pod density, productivity or oil content. The determinate growth habit led to a severe reduction of the plant growth with a reduction in the number of nodes and leaves and in plant height. It also strongly modified the distribution of the leaves on the branches as well as the relationship between the structure of the main shoot and of the branches. Determinate forms produced more branches than their indeterminate complements. Due to the modifications in the number of leaves and nodes, the leaf area index was generally lower in the determinate genotypes. Interception of the incident light was also influenced. However, whatever the plant density, the threshold for intercepting all the incident light was generally reached later and the duration of maximum interception shorter. As a consequence, the total biomass was generally lower in determinate than in indeterminate canopies. Besides modifying the total light interception, determinacy also caused variation in the photosynthetic activities of the different organs. Greater distribution of pods on the top of crop canopy implied greater contribution of the pods to the total photosynthesis in the determinate types. Determinate progenies with high agronomic performance were identified. Seed oil concentration of the grains was similar in the determinate and indeterminate populations selected in two crosses. While there was no significant relationship between seed yield and seed oil concentration among the determinate lines, it was negative for the indeterminate ones. The trait has been transferred to a number of

B.juncea genotypes.Responses to trait conversion varied. It is likely that the genetic background or phenological characteristics may be optimum for the indeterminate growth habit and suboptimum for the determinate growth in some genetic backgrounds, while reverse was true in other cases. Pod number was the major contributor to yield in crosses involving indeterminate fertility restorers and determinate CMS lines. One determinate genotype, PC6 of *B. carinata*, with outstanding yield potential has since been released for commercial cultivation in Punjab.

Dwarfism

The dwarf genotypes are sought for improving partitioning of photosynthates to the developing sinks. This may also influence the reproductive/vegetative ratio due to the reduction of the internode length. Dwarfing genes have been used to reduce lodging in other crops, and their use in wheat and rice was a major factor in the success of the 'Green Revolution'. A single, semi-dominant, gibberellin insensitive dwarf mutant of B. rapa (Brrga1- d), have been previously reported along with evidence for homology of this gene to the wheat 'Green Revolution' dwarf gene(Muangprom et al.,2004, Muangprom et al.,2005).A 'perfect' PCR marker for selection of the Brrga1-d gene, based on detecting the nucleotide mutation causing the dwarf phenotype has also been reported (Muangprom et al.,2006).We have identified a *B. rapa* landrace with short internodes, possibly due to because a deficiency in the level of endogenous gibberellic acid (GA). They are called synthesis mutants . In these variants, application of exogenous GA restores the normal internode length. The dwarf gene Bzh, which was derived from *B.napus* cv. Primor through chemical mutagenesis (Foisset *et al.*1995). The dwarf gene Bzh has an additive effect, which may bring about a greater than 30 % reduction in plant height (Barret et al.1998). Using this gene, several dwarf or semi-dwarf rapeseed cultivars, such as 'Bienvenu-bzh', '2405-bzh' and 'Darmor-bzh' (with formally released genome sequences), have been raised. Another major pleiotropic locus/ QTL, *BnDWF/DCL1* has been recognized(Wang et al.2016).It may reduce plant height, alter plant type traits and change leaf shape, and thus may lead to compact plant architecture. Accordingly, this locus may have substantial breeding potential for increasing planting density.

Root traits

Although poorly studied, roots are important for their role in water and nutrient uptake to support the aerial plant canopy. This trait is, however, very difficult to measure due its below ground spread and environmental sensitivity. There are only a few reports describing variation for root traits and associated markers in *B.juncea* (Akhatar and Banga, 2015) and *B.napus* (ArifUzZaman et al., 2016). One QTL, NRV (Napus Root Vigor) was identified on chromosome A01 (24.7 Mbp) for root vigor explaining 16.3% of the phenotypic variation. *GBF* Interacting Protein 1 (*GIP1*) and *SAUR*-like family proteins is the two candidate genes related to root growth and development identified within this QTL region (Zhang ET al.2016). QTL for root and shoot biomass were co-located on chromosome A3 and for lateral root emergence were co-located on chromosomes A4/C4 and C8/C9 in *B.napus*. There was also a major QTL for lateral root density on chromosome C9 explaining ~18% of the phenotypic variation.

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Breeding climate resilient short duration *Brassica juncea* varieties for multiple cropping systems of India

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Short duration, higher yield and stress tolerance are important factors required for making Indian mustard suitable for multiple cropping systems of India. At IARI the efforts were made to develop such varieties and as a result Pusa Agrani, Pusa Mahak, Pusa Tarak, Pusa Mustard 25, Pusa Mustard 26, Pusa Mustard 27 and Pusa Mustard 28 varieties were released for commercial cultivation. Continuous directed effort helped in breaking negative linkage between maturity and yield with significant improvement in harvest index. These varieties are improving the cropping intensity and also fast replacing *B. rapa* var. *toria* in Northern and North Eastern India.

India is world's fourth largest edible oil economy after the U.S., China and Brazil. Globally, it contributes almost six per cent of global vegetable oil production; 14 per cent of vegetable oil imports and 10 per cent of edible oils. The total market size of the Indian oilseed sector is about Rs 600 billion (US$13.4 billion). In the context of national agricultural system, oilseeds occupy 13 per cent of the country's gross cropped area and 3% to gross national products and 10% value of all agricultural products. Groundnut, soybean and rapeseed-mustard are the major oilseeds and contribute approximately 80 per cent of production. The average contribution of rapeseed-mustard to the total oilseed production in India was 24.2%, with its average productivity 1083 (kg/ha) during 2014-15. Though, rapeseed-mustard is placed 2nd in terms of production, after soybean, it ranks 1st in terms of oil yield among all oilseed crops. Oilseed Brassicas grown in India are *B.juncea, B.rapa. B. napus* and *B. carinata. B. juncea* (2n=36, AABB genome), an allopolyploid commonly called as Indian mustard, predominates and accounts for about 90% area under rapeseed-mustard crops. These crops are grown in diverse agro-climatic conditions varying from north-eastern/north-western hills to down south under irrigated/rainfed, timely/late sown and sole/mixed cropping. Indian mustard possesses better level of tolerance against most of the abiotic stresses such as drought, heat, salinity etc. than most of the cultivated crops. Though the level of abiotic stress tolerance is better in Indian mustard than other field crops, however, the crop growing environments still demands a better level of tolerance. It is also known to be higher yielder than *B. napus* and *B. rapa*, therefore, has an enormous cultivation potential in semi-arid areas. Due to this fact proportion of area under *Brassica juncea* (Indian mustard) has increased whereas, the area under other species likes *B. rapa* cvs. yellow sarson, brown sarson and *B. napus* have declined.

To make Indian mustard suitable for multiple cropping systems flexibility in date of sowing and resistance against biotic and abiotic factors are required. Short duration is the most important factor for improving the cropping intensity by adding additional crop to the cropping systems. Developing such varieties would help in replacing low yielding *B. rapa* (*toria*) which is highly susceptible to pod shattering and relatively more susceptible to different biotic and abiotic stresses. Furthermore, being cross pollinated species its varieties are maintained as population which don't have synchronous maturity. Poor plant stand is one of the factor for non-realization of actual yield potential in early and timely sown crops, which is mainly because of high temperature at seedling stage. If crop is sown late in the season, high temperature at reproductive stage leads to forced maturity resulting in reduced seed and oil yields. Hence, genotypes having inbuilt tolerance to high temperature at seedling stage as well as terminal stage heat tolerance are needed. At IARI, New Delhi continuous efforts are being made to develop such varieties and a brief account of research methodology and progress achieved is presented.

Despite genetic variation for short duration was not available in the cultivated and conserved germplasm, even then, efforts on development of short duration varieties was initiated in 1990s and a result first short duration variety Pusa Agrani was released in 1998. This variety was developed through resynthesis of *B. juncea* from crossing *B. rapa* with *B. nigra*. It takes about 110days to mature and possesses high temperature tolerance at early seedling stage. It proved as base material for development of number of short duration high yielding varieties. viz., Pusa Mahak, Pusa Tarak, Pusa Mustard 25, Pusa Mustard 26, Pusa Mustard 27 which were released for commercial cultivation at farmers' fields. Out of these, Pusa Mustard 26 also possesses high temperature tolerance at reproductive and post reproductive stage. A detail account of these varieties released from IARI is given in table 1.

Table 1: Short duration varieties released from IARI, New Delhi

Variety	Year of Release	Maturity	Yield (q/ha)	Area of Recommendation
Pusa Agrani	1998	110	17.5	Bihar, Jharkhand, Chhatisgarh, West Bengal, Orrisa, Assam and National Capital Region
Pusa Mehak	2005	118	17.5	Bihar, Jharkhand, Chhatisgarh, West Bengal, Orrisa, Assam and National Capital Region
Pusa Tarak	2009	120	19.24	National Capital Region
P Mustard 25	2010	100	15.20	North west plain zone for early sowing
P Mustard 26	2010	120	16.04	North west plain zone for late sowing
P Mustard 27	2010	114	15.35	Central Zone
P Mustard 28	2011	107	20.00	North west plain zone for early sowing

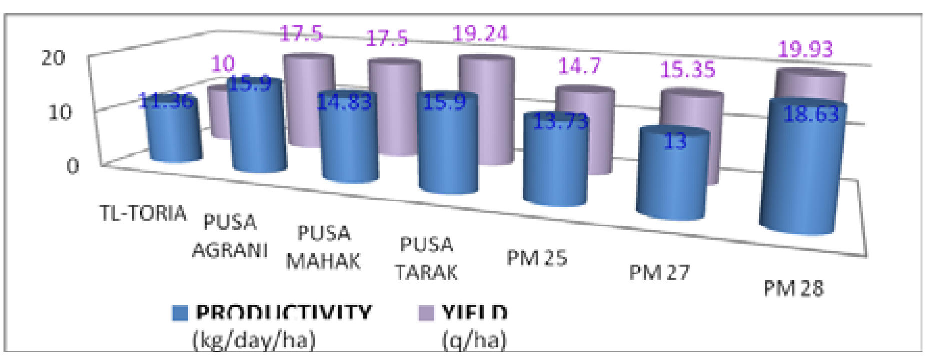

Fig. 1: Per day productivity and yield of short duration varieties released from IARI, New Delhi

After the release of Pusa Agrani the biggest challenge was to break the negative correlation between maturity and yield potential while maintaining the high temperature tolerance in the segregating generations. By developing a reliable screening methodology against high temperature stress at early seedling stage (Singh *et al*. 2012) genotypes viz. EJ-22, NPJ-113, NPJ-124, Pusa Bahar and 5011 (Pusa Agrani x Laxmi) identified as heat tolerant (Azharudheen *et al*. 2013). With the standardized screening methodology in place and raising large F_2 population the negative correlation was broken down in the genotype NPJ 124 which was later on released as Pusa Mustard 28. This a high yielding variety where the per day productivity has reached to 18.68 kg/day/ha as against about 13-14 kg/day/ha for most of other conventional mustard varieties (Fig. 1). The harvest index of this variety was 0.33 against less than 0.30 for other conventional varieties. Efforts are now going on for developing extra early Indian mustard genotypes which matures in about 90 days and observing higher harvest index. NPJ 176 is one such extra early genotype which is giving better yield under closer spacing. Likewise few more genotypes have also been evaluated during 2015-16 which have seed yield average more than 20q/ha and maturity ranges from in 95-118 days, details are given in Table-2 and these have been contributed for multi-location testing at national level.

Table 2: Advance promising lines evaluated for yield and maturity under early sown condition during 2014-15 and 2015-16

Genotype	**Pedigree**	**2014-15**		**2015-16**		**Average**	
		Yield (kg/ha)	**Maturity (days)**	**Yield (kg/ha)**	**Maturity (days)**	**Yield (kg/ha)**	**Maturity (days)**
NPJ-201	EJ-9913 x SEJ-8	2278	115	2185	109	2232	112
NPJ-202	NPJ-102 x Laxmi	2314	118	2099	95	2207	106
Pusa Mustard 25	Check	2338	121	2018	109	2178	115
Pusa Mustard 27	Check	2447	128	2004	111	2226	120
Pusa Mustard 28	Check	2105	132	2061	108	2083	120
TL-15	Check (Toria)	1328	108	1357	97	1343	103

With the introduction of these short duration (100-110 days) Indian mustard varieties, *B. rapa* cv. *toria* is being replaced by *B. juncea* in Eastern and North-Eastern states. Well established short duration varieties viz. Pusa Agrani (SEJ-2), Pusa Mahak (JD-6), Pusa Tarak (EJ-9912-13), Pusa Mustard 25 (NPJ-112), Pusa Mustard 27 (EJ-17), Pusa Mustard-28 (NPJ-124) are being preferred by the farmers in these regions and the cropping intensity is increased by planting these varieties under rice fellows. In northern India, these varieties are cultivated as an additional crop by sowing the crop in the first fortnight of September followed by harvesting in early December. This is opening many opportunities for establishing these short duration varieties in many cropping system and increasing the cropping intensity from 200% to 300%.

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Prospects of using exotic germplasm and allied species for the improvement of spring *Brassica napus* canola

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Broadening the genetic base of spring *Brassica napus* (2*n* = 38, AACC) canola is important for continued improvement of this crop for seed yield and agronomic traits. For this, allelic diversity of its primary gene pool, such as winter *B. napus* canola and rutabaga (*B. napus* ssp. *napobrassica*), and the secondary gene pool, such as its parental species can be utilized. By using winter canola in breeding, genetically diverse spring canola lines with significantly increased seed yield has been achieved; however, intensive selection for spring growth habit and earliness of flowering and maturity is needed while using this gene pool. The use of rutabaga in the breeding of spring canola is more challenging as the non-canola quality traits, high erucic acid in oil and high glucosinolate in seed meal, are also introduced in the progenies of spring canola × rutabaga cross; intensive selection is needed not only for spring growth habit and earliness of flowering and maturity but also for the canola quality traits. The genetically diverse germplasm developed from the use of primary gene pool have shown potential for the development of open-pollinated as well as hybrid cultivars.

In case of the two progenitor species, *Brassica rapa* (AA, 2*n* = 20) and *Brassica oleracea* (CC, 2*n* = 18) several researchers used *B. rapa* in the breeding of *B. napus*. Interspecific hybrids of *B. napus* × *B. rapa* can be obtained without application of *in vitro* cell and tissue culture technique, and genetically distinct gene pool was developed through utilizing wide genetic diversity of this progenitor species. In contrast, very limited progress has been made regarding the use of *B. oleracea* in breeding spring *B. napus* canola for the improvement of its C genome, which is known to have a narrow genetic base compared to the A genome, due to the difficulty of producing interspecific hybrids of *B. napus* × *B. oleracea* cross – despite this parental species harbor wide morphological and genetic diversity. Sterility in the interspecific hybrids and in their progeny, and introduction of non-canola quality traits from *B. oleracea* and from some variants of *B. rapa* into the progeny of these interspecific cross are some of the additional constraints of using these diploid species for the improvement of *B. napus* canola. *In vitro* ovule culture technique proved to be efficient for the production of interspecific hybrids of *B. napus* × *B. oleracea*. Variation for the canola quality traits in the progeny of *B. napus* canola × *B. oleracea* involve segregation of only the C genome alleles and in case of *B. napus* canola × *B. rapa* it involve only the A genome alleles governing these traits; this simpler segregation simplified the development of canola quality lines from these interspecific crosses. The progeny of the AAC F_1 plants of *B. napus* × *B. rapa* and ACC F_1 plants of *B. napus* × *B. oleracea* stabilized into *B. napus* type (2*n* = 38) only – despite, theoretically, it was expected that diploid parent type plants would occur in the progeny of these interspecific cross owing to elimination of the haploid set chromosomes of the F_1 plants. Several alleles of *B. oleracea* and *B. rapa* get lost during the development of the advanced generation lines from these interspecific crosses; therefore, selection for these exotic alleles needs to be done in early generations to retain a greater number of these alleles.

Comparisons of the genetically diverse *B. napus* lines derived from *B. napus* × *B. oleracea*, winter × spring and spring × spring *B. napus* crosses for heterosis in *B. napus* showed that, mid-parent heterosis (MPH) was two times greater in hybrids of the population derived from *B. napus* × *B. oleracea* cross than the level of MPH found with the populations derived from spring × spring or winter × spring *B. napus* crosses. MPH showed a negative correlation with seed yield of the inbred line; however, it showed a positive correlation with heterosis over Hi-Q (HiQH) or with hybrid yield indicating its importance for greater productivity in the hybrid cultivars. Correlation between seed yield of the inbred lines and HiQH or hybrid yield was positive; this indicate the importance of general combining ability of the parents for the development hybrid cultivars. Among the three inbred populations, the population derived from winter × spring cross produced the highest seed yield while the population derived from *B. napus* × *B. oleracea* cross produced the lowest yield. The winter × spring population also showed highest HiQH; however, it was not the *B. napus* × *B. oleracea* population, the spring × spring population that showed the lowest HiQH. The results suggest that the alleles exerting non-additive effects in the genetic control of heterosis can be found more frequently in *B. oleracea* than in spring or winter *B. napus*, whereas the alleles for greater general combining ability of the hybrid parents can be found more frequently in winter canola than in spring canola or *B. oleracea*. Therefore, a knowledge-based breeding may utilize the *B. oleracea* and winter canola gene pools for increasing the level of heterosis and productivity of the spring hybrid *B. napus* canola cultivars.

The progenitor species *B. oleracea* was also found to carry alleles for earliness of flowering – despite this species flowers and matures much later than spring *B. napus* canola. The Chinese kale of *B. oleracea* was found to carry unique alleles for earliness of flowering which make the *B. napus* to flower about a week earlier. One of the unique alleles of the C genome of *B. oleracea*, which was introgressed into *B. napus*, mapped on the chromosome C1. This allele was found not to be affected by the environment and contributed to earliness in *B. napus* without a significant negative effect on seed yield in majority of the field trials conducted in Alberta.

Brassica rapa L. improvement for yield and crop resiliency

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Rapeseed crops in India comprised of traditionally grown sub-species of *Brassica rapa* namely toria (*B. rapa* var. toria), brown sarson (*B. rapa* var. brown sarson) and yellow sarson (*B. rapa*. var. yellow sarson). Toria is self incompatible and cross pollinated, yellow sarson is self compatible and self pollinated while brown sarson comprise of two forms- *tora* type which is self pollinated and the other is lotni type which is self incompatible and cross pollinated. It is widely believed that *lotni* type brown sarson is oldest type and *tora* type is a derivative from hybridization between yellow sarson and *lotni* brown sarson. The ecotypes yellow sarson and toria are again derived from brown sarson; the former being the mutant for superior quality and latter being the result of selection, developed probably in the foothills of Himalayas, as an early type in response to particular ecological requirements

Of the ecotypes of *B. rapa*, toria is cultivated largely rainfed in Assam, Odisha, West Bengal and in northern states. In the northern parts of the country, it is cultivated in Haryana, Himachal Pradesh, Punjab, Jammu & Kashmir, Uttar Pradesh and Uttarakhand as a catch or mixed crop due to its short duration. It is a valuable donor source for high temperature tolerance at seedling stage. This character makes it a most suitable crop for sowing when the temperature is high before commencement of sowing time for main *rabi/*winter season crops. Cultivation of yellow sarson is confined to northern states either as pure or mixed/inter-crop with other *rabi* crops. *Tora* type brown sarson is not seen at farmer’s fields. *Lotni* type brown sarson, owing to its low water requirement is grown in some areas of north-west and in hilly tract mostly at mid and high hills in India. It is a useful source for drought tolerance traits. At high hills brown sarson forms grown are winter type which has inherited low temperature tolerance in addition to drought tolerance.

Harnessing desirable traits through inter-transfer between ecotypes of *Brassica rapa* L.

In the past, breeding of three ecotypes of *Brassica rapa* has confined mostly within each of the ecotypes and limited efforts have been made to harness the desirable features of one ecotypes into the others, resulting in slow progress. The presence of variable degree of incompatibility and temporal isolation have restricted and narrowed down the variation within each of the sub-species of *B. rapa*- toria, yellow sarson and brown sarson. It is, however, known that their desirable traits can be recombined (Ram Bhajan and Singh, 1988). Modification of plant architecture through alignment of genes from different ecotypes and novel allelic combinations may offer great opportunities in addressing climate resiliency, productivity and quality. This, however, calls for a more comprehensive approach based on the inheritance patterns of various characters.

Exploitation of simply inherited traits such as seed coat colour, siliqua traits (siliqua locules, upright/pendant siliqua bearing habit), earliness of flowering and maturity seems easier through conventional breeding approaches owing to their high heritability and/or simple genetic control. However, for quantitative traits, it has been found that in generations descending from wide crosses such as yellow sarson x toria and yellow sarson x brown sarson (*lotni*) usually display complex inheritance in the form of epistasis (Patnaik and Murty, 1978; Ram Bhajan and Singh, 1989). The presence of marked epistasis for various quantitative traits suggests the need for maintenance of heterozygosity in breeding populations. The dominant self incompatibility alleles contributed by self-incompatible toria/ lotni type brown sarson in such crosses is expected to ensure cross pollination and maintain heterozygosity in the population. A large part of this epistasis has been shown to be of fixable types (additive x additive and additive x additive x additive) which suggests for mild selection in early segregating generations (Patnaik and Murty, 1978; Ram Bhajan and Singh, 1989). Inter-mating in early segregating generations may be expected to foster the settling of desirable fixable epistatic combinations. Breeding approach based on such crosses can effectively mobilize the genetic variability occurring within each of these sub-species of *B. rapa.*

This has been fruitfully utilized in the development of more productive and widely adapted variety PT-303 of toria which was developed from a cross between toria (B-54) and *tora* type brown sarson (DSH17MD).

Enhancing yield and crop resiliency

Breeding methods applied to these crops vary greatly from simple method of mass selection to development of synthetics. Scientific and practical considerations, as well as breeding objectives, determine the suitability of breeding procedure.

Maintenance of genetic purity

Though yellow *sarson* and *tora* type brown sarson are largely self pollinated but varying amounts of natural out crossing occurs under field conditions depending upon wind and bee activity. *Toria* and *lotni* brown sarson, being self incompatible fail to set seed under selfing by simple bagging due to sporophytic self incompatibility. Occasionally in some genotypes few seeds may be obtained in S_0 plants that are not sufficient to serve the purpose. Thus, cross pollinating *B. rapa* varieties are difficult to maintain in pure form and also difficult to produce sufficient seed.

One of the approaches for maintenance of germplasm of *toria/lotni* brown sarson is to plant a variety in 10 rows of 10m long and harvest open pollinated seed from central two rows of two meter. This is based on the premise that pollinators/bees carrying foreign pollen will be washed away while initial visiting on bordering plants and as they move inside the plot, they will pollinate central plants with native pollen. This ensures reasonably pure seed but requires more space to produce seed.

We are using modified method for maintenance by planting at least one meter border row of short duration, dwarf height mustard (NDRE-4 or Divya) and sowing desired *toria*/*lotni* brown sarson rows inside the rectangle. This practice has shown great promise in maintaining the genetic purity of the lines. However, the success of this practice depends upon matching of flowering and height of bordering mustard. A success in this direction has been achieved as we have been successful in developing a genotype of mustard (PRHC-13-7) that is early and dwarf and expected to be more effective as bordering barrier for *toria* maintenance.

Genetic variability a key improvement

Two landraces of toria from Utttarakhand (India) were found to have extra early maturity (<60 days). Further selection for earliness, uniformity, height and other characteristics resulted in extra-early maturing lines of *B. rapa* var. toria named as PT-141 and PT-145 (Ram Bhajan *et al*., 2013). In these lines, flowering period was considerably reduced, which increased synchrony both within and between racemes of a plant. It is known that earliness is associated with increased photoperiod insensitivity (day neutrality) in different crop plants (Singh and Sharma, 1996). Earliness or day neutrality is also known to increase the adaptability of varieties.

With the availability of such extra-early maturing germplasm, it is possible to design a plant type of *B. rapa* var. toria which is high yielding, short stature and also matures early. The extra-early maturity of these lines makes them more suitable for their use as catch crop and also to regain the toria area that has declined in the recent past.

Climate changes are also likely to pose a bigger challenge in the form of temperature rise, unexpected high or low rainfall, and shifts in the onset of monsoon and also in growing seasons. A slight shift towards earliness in sowing time of major winter crops, including oilseed brassicas, or due to the early rise in temperature at the terminal stage of the crop may necessitate the need for extra-early genotypes of *toria* to fit in as catch crop in the emerging climate regimes and cropping situations. The short plant height of PT-141 and PT-145 also offers opportunities for re-synthesizing dwarf stature, short-duration genotypes of *B. juncea*, a major *Brassica* oilseed crop grown in India. With increased day neutrality of varieties, it may be possible to introduce toria as a *Zaid* season crop (these are crops grown on irrigated lands that do not have to wait for monsoons, mainly from March to June). However, such possibility requires critical analysis, experimentation as well as a selection for specific adaptation from the base collection of such short duration germplasm. Possibilities can also be explored for reshaping the genotypes using advance tools of genome modifications and editing.

Normally, branching in *B. rapa* var. toria arises from the main stem at a wide angle with a semi-spreading to spreading growth habit, which means that plants tend to spread more in spaced growing environments than at normal spacing intervals. A new line, PTHC-11-22, with a profuse base branching trait, has been identified out of local collections adapted to rainfed conditions of the Uttarakhand hills. The plants of this line had 9–16 primary branches and about 40% of branches were formed within 10 cm height from the base. The primary branches were found to grow as tall as the main raceme, which probably caused relatively more synchronous flowering among racemes on a plant. As such this appears to be a desirable trait which is lacking in existing varieties and can be used effectively for improving the resiliency against water deficits.

Improvement within ecotypes of *B. rapa*

Toria

Development of composites and synthetics has been the main stay of toria/lotni brown sarson improvement. Limited efforts for improvement using recurrent selection have been made. Mass selection for two cycles in toria showed an improvement ranging from 5.10% to 9.09% in C2 populations over C0 (Ram Bhajan, 2000). Recurrent selection for seed size and yield in PT 303 resulted in significant improvements culminating in to the development and release of ‘Uttara’ variety of toria. Hybridization of superior high yielding varieties with local germplasm from stress prone areas followed by selection for yielding ability under normal environment and for stress tolerance in the target environment(s) using recurrent selection is expected to bring about desired improvement in terms of climate resiliency as well as yield and quality of toria/brown sarson.

Brown sarson

Like toria, composite and synthetic varieties have been bred in lotni brown sarson viz. Gluechin, KBS 3, Pusa Kalyani and VLT-3. BSH-1 is the only variety which has been developed through population improvement. Considerable variation for important traits (number and pattern of branching, siliqua traits, etc) is available in local germplasm collected from

Uttarakhand hills. Besides, it is low temperature and moisture stress tolerant but appears susceptible to Alternaria blight. Similarly germplasm from drier areas in plains possesses tolerance to drought and high temperature. As such this offers opportunities for improvement through combination breeding or population improvement to evolve varieties with increased yield and tolerance to stresses.

Development of frost tolerant brown sarson

With a view to overcome the problem of frost in highly susceptible lotni type of brown sarson, an effort was made to transfer frost resistance trait from Japanese variety Yukina of *B. rapa* L. to Indian high yielding cultivar, Pusa Kalyani. Initial crosses between Pusa Kalyani and Yukina were made in Japan by Dr. PR Kumar (personal communication). Selection pressure was applied in segregating populations and extensive testing of the newly developed line FR-80, was done by HAU, Hisar in frost prone areas of Haryana, Punjab and Himachal Pradesh, The efforts led to the development of frost tolerant variety, KBS-3, which was released and notified for general cultivation in Himachal Pradesh in 1998.

Yellow sarson

Most of the successful varieties of yellow sarson have been developed using pure line selection viz. YST 151, T 42, Benoy, Jhumka, K 88, Ragini, NRCYS 05-02, YSH 0401, Pitambari and Pant Pili Sarson-1. The crop has experienced limited use of hybridization followed by pedigree selection in varietal development. Some of the varieties developed using pedigree selection includes Gujrat Sarson-1, Subinoy and Pant Sweta. Thus, there is ample scope for improvement through combination breeding using desired traits available in potential germplasm. In this direction, work on bearing habit suggested perceptible yield advantage of upright siliqua inclination as compared to pendant and horizontal types (Shikari and Sinhamahapatra, 2004). Terminal unfruitfulness has been a problem in yellow sarson. Utilization of a donor source (PYS 2008-5) for terminal fruitfulness through hybridization may be expected to correct this defect and enhance the yield (Ram Bhajan *et al*. 2013).

Mutation breeding has also been utilized to develop varieties like NDYS 2 with carmel colour seed and white rust resistance. However, this variety could not be successful due to instability for major yield traits. Yet different types of mutagens can be explored in the induction of variability especially for the traits not available in the gene pool.

Exploiting heat and drought tolerance in toria and brown sarson

Studies on impact of temperature increase on the rate of crop growth and yield (Cooper *et al.*, 2009) indicate that there will be reduction in ‘time of maturity’ of cultivars. This mean in a warmer situation, a currently defined ‘medium duration’ type will become a ‘shorter duration type’. Considering this, the crop improvement programmes in future should focus on medium maturing types with heat tolerance and pest and disease resistance to deal with yield reduction resulting from temperature increase. Climate change will modify the length of the growing period across the regions of interest, but this can be mitigated by the re-targeting and re-deployment of existing germplasm. Owing to the evolutionary advantages, its genetic resources have useful genes for stresses like heat and drought tolerance, *B. rapa* ecotypes are in a unique position to cope with climate change.

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Harnessing heterosis in rapeseed-mustard

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Oilseed Brassica crops are important source of vegetable oil and contribute almost 15 percent of the world's vegetable oil. India ranks second in the acreage after China and third in the production after China and Canada of oilseed Brassica crops. In India these crops occupy premier position with a contribution of about 28 percent of the total oilseeds production. These were grown on approximately 5.79 m ha area and produced 6.31 m tonnes of oilseeds with 1089 kg per ha seed yield during 2014-15. Low and unsustainable yield of rapeseed-mustard has always been a cause of concern in enhancing domestic availability of edible oil in India. Hetersois breeding may be regarded as the most spectacular phenomenon of crop breeding in twentieth century which witnessed not only the increase in productivity of crops like maize, pearl millet and sorghum but also the application of hybrid technology in self fertilized crops, predominantly in rice. The earlier concepts of exploiting the heterosis in cross pollinated crops changed, mainly due to success of hybrid technology in rice. Indian mustard (*Brassica juncea*) has considerable extent of outcrossing and that provides vast scope for the development of hybrids in this crop. Success of a hybrid development programme in a crop mainly depends upon the extent of heterosis. In last century, many scientists reported considerable extent of heterosis in *Brassica juncea*. These reports *vis a vis* development and release of hybrids in *Brassica napus* in Canada and other countries were the main stimulants to start work on hybrid development in Indian mustard. Indian Scientists developed many cytoplasmic male sterility systems during1980-2005; however their use in hybrid development could be possible since the beginning of present century.

International scenario of hybrid development:

First winter oilseed rape hybrid varieties were registered in 1995 in Europe. The yield increase of these first hybrids was between 5 - 15% compared to the best checks. More than 40 MSL (male sterility system Lembke) hybrid varieties were released in different countries of Europe and about 0.31 t /ha higher seed yield in comparison to open pollinated varieties was recorded. At present, European canola (low erucic and low glucosinolate content) hybrids comprise over 90 percent of the total crop. Canadian canola acreage planted to hybrids has more than doubled in the past few years reaching approximately 70 percent market share. Thirty seven hybrids were released in Canada during 2008 and 20 to 25 percent yield improvements from new hybrids were demonstrated commercially by Canadian growers above standard open pollinated varieties. The hybrids of *B. napus* are being developed and marketed by several multinational companies in Europe, Canada and Australia. Out of 144 double and single low cultivars registered officially in China during 1985 - 2002, 77 were hybrids. The potential yield of the double low hybrids was 15 - 20 % higher than that of the normal checks. Now hybrids account for more than 75 percent of the total cultivated rapeseed in China. In India tour CMS based hybrid PGSH 51 was released during 1994 from PAU, Ludhiana and Hyola 401 by Advanta India Ltd in 1996.

Hybrids in Indian mustard (*Brassica juncea*)

Systematic and coordinated efforts for developing hybrids in Indian mustard started in 1989 under the ICAR sponsored project on "Promotion of Research and Development Efforts on Hybrids in Crops" with 2 CMS systems in *B. juncea*, *i.e.* ogu and tour and one in *B.napus*, *i.e.*, polima. Major emphasis was given to the simultaneous development of CMS-fertility restorer systems. The approach led to the development of seven new CMS systems, *viz.,* siifolia, oxyrrhina, muralis, catholica, nigra, moricandia and trachystoma till 1995. These systems due to several limitations particularly non availability of full fertility restoration, could not be utilized for hybrid development. Due to the failure of conventional breeding methods in identifying the restorer gene (s) in *B. juncea*, it was felt to find out restorer gene (s) in the same species from which cytoplasm had been introgressed. Concerted efforts were made at National Research Centre for Plant Biotechnology, New Delhi for the development of fertility restorer through protoplast fusion between the wild species and *B. juncea*. These efforts resulted in the development of fertility restorer for mori and trachy CMS systems. Mori CMS and fertility restorer were found to be associated with severe chlorosis and retarded growth. Segregation for fertility/sterility coupled with crooked siliqua formation was observed in trachy system. Efforts were then put to rectify the chlorosis and to improve the transmission of fertility restorer gene (s). Considering its potential, efforts were concentrated on mori CMS-fertility restorer system. Chlorosis associated with mori CMS systems was rectified and have been diversified into the improved background of identified heterotic combination for developing commercial hybrids. Lyratus, Erucoides, Canariense, Berthautii and 126-1 CMS systems were later reported.

In *B .napus*, CMS development programme has been in progress with three CMS systems viz., polima, tournefortii and lyratus. The three-line technology has already been perfected with the release of first commercial hybrid PGSH 51 based on tour CMS system by PAU, Ludhiana. In *B. rapa syn campestris ssp yellow sarson*, three GMS lines viz., YSMS-2, YSMS-6 , and YSMS 8163, provided the base for developing the hybrids. YSMS 8163 has been quite stable. Currently major thrust is on the search of a marker to identify male sterile plants in the initial phase of vegetative growth.

In the subsequent phase (1999-2005) under NATP, efforts were concentrated on evaluation, refinement and diversification of moricandia CMS – fertility restorer system in *B .juncea* under NATP sponsored project “Development of hybrids-crop”. Selfing/ backcrossing with *B. juncea* coupled with rigorous selection of green sterile and fertile plants helped in identification of plants with perfect green colour. Green fertile plants were further used as female parents for backcrossing with *B. juncea,* accessions. Emphasis was laid on conversion of normal green mori CMS and restorer plants into high yielding heterotic parents at DRMR, Bharatpur.

Extent of heterosis

Reports on the availability of heterosis in rapeseed-mustard dates back to 1943 (Sun 1943), which shaped interest amongst plant breeders to develop the means for harnessing hybrid vigour. In Indian mustard heterosis of high level (> 100% on plant basis) was recorded by earlier researchers (Labana *et al* 1975; Banga and Labana 1984 a; Dhillon *et al* 1990).Yield advantage of experimental hybrids over standard checks under commercial sowing densities was, however, significantly lower (<40%). Various Indian mustard cross combinations showing hybrid yield advantage over better parent or standard cultivar have been reported. In general the hybrid yield advantage has been greater under optimum conditions than that realized under suboptimal conditions. Heterosis for increased biomass, branches and siliquae number were the largest contributors to the heterosis for seed yield. Several approaches were carried out to identify the heterotic combinations but most of the reports lack multilocation and multiyear testing, hence, have been subjected much to the environmental factors.

Male sterility systems

Development of cytoplasmic male sterility in radish (*Raphanus sativus* L) by Ogura 1968 and subsequently its transfer to *Brassica napus* (Bannerot *et al* 1974) and later on into *Brassica juncea* (Labana and Banga 1984) raised hopes to develop hybrids in rapeseed mustard. In the later years, several cytoplasmic male sterility systems were reported (Table 1). Other mechanisms available for pollination control in rapeseed mustard are self incompatibility (SI), genetic male sterility (GMS) and chemical hybridizing agents (CHA) induced male sterility. Male sterility in Indian mustard (*Brassica juncea*) was reported by Rawat and Anand in 1979 but it could not be utilized due to incomplete fertility restoration.

Table 1 Cytoplasmic male sterility systems available in rapeseed-mustard in India

Name of the system	Discovered by	Status of fertility Restoration
Nap	Thompson (1972 b), Baba (1971, 1973)	One to four "*Rf*" *genes* are reported in *B. napus*
Ogu	Ogura (1968) in radish	reported in *B. napus*
Pol	Fu (1981 a)	reported in *B. napu, B. campestris*, *B. Juncea*
muralis	Hinata and Konno(1979)	Rf gene in *B .napus* Lacks maintainers
Korean	Lee et al. 1976	Rf gene in *B .napus* Lacks maintainers
tour	Rawat and Anand(1979)	reported in *B. napus*
juncea	Shi et al (1991)	Presently being used in Yunan Provinces of China.
campestris	Ohkawa (1985)	available in *B. campestris*
nigra	Pearson(1972) (in *B. napus*)	Reported in *B. carinata* lack maintainers
oxyrrhina	Prakash and Chopra(1988)	No restorer
siifolia	Rao *et al*. (1994)	No restorer
trachystoma	Kirti *et al*. (1995 c)	reported but not in use
moricandia	Prakash *et al*. (1995)	single dominant gene is reported
catholica	Kirti *et al*.(1995 b)	No restoration
alba	Prakash *et al*.(1995)	No restoration
lyratus	Banga and Banga (1997)	reported in *B. napus*
canariense	Prakash *et al* (2001)	Reported
erucoides	Bhat *et al* (2006)	Reported
126-1	Sodhi et al (2006)	Reported
berthautii	Bhat *et al* (2008)	Reported

In subsequent years, several pollination control systems were reported of which following have been commercialized:

B. napus : CMS ogura, CMS Lembke, CMS polima, CMS Shann, CMS tournefortii,
Geneticcally engineered Barnase-Barstar
B. juncea : CMS ogura, CMS moricandia, 126-1

Molecular tagging of *Rf* gene(s)

DNA markers tightly linked to a restorer gene are valuable tools for marker assisted breeding. In *Brassica*, Delourme and Eber (1992) identified an isozyme marker *pgi*-2 tightly linked (0.25cM) to *Rfo* restorer gene for *ogura* CMS system. Four RAPD markers $OPC02_{1150,}$ OPD 02_{1000}, $OPF06_{1200}$ and OPG 02_{700} linked to *Rfo* locus were also reported (Delourme *et al* 1994). The region around *Rfo* gene was further saturated (Delourme *et al* 1998) and a RAPD primer, RAPD13 was identified, which co-segregated with *Rfo* locus. Hausen *et al* (1997) also reported a RAPD marker $AA16_{700}$ tightly linked (1.9cM) to *Rfo* locus.

Genetically engineered male sterility

The first success in developing genetically engineered male sterility in crop plants was by transforming tobacco and rapeseed plants with dominant gene *barnase* (bacterial *RNase*) driven by a tapetum-specific promoter *TA 29* (Mariani *et al*., 1990). To restore fertility, the pollen parents were transformed with *barstar* gene from same bacterium (Mariani *et al*., 1992). Upon crossing *barnase* male sterile plants with transgenic fertile plants carrying *TA29-barstar* chimaeric gene, the F_1 progeny showed coexpression of both the genes in the anthers of the male fertile plant. It was found that *barstar* gene is dominant to the *barnase* gene, and fertility restoration was due to the formation of tapetal cell-specific *barnase* and *barstar* complexes. Female fertility was not affected, and transformed plants had normal morphology. By coupling the *TA29-Barnase* gene to a dominant herbicide resistance "bar" gene, uniform populations of male sterile plants could be produced. "*Bar*" gene confers resistance to the herbicide *bialophos* (phosphinothricin or PPT) and is used as a marker for male sterility (Denis et al., 1993). Transgenic male sterile plants of *Brassica napus* variety Drakkar were linked to the "*bar*" gene coding for PPT acetyl transferase and were resistant to herbicide PPT. Maintenance progeny showed 50 percent male fertile susceptible plants. Application of PPT permitted the elimination of male fertile susceptible segregants in the field by herbicidal application and assured 100 percent production of hybrid seed on male sterile plants. Reversion to fertility from male sterile plants has been observed in some cases. Jagannath *et al*. (2001) could develop stable transgenics by using gene constructs having spacer DNA in between the *barnase* gene and the *CaMV 35S* promoter-driven *bar* gene. The newly developed male sterile lines, however, could not be restored by transgenics carrying wild type barstar. To restore fertility in such male sterile lines modified barstar constructs were developed (Jagannath *et al*., 2002).

Incomplete elimination of male fertile segregants from female line in hybrid seed production plots and the necessity of using two transgenic lines for synthesis of hybrid is a major limitation of barnase-barstar system. To overcome these, a two component system of barnase induced cell lethality has been developed (Burgess *et al*., 2002). This involves engineering extracellular ribonuclease, into two complementary fragments, the N-terminal and the C-terminal peptides. The DNA encoding modified N-terminal and C-terminal barnase peptides were cloned and fused separately with a tapetal-specific promotor 127a from tomato to generate chimaeric gene constructs, p127a-Bn 5-2 and p127a-Bn 3-2.

Chemical hybridizing agents

A chemical with the ability to induce pollen sterility or check pollen shed can not only help to overcome problems associated with the CMS but will also impart greater flexibility in choice of genotype as potential female parent in the development of hybrids. Chemicals namely DPX 3778, ethrel and GA_3 have been evaluated in Indian mustard (Banga and Labana, 1983a, 1984; Banga *et al*., 1986). Foliar application of 2000-3000 ppm ethrel three times before flowering shoot emergence led to retarded anthers. Treated anthers were upto four days late in pollen release compared to check and up to 90 per cent self-sterility could be achieved. Female fertility was affected at higher doses but cross pollination was possible. Genetical check revealed that up to 54% of the total seed set on ethrel treated populations to be of hybrid origin (Banga and Labana, 1984). Another factor that limited the use of ethrel as CHA is that the gametocidal effect is present for only up to 20-25 days after treatment, while flowering in mustard continues for 60-70 days. Higher dose and repeated applications resulted in a longer duration of gametocidal response, but this caused reduced female fertility and other abnormalities, like phytotoxic effects. DPX 3778 and GA_3 failed to induce any male sterility. In *B. napus*, Guan and Wang (1987) and Guan *et al*. (1990) investigated the extent of male sterility induction. Three arsenate-based gametocides (MG_1, MG_2, MG_3) induced male sterility when sprayed at bud stage. First hybrid variety Shuza No. 2 produced by application of gametocide no. 1 was released in 1990.

Hybrid seed production utilizing CMS with restorer

Hybrid seed production based on CMS-FR system requires four isolations; maintenance of CMS line (A x B), multiplication of maintainer (B) line, multiplication of restorer (R) line and hybrid seed (A x R) production. The production of hybrid seed by cross pollination is the most important factor affecting the bio-economics of seed set on female lines using various production techniques. Wind and insects have been reported to be the main agents for pollination. The factors that influence the extent of seed setting on female lines include : male – female ratio, synchronized flowering of male and female parents, nectar production and bee foraging, yielding ability of CMS lines, pollen production of male parents. A very wide variability in seed yield has been observed in different experiments. Greater proportion of female rows is desirable to enhance the production of hybrid seed, care must be taken to ensure adequate pollen supply to facilitate hybrid seed set on female plants. Singh *et al* 2011 reported 8 female: 2 male row ratio for hybrid seed production as well as for multiplication of the seed parent Orientation of rows against the direction of wind has generally been found useful to maximize out-crossing on female plants. The block seed production method, using *ogu* CMS material has been found to be suitable in *B. napus* (Hogarth *et al*., 1995). Isolation distance depends upon several factors. These include location, wind direction, viability for air borne pollen and extent of bee population. Production of hybrid seed should be carried out in fields isolated from other plants of related species with a minimum distance of 500 to 3000 m depending upon the species. Crucial role of nectar production for bee foraging and seed set on male sterile plants has been established in various crops. Keeping beehives in the seed production plots of rapeseed-mustard has been found to be useful. Another factor, which has profound influence on the economics of hybrid seed production, is the synchronized flowering of male and female parents. Nicking coupled with cultural manipulations or by selective application of growth regulators to delay or advance flowering in male / female lines is suggested to bring synchronization.

Present status of hybrid development in India

The basic material required for hybrid development has been perfectized and a large number of experimental hybrids have been produced at different centres viz., PAU Ludhiana, CCS HAU Hisar, ICAR- Directorate of Rapeseed Mustard Research Bharatpur and ICAR Indian

Agricultural Research Institute, New Delhi. A multilocation coordinated yield evaluation trial for hybrids was constituted in 2005-06 under All India Coordinated Research Project on Rapeseed-Mustard (AICRP-RM). Since 2005-06 120 experimental hybrids have been tested that included 31, 23, 16,15,10,10,05, 03,02,02 01 and 01 from PAU Ludhiana, ICAR- Directorate of Rapeseed Mustard Research Bharatpur, ICAR Indian Agricultural Research Institute, New Delhi, CCS HAU Hisar, Bayer Bioscience, Pioneer Overseas, Advanta India Ltd, Krishna Seed, Nirmal Seeds, Delhi University, Nuziveedu Seeds pvt. Ltd. and J.K. Agri- Genetics, respectively. Two hybrids NRCHB 506 developed by ICAR - Directorate of Rapeseed-Mustard Research, Bharatpur, using moricandia CMS system and DMH 1 developed by DU/NDDB using 126-1 CMS system were identified for release in zone III and zone II respectively, during 15th annual group meeting of AICRP-RM held in 2008 at OUAT Bhubaneswar. The hybrid NRCHB 506 had superiority over the all three checks Kranti, Maya and Varuna by a margin of 10, 24 and 13 percent, on the basis of mean seed yield and 12, 26 and 20 percent, respectively on the basis of mean oil yield over three year testing. The another hybrid DMH 1 showed superiority for seed yield by a margin of 13 percent over RL 1359, 21 percent over Kranti and 29 percent over Varuna. Since then a total of five hybrids have been released in Indian mustard (Table 2).

Table 2. Indian mustard hybrids released in India

Name of hybrid	**Developing Institution**	**Year**	**Area for which released**	**CMS source**
Brassica juncea				
NRCHB-506	DRMR, Bharatpur	2009	Rajasthan, U.P.	*Mori*
DMH-1	DUSC, Delhi	2009	Punjab, Haryana, Delhi, J&K, Rajasthan	126-1
Coral (PAC)-432	Advanta India Ltd.	2010	Rajasthan, Haryana, Punjab, Delhi	*Ogu*
Coral (PAC-437)	Advanta India Ltd.	2012	Rajasthan, Haryana, Punjab, Delhi	*Ogu*
44S01	Pioneer Overseas Corporation	2013	Asom, Bihar, Jharkhand, Orissa for rainfed situation	*ogu*

Future Thrust

Success of hybrid development depends upon the level of heterosis. Several hand bred F_{1s} have been evaluated so far to identify the heterotic combinations in *Brassica juncea*. Efforts were also carried to develop heterotic gene pools through random mating among maintainers. Selection was also practiced from segregating generations to develop parental lines with wide genetic base. All these efforts have provided the sound basis for hybrid development. Hybrid development is a continuous process. In mustard hybrid development programme, future thrust shalll be on enhancing the level of heterosis, and the development of agro – technology for hybrid seed production as well as for hybrid cultivation. Multilocation testing of large number of experimental hybrids is needed to assess the level of yield heterosis. Doubled haploid

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Quality improvement in rapeseed-mustard - Indian perspective

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erucic acid in *B. napus*, whereas another study by Agnihotri and Kaushik (2000) showed an increase of 45% in *B. juncea*. Selections from *B. carinata* with low erucic acid content showed an increase in linoleic and linolenic acids and reduction in oleic acid content (Rakow 1995). Low erucic acid and high oleic acid have been transferred in *B. napus* and *B. juncea* (Agnihotri *et al*. 2007; Agnihotri *et al*. 2011). Oil quality modifications have also been achieved by RNAi based post transcriptional gene (PTGS) silencing or by addition of new genes. These methods have enabled the development of traits like seed oil and protein content. In *B. napus* silencing of the Δ12 desaturase gene resulted in development of genotypes with 89% oleic acid (Smith *et al*. 2000).

Spasibionek *et al* (2011) have obtained high oleic (<80%) and low linolenic acid (<2%) *via* chemical mutagenesis induced by EMS (Ethyl methane sulfonate) treatment and DH (Doubled haploid) approach. The yellow seeded lines in *B. napus* have been bred with high oleic acid (>80%) and low linolenic acid (<3%) by Li *et al* (2011). Also, a new generation of rapeseed oil, HOLL (High Oleic Low Linolenic) has been introduced that has a high oxidative and thermal stability during processing and storage that result in high quality tasty food (Matthaus *et al.* 2011).Laakso *et al* (2011) have reported that rapeseed oil containing moderate amounts of linoleic and linolenic acids in the ratio of 2:1 combined with high oleic acid best meets the essential fatty acids requirements in the body. Linolenic acid exhibits new significant functions by initiating the reducing process of elevated fibrinogen through competitive inhibition of n-6 PUFA. It therefore has a desirable impact on homeostatic balance by regulating the n-6/ n-3 ratios.

In India, initial efforts to acquaint the internationally known canola quality varieties met with limited success due to Indian agro-climatic conditions. Inter-specific / inter-generic hybridization backed by established tissue culture techniques, followed by pedigree selection led to considerable progress towards development of nutritionally improved *B. juncea* genotypes, such as TERI (OE) M21, PRQ 9701, PBCM 1150-6 and LES-39, and low glucosinolate genotypes LGM 06 and LGM 08. Some other promising low erucic genotypes of *B. juncea* include LES-39, LES 1-27, LET-17, LET-18, LET-36 from IARI, New Delhi, and RH-801 (Annual reports AICRPRM, ICAR). Three double low *B. juncea* genotypes, NUDH-YJ-5 (INGR No. 03034), Heera (INGR No. 03033) and TERI-GZ-05 (INGR No. 04078) having yellow seed coat color was registered by ICAR. In another approach of microspore mutagenesis followed by doubled haploids production (Prem *et a.l* 2008), selections have been made for palmitic acid ranging from 3.22-16.0 %, oleic acid from 18.4-44.0 %, linoleic acid from 18.0-37.0 %, linolenic acid from 4.0-16.0 % and erucic acid < 2.0% in Indian mustard *B. juncea* genotypes (Agnihotri *et al*. 2011). Low erucic genotype (LES-39 from IARI) was released.

Notable progress has also been made for quality improvement in *B. napus* with the development of several double low genotypes suitable for mustard growing belt [*B. napus*; TERI-Unnat (INGR No. 98001 from TERI); GSC-6 (OCN-3) and RLC-1 (from PAU, Ludhiana); and NUDB 26-11 (from Delhi University/ NDDB]. The double low *B. napus* genotypes GSC-5 and TUJ [TERI-Uttam-Jawahar (INGR No.04077): National Identity no. IC 405232 with >43% oil content] were released. Owing to early maturity and shattering tolerance the latter was notified and released for cultivation in the mustard growing belts (Gazette of India, July 2007). The meal from TUJ variety, in the studies conducted at IVRI, showed better digestibility as animal feed at par with soybean meal (Ravichandran *et al.* 2007, 2008). The oil contains negligible amounts of harmful trans- fatty acids, and conforms to the codex standards for low erucic 'canola' oil as per the quality standards of Government accredited laboratory. The significant improved quality Rapeseed-mustard genotypes/ varieties developed in India are summarized in Table 1.

Gupta *et al.* (2010) used interspecific hybridization technique in combination with *in vitro* ovule culture to incorporate resistance to fungal diseases *Alternaria* blight and white rust from *B. carinata* cv. Kiran into low erucic acid *B. juncea* genotype TERI (OE) M21. Selections have been made for mustard lines with high tolerance to *Alternaria* and white rust with negligible amount of erucic acid (1.25%) and moderate (42.50%) oleic acid. Moderate palmitic acid (17.0%) and stearic acid (6.8%) were also reported for the first time in Indian mustard; this property is suggested to replace animal fats and tropical oils in margarine and confectionary products.

In addition to the fatty acids profile, other minor constituents of high nutritional importance include sterols, phenolics and vitamins. Phenolic compounds; flavonoids (flavonols, anthocyanins, isoflavones, etc.) and non-flavonoids (hydroxycinnamates, phenolic acids) impart antioxidant activity. *Brassica* species, mainly *B. oleracea* species of vegetable brassicas provide a diverse group of polyphenols (flavonols, anthocyanins, and hydroxycinnamic acid) and flavonols (kaempferol, quercetin, and isorhamnetin). One of the important vitamins, α-tocopherol (Vitamin E) is predominant tocopherol in all Brassica vegetables (Cartea *et al*. 2010; Piironen *et al*. 1986). The project, NAPUS 2000 was initiated to create novel tocopherol containing variants by breeding and genetic engineering techniques (Leckband *et al*. 2000). High carotenoid canola oil (HCCO) having 960 µg/g of beta-carotene has been developed by seed specific overexpression of phytoene synthase gene (Shewmaker *et al*. 1999).

Phytosterols are another important component desired for the oil quality improvement. They are the minor components found in the rapeseed oil with multi faceted advantages; having anti-cancerous properties and lower LDL Cholesterol that can be effectively used for reducing the risk of coronary heart diseases. Among oil yielding Brassicas, canola seeds are the richest source of phenolic compounds, mainly sinapic acid derivatives and also minor phenolics such as syringic, *p*-coumaric, ferulic, caffeic, *p*-hydroxybenzoic etc (Szydlowska-Czerniak *et al*. 2010). Overexpression studies have been carried out in *B. napus* and leaf phenolics were quantified in transgenic and non-transgenic plants (Li *et al*. 2010). Rapeseed is also the richest source of natural phytosterols which are the precursor of steroid hormones and phytohormones in humans and plants, respectively (Lindsey *et al*. 2003). Studies have reported 65% free phytosterol and 35% steryl ester fraction and even up to 10 g phytosterol fraction /kg of rapeseed oil (Gordon *et al*. 1997; Piironen *et al*. 2000).

Phytosterols are among the first food compounds which received an approved risk reduction health claim based on European Food & Safety Authority under the European Nutrition & health claims regulation. Thus, they are incorporated by food industry as bioactive components to develop functional food products, particularly in margarine and dairy products. Among the major phytosterols found in rapeseed-mustard oil Sitosterol is the most abundant (50-53%), followed by campesterol (19-25%), brassicasterol (13-15%), avenasterol (2-4%) and stigmasterol (in traces). Kilam *et al* (2015) used rhizosphere engineering by an endophytic fungus *Piriformospora indica* for enhancement of phytosterol content in *B. juncea.* Ten varieties of control and *P. indica* treated plants of *B. juncea* were analyzed. All ten varieties showed enhanced phytosterol content (176 to 340 µg g^{-1}) with highest enhancement (15.7%) seen in var. Vaibhav. Effect of *P. indica* inoculation on *Brassica spp*. can thus provide new leads into enhancement of oil quality and content.

Despite these impressive developments, we have still not been able to bring indigenous canola quality oil on the shelf in Indian market, which needs serious thinking and strategic planning. However, the awareness about quality of edible oil has increased rapidly among Indian consumers in the last one decade. Imported canola is now available in most stores at premium prices which reflect increasing consumer interest in quality edible oil. In India, canola type *B. napus* (Ghobhi sarson) varieties are now available but their cultivation is not picking up. Kumar *et al* (2009) outlined the strategies for cultivation and commercialization of 'canola' quality cultivars in India by bringing in the improvement in yield attributing agronomic traits; management practices for biotic and abiotic stress tolerance; availability of appropriate farm inputs; generation of canola quality *B. juncea* genotypes for wide adaptability in rapeseed-mustard growing regions of India; expansion of canola quality *B. napus* to wider regions in India; farmer's and public awareness about health benefits of canola oil and its expansion in non -traditional areas. Bringing the 'canola' quality oil as accepted health oil against traditional pungent mustard oil remains the biggest challenge as on date for its commercialization in India and neighboring Asian countries. Both public and private agencies can play a major role in promotion of cultivation and processing of canola quality *B. napus* and initiate an aggressive breeding program for advancing development of improved canola type Indian mustard varieties. In addition, a tripartitite arrangement between scientists, growers and oil industry, and an incentive prices to farmers will go a long way in making available locally produced canola oil in India

Table 1: Low erucic/double low rapeseed-mustard varieties/germplasm till 2016 in India

Species	Characteristics	varieties/germplasm	Pedigree/National ID
Brassica juncea (Indian mustard)	Low erucic germplasm	TERI-Swarna TERI-GZ-05 PRQ-2005-1	IC 296684 IC 405233 IC 546947
	Low erucic varieties	PusaKrishma Pusa Mustard-21 Pusa Mustard-22 Pusa Mustard-24 Pusa Mustard-29 Pusa Mustard-30 RLC-1 RLC-2	PusaBasanti x Zem-1 Pusa bold x Zem-2 PusaBarani x Zem-2 (Pusa Bold x LEB 15) x LES 29 (ZEM-2 x PusaBarani) x EC-287711 Bio-902 x ZEM-1 QM4 x Pusa Bold QM 4 x Pusa Bold
	Double low germplasm	Heera NUDH-YJ-5	IC 296501 IC 296507
	Double low varieties	PDZ-1 RLC-3	LES-1-27 x NUDHYJ-3 JM-06003 x JM-06020
Brassica napus (Gobhi sarson)	Low erucic germplasm	TERI-Phaguni TERI-Shyamali	IC 296685 IC 296688
	Double low germplasm	TERI-Gaurav TERI-Garima NUDB-38 NUDB-42 TERI (00) R 9903	IC 296731 IC 296732 IC 296827 IC 296828 IC 405232
	Double low varieties	Hyola-401 (Hybrid) GSC-5 GSC-6 GSC-7 TERI-Uttam-Jawahar NUDB 26-11	44002A x 4154R Hyola 401 x (Agat x GSL 8888) (NECN13 x Tribute) x NECN 13 Rivette x RR 001 TERI (OE) R 03 x Cyclone Derived from mutation of Westar

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Induced mutagenesis for breaking the yield barrier in *Brassica juncea* resilient to the climate change

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Seed yield enhancement under stress conditions is challenging job in the crop improvement programme. With an increasing demand of oil consumption, seed and oil yield improvement is inevitable. Though the oilseed Brassicas have large plasticity for yield and its components, either it has not been fully exploited for development of high yielding varieties or favourable cross combinations might be unable to break the undesirable linkages which limits the yield potential. Because, variation for seed yield and yield components is minimal among the released varieties. Wide range for genetic, biochemical, and metabolic mutations needs to be generated to utilize beneficial allele for effective crop breeding. Mutation breeding is one of the approaches to improve one or two specific characters and to enhance the spectrum of variability for agronomic and economic significance in an otherwise a high yielding and adapted varieties. It has been successfully employed to enhance the production potential of many crop plants (Chopra, 2005). Substantive improvement of qualitative and quantitative traits has been achieved in oleiferous *Brassicas* (Robbelen, 1990, Bhatia *et al*., 1999, Jambhulkar, 2007, Jambhulkar, 2015). Using such novel source of yield components, desirable plant type/cross combination could be tailored to cross the existing limit of seed and oil yields. Some of the novel mutations are mentioned below.

Dwarf and Early Plant Type:

Dwarf and early high yielding plant type has advantages over the tall and late plant type. Unwanted vegetative growth wastes the energy of the plant which could be effectively used in dwarf plant type to give the same output in terms of seed yield. Decreasing duration and height could be helpful in escape mechanisms of biotic and abiotic stresses which are prevalent under the climate change.These plant types could be responsive to fertilizer. A desirable dwarf mutant has been isolated from high yielding variety 'Varuna'. The height of the dwarf mutation has reduced to half i.e.90cm as compared to its parent 180cm. Length of main fruiting axis is 55cm compared to 70cm in parent. However, number of siliquae on main fruiting axis of mutant remained same i.e.50-55 as parent and total number of siliquae were more (250-300) as compared to parent (225-260). In distantly placed plant, number of siliquae were 650. This indicated that the siliqua density has been increased. Other desirable characters of this mutation are early i.e. 90 days maturity, yellow seed coat, and bold seed size. This is the first report on isolation of desirable dwarf mutation in Indian mustard. The harvest index of the mutant is better than parent. Therefore this mutation could be exploited for reconstruction of the desirable plant type against tall high yielding varieties. To achieve this objective large number of crossed have been attempted with diverse parents to isolate desirable transgressive segregants. Dwarfism is a desirable characteristic for many agricultural plants. In grain crops, dwarfism can reduce lodging and increase harvest index, and the breeding of dwarf wheat (*Triticum aestivum*) and rice (*Oryza sativa*) cultivars was a major factor in the success of the Green Revolution (Khush, 2001).

Enhanced Siliquae and Seed Number:

Seed yield of the plant is determined by number of siliquae and seed number. In a defined population, increase in seed yield is inevitable if number of siliquae and seed are increased. Two novel recombinants (mutations) namely fasciation and non-locular siliquae were isolated from segregating generations of two different crosses. Fasciation is the manifestation of fusion of 3-4 plants and non-locular siliqua has no defined locules. In standard plant population, number of siliquae in fasciation is ranging from 400-600 because there is no defined internodes and 3-4 siliquae were found one place. This character could help in increasing number of siliquae per plant and ultimately to develop a variety with more number of siliquae. The only disadvantage is the lodging. It is obvious due to more siliquae. A cross combination involving sturdy stem and this mutation could result into the desirable recombinants with non-lodging and more siliquae per plant. Maximum seed number in the present cultivars is in the range of 15-19. This is the main limiting factor. Seed number per siliqua could be increased either by increasing seed density or by increasing siliqua length. But long siliqua does not necessarily have more seed number. Keeping the siliquae constant and increasing seed density in long siliquae could definitely increase the seed yield. Non-locular siliquae has no locules and looks like a single tube like structure. Number of seeds in the range of 20-28 is packed in this mono-locular siliquae. The position of the siliquae is appressed in nature and siliquae in the range of 250-350 are observed. This is very good character for increasing number of seeds per siliquae. Thus, plant type with more siliquae per plant and more seed number per siliqua could be developed.

Reduced Chlorophyll Content:

Effective source-sink relationship could be exploited to break the physiological limiting factor of seed yield. Dark green leaf and more biomass per plant may not necessarily result into more yield rather it waste the energy of the plant. We have isolated a light green leaf mutation. It has intermediate leaf colour between yellow and dark green leaves. The characteristic of this mutation is that it always segregates for yellow, light green, and dark green progenies in the ratio of 1:2:1 indicating incomplete dominance for leaf colour. The SPAD value for chlorophyll content are 21, 41, 59, and 59 for yellow, light green, dark green and parent Pusa Bold respectively. However, it is vigorous and produced more fresh biomass and seed yield than dark green leaf plants and parent 'Pusa Bold'. It suggested that reduced chlorophyll content than parent 'Pusa Bold' could result in efficient photosynthesis and source-sink relationship.

Mutations for Yellow Seed Coat:

Thinner seed coat, higher oil content, high protein and lower fibre content in yellow seeded rapeseed-mustard have advantage over brown/black seed. It has improved nutritive value of the meal after oil extraction. Yellow seeded genotypes are available in *B. rapa, B. juncea, and B. carinata, and B. napus*. Induced mutation to isolate yellow seed coat was initiated at BARC, Mumbai, India. Using S^{35} radioisotope, two yellow seed coat mutants (*YSM1* and *YSM2*) were isolated from blackish brown seed variety Rai5 but could not published. New yellow seeded mutant was isolated from the same variety Rai5 using ^{32}P radioisotope (Nair, 1968) and named as Trombay Mustard 1 (TM1). Using gamma rays, we have isolated yellow seed coat colour mutations in high yielding varieties namely Varuna, Pusa Bold and Kranti. Their yield potential are being tested and being used in hybridisation to isolate high yielding recombinants.

Development of Zero Erucic Acid Genotypes:

Same source of zero erucic acid has been extensively used to develop high yielding zero erucic acid varieties/genotypes. Efforts to diversify these source is minimal. We have isolated two mutations namely TPM1 and Trombay Juncea Dwarf (TJD1) with changed fatty acid composition. Erucic acid content in both these mutations has been reduced to nearly 25% compared to their parents 46%. The erucic acid content of the normal varieties is 48% which is controlled by two dominant genes $E_1E_1E_2E_2$ contributing 10-12% by each allele. Reducing erucic acid to 50% in mutants indicated that these mutations could be either in E_1 or E_2 genes or could be in E_1 and E_2 independently. If both the mutations lie either in E_1 or E_2 genes it may not lead to the isolation of zero erucic acid recombinants. But, if both the mutations are independently occurred in E_1 and E_2 then it will lead to the isolation of zero erucic acid recombinants. The hybridisation of these two mutations has been done to test the allelism. The erucic acid content in F_1 generation was 25% indicating that these mutations could in either in E_1 or in E_2 or could be independently in E_1 and E_2. The F_2 generation has been raised and the segregation pattern for erucic acid in F_2 generation shall determine the occurrence of mutation. Digenic control of low erucic acid has been reported by Bhat *et. al.* (2002) and Jai Singh *et. al.*(2015). Mutation breeding has been successful in tailoring oil crops for desirable fatty acid composition (Robbelen, 1990) because oil crop plants tolerate wide range of fluctuation in fatty acid composition without losing viability and single mutation can result into desirable oil composition. Liho the first zero erucic acid mutant was reported by Stefansson et al. (1961) in *B.napus*, which opened the era of mutant assisted quality improvement in oilseed crops. Downey (1964) suggested that erucic acid free oil should also occur in *B. campestris* as it is one of the parents in *B.napus* and reported zero erucic acid natural mutant/variability in *B. campestris*. Two zero erucic acid natural mutants were found in Chinese accession of *B. juncea* (Kirk and Oram, 1981) and termed them as zem1 and zem2. Olsson (1984) also reported natural mutation/variability for low erucic acid in *B. juncea*.

High Yielding Mutant Varieties:

Utilization of induced mutations in crop improvement programme has resulted into the development of more than 3242 high yielding varieties in different crop plants. Mutation breeding in rapeseed-mustard has been resulted into the development of total 31 high yielding varieties comprising 12 in *B .juncea*, 14 in *B.napus*, 2 in *B.rapa*, and 3 in white mustard. Fifteen varieties have been developed using gamma rays and 4 by X-rays. Remaining varieties were developed using chemical mutagen and mutants used in hybridization. Mutation breeding efforts at BARC has resulted into the development of 3 high yielding varieties namely TM2, TM4 and TPM1. Among them TM2 and TPM 1 are direct mutants whreas TM4 id derivative of mutant used in breeding programme. TM4 and TPM1 are yellow seed coat varieties.

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Management of *Brassica* gremplasm in india

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Currently, India accounts for about 12-13% of world oilseeds area, 6-7% of world vegetable oil production, 15-17% of world vegetable oil import and 10% of the world edible oil consumption. With the diverse agro-ecological conditions prevailed, nine different oil seed crops are grown in India which include seven edible oilseeds, *viz*., groundnut, rapeseed-mustard, soybean, sunflower, sesame, safflower and niger and two non-edible sources, *viz*., castor and linseed. Some other minor oilseeds like coconut and oil palm are also grown in the country. Important oilseed crops producing states viz. Madhya Pradesh, Gujarat, Rajasthan, Uttar Pradesh, Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu account for nearly 89% of area and production in the country. Among different oilseeds, groundnut, rapeseed-mustard and soybean, account for nearly 77% of oilseeds area and 88% of oilseeds production in the country.

Rapeseed and mustard rank second with about 24% average contribution to the total oilseed production and 32% to total edible oil produced indigenously. They are the main source of edible oil in Indian diet after groundnut. The genus *Brassica* L. (Brassicaceae) possess different annual or biennial species is considered to be potential source of edible oils and vegetables and contains about 37 species across the globe and six species are present in India (Warwick *et al*. 2000, Kumar *et al*. 2004). Rapeseed-mustard includes the important annual oilseed brassicas namely Indian mustard (*B. juncea)* commonly called rai, raya or laha, three ecotypes of Indian rapeseed (*B. rapa* syn *B. campestris*) *viz*., toria, brown sarson (lotni and tora types) and yellow sarson, Swede rape or gobhi sarson (*B. napus* L.), Ethiopian mustard or karan rai (*B. carinata* Braun.) and black mustard (*B. nigra* (L.) Koch). The other minor oilseed brassicas grown in dry areas of Rajasthan and Haryana are taramira or tara (*Eruca sativa* Mill.) and wild turnip (*Brassica tournefortii* Gouan) (Chopra and Prakash 1991). In the Indian subcontinent, *B. juncea* is the dominant species grown along with *B. rapa* which constitute the important sources of edible oil, while *B. oleracea* L. is used as leafy mustard in most parts of the country. The different rapeseed & mustard species are, Indian mustard (*Brassica juncea* (L.) Czern. & Coss.), toria (*B. rapa* L. ssp. *toria)*, yellow sarson (*B. rapa* L. ssp. *yellow sarson)*, brown sarson (*B. rapa* L. ssp. *brown sarson)*, gobhi sarson (*B. napus* L.*),* karan rai (*B. carinata* Braun.) and taramira (*Eruca sativa* Mill.*)*. Oilseed Brassicas represent a rich diversity which is being cultivated in Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat, Himachal Pradesh, Bihar, Assam, West Bengal, Orissa (Mishra and Kumar, 2008). However, much of diversity is concentrated in the Indo-gangetic plains and sub-mountain Himalayas.

Germplasm Collection and Introduction

As far as the pace of germplasm is concerned, the collection of rapeseed-mustard gained further momentum under mission mode sub-project on Sustainable Management of Plant Diversity of the World Bank-funded National Agricultural Technology Project during 1999-2005. During this period, over 2,894 accessions were collected from Andhra Pradesh (121), Arunachal Pradesh (122), Assam (176), Bihar (192), Jammu & Kashmir (154), Gujarat (42), Haryana (34), Himachal Pradesh (382), Jharkhand (177), Meghalaya (52), Rajasthan (111), Uttar Pradesh (671), Uttarakhand (537) and West Bengal (133) in collaboration with crop-based institutes of ICAR and SAUs and other organizations including NGOs. Some of the unique collections made during the period include yellow-seeded *toria*, dwarf mustard, dwarf and early *toria*, white flowered yellow *sarson* etc. (Singh and Sharma 2007). In addition, leafy mustard or vegetable brassicas were also collected from different parts of the country. *B. oleracea* subsp. *botrytis* L.*, capitata* Braun.*, italica* Plen.*, gongylodes* L., germplasm was collected mainly from parts of Jammu & Kashmir (154), Uttar Pradesh (104) and Himachal Pradesh (63), while *B. rapa* subsp. *chinensis* L.*, B. juncea,* subsp. *rugosa* (Roxb.) N. Tsen & S. N. Lee, were collected from parts of Arunachal Pradesh and Uttarakhand. Most of these species are used as leafy vegetables in different parts of the country (Singh and Sharma 2007, NBPGR Annual Reports 1976-2010).

Based on the passport data of collected germplasm, the gaps among exploration and germplasm collection find out for the eco-geographic diversity distribution of rapeseed-mustard through mapping the sites (Figure 1). Mapping of diversity collected indicates that some of the diversity rich areas *viz*. parts of north-western plains (foothill regions of Himachal Pradesh, Uttarakhand and Western Uttar Pradesh); eastern and north-eastern parts (Bihar, Jharkhand, Assam and West Bengal) were extensively surveyed for germplasm collection. The rapeseed-mustard is mainly grown as mixed crop with wheat and barley in limited holdings; hence area specific surveys are required for collection of trait-specific germplasm from less explored/under-explored areas.

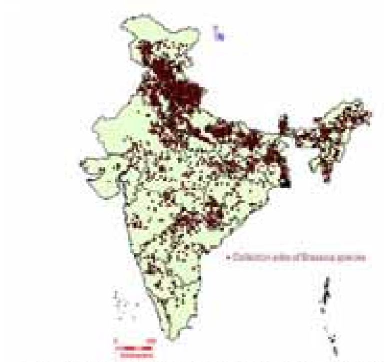

Figure 1. Geo-referencing of germplasm collection sites of rapeseed mustard in India

Rapeseed-mustard is required to collect and conserve particularly with biotic and abiotic stress resistant traits for further utilization. The collected germplasm exhibits great diversity for plant types, seed size, siliqua length and maturity period in *B. juncea* mainly from northern parts of India. There was outsized variation reported in plant habit, flowering period, siliqua size, seed size and number, maturity period and oil content in yellow sarson. Moreover, variability in *B. juncea* and *B. nigra* was also collected from drier tracts of Andhra Pradesh, Haryana and Rajasthan showed variation in seed size and seed colour and siliqua size. *B. tournefortii* was collected with seed colour (brown, dull brown and yellow), compact type with upright branches, leaves and pods, bushy or spreading type with horizontal branches, siliqua and leaves, early to late maturity, dwarf and tall types from parts of Rajasthan and Haryana (Plant Germplasm Reporter 2008, NBPGR Annual Reports 2008 - 2010).

Effective crop improvement programme of a country is possible only if a broad genetic base of diverse origin is available for which the germplasm distributed in the centre of diversity is of special interest. ICAR-NBPGR through its single window system continuously introduces the potential valuable trait-specific germplasm from diversity rich areas of the world to support the national crop improvement programme. During the last four decades ICAR-NBPGR has introduced over 4,213 accessions of oil seed *brassica* species from more than 20 countries (Table 1).

Table 1: Introduction of Oilseed *Brassica* species in India

Botanical Name	No. of Accessions	Source
Brassica juncea	17	UK, USA, Germany, China
Brassica rapa (syn. *B. campestris)*	43	Bangladesh, Canada, USA, Sweden
Brassica napus	3293	Belgium, UK, Czech Republic, Poland, Germany, Argentina, France, Sweden Italy, Holland, USA, Canada, Australia,
Brassica nigra	295	Australia, Canada, Germany, Sweden, USA, France, Japan, Argentina, Hungary
Brassica carinata	323	Germany, Argentina, France, Pakistan, Uruguay, Italy, Holland, USA, Canada, Australia,
Eruca sativa	60	Germany, Hungary, Canada, Australia, Germany, Italy, USA
Sinapis alba	42	UK, France, Hungary, USA, Canada, Australia, Sweden, Japan, Spain, Italy
Crambe abyssinica	121	Bulgaria, Denmark, Spain, Mexico, Poland, USA, UK
Lepidium sativum	16	Switzerland, USA, Nepal, France, Israel, Portugal, Italy, Germany
Capsella bursa-pastoris	1	USA
Sisymbrium officinale	2	Spain, Canada

Some useful traits specific Brassica germplasm like high yield, high oil content, resistance to biotic stresses (white rust and *Sclerotinia* wilt), abiotic stresses (drought, salinity and frost) as well as desirable quality traits (low erucic acid and low glucosinolates) also introduced from different countries. The germplasm introduced from Europe and Canada are mostly of *B. napus* and *B. rapa*. European types are mostly winter types (Table 2).

Table 2: Promising traits of introduced brassica germplasm

Species	Accession/ Source	Promising Trait
Brassica napus	EC763819- EC764472 /UK	Resistant and susceptible lines for white rust
	EC557008, EC557014/ Australia	High oil content
	EC557012, EC557019, EC557026-27/ Australia	Lodging resistant
	EC564728-EC564749/ Russia	Low glucosinolate
	EC597255-EC597264, EC597275-EC597278, EC557023, EC557025 / Australia	Early Maturity
	EC596635/ USA	Edible quality oil, low erucic acid, glucosinolates
Brassica juncea	EC764472- EC766024/UK	Resistant and susceptible lines for white rust
	EC223759-60/ China	Low erucic acid
Brassica rapa	EC232318/ Canada	High oil content
	EC226808/ Canada	Low erucic acid
B. nigra	EC472729-EC472738/ Germany	*Alternaria* blight tolerant

Germplasm Conservation

Genetic resources are critical for enhancing production and productivity by providing new gene sources for resistance and tolerance to biotic and abiotic stresses. For strengthening genetic resources management; evaluation, conservation and documentation of germplasm, exchange under appropriate quarantine measures and distribution of germplasm for utilization as well as medium and long term conservation of valuable germplasm in national gene bank for posterity of mankind are essential activities. In India National Bureau of Plant Genetic Resources (NBPGR) conserved about 55,414 accessions of different oil seed crops (Table 3).

Table 3. Status of oil seed crops germplasm at national genebank

Crop Name	Indigenous Collection (IC)	Exotic collection (EC)	Total
Groundnut	8768	4904	13672
Castor	2543	178	2721
Linseed	2681	154	2835
Niger	1681	5	1686
Sesame	7606	2405	10011
Soybean	2315	1581	3896
Sunflower	277	1089	1366
Safflower	2644	4658	7302
Brassica	10776	793	11925
Total			55414

A total of 12,673 collections of Brassica germplasm from different agroclimatic zones from India and international sources are conserved at National Genebank. Of the total germplasm, 98% is represented by cultivated species and remaining 2% consists of wild species. The total collections include mainly *B. juncea, B. rapa, B. carinata, B. napus* and *B. oleracea* (Table 4).

Table 4. Species-wise status of Brassica and wild relatives in National Genebank

Common name	**Species**	**No. of Accessions**
Indian Mustard	*Brassica juncea*	7272
	Brassica juncea subspp. integrifolia var. rugosa	14
	Brassica juncea var. cuneifolia	19
	Brassica juncea var. japonica	1
	Brassica juncea var. rugosa	95
Rapeseed	*Brassica rapa*	1096
	Brassica rapa var. yellow sarson	1678
	Brassica rapa var. brown sarson	724
	Brassica rapa var. toria	890
	Brassica rapa var. sepa	6
African Mustard	*Brassica carinata*	76
Rape	*Brassica napus*	224
Black Mustard	*Brassica nigra*	53
Cole crop	Brassica oleracea	50

Chinese white cabbage	Brassica chinensis	25
White Mustard	*Brassica hirta*	5
Taramira	*Eruca sativa /E. vesicaria*	131
Wild Brassica	Perilla	228
Asian Mustard/ Wild Brassica	*Brassica tournfortii*	13
Crambe	Crambe abyssinian	48
Garden Cress	*Lepidium sativum*	23
Sisymbrium	Sisymbrium species	2
Total		**12673**

Characterization and evaluation

Characterization and evaluation are important activities under plant genetic resources programmes. The genetic resources can be broadly classified into landraces, wild relatives of crop species, genetic and cytogenetic stocks, breeding lines, modern cultivars and mapping populations which provide basic raw materials to crop improvement programmes and acts as reservoir of genes for resistance to various biotic and abiotic stresses.

Evaluation of germplasm is mainly focused for important morpho-agronomic traits under different agro-climatic conditions and for disease and pest reactions at the hot spots. A large number of rapeseed- mustard germplasm evaluated and characterized for various agro-morphological traits and biotic stresses. Range values of various agro-morphological and quality traits in different Brassica spp have been given in table 5. It has been observed that maximum variability was for siliquae on main shoot, seeds per siliqua, plant height and least for oil and protein content. Information collected on germplasm of rapeseed-mustard in the country demonstrates the availability of valuable genetic reservoir, which could be exploited for improving the existing cultivars.

Table 5. Range of some of the important agro-morphological traits in important Brassicas germplasm accessions

Characters	Crop species		
	Indian mustard	Yellow sarson	Toria
Plant height (cm)	69-241.8	51.4-185.2	35.4-167.3
Main shoot length (cm)	23.8-112.4	22.8-93.6	16.6-75
Siliquae on main shoot	10.0-86.8	6.3-78.3	13.3 -79.6
Siliquae length (cm)	2.4-6.5	2.4-7.9	2.4-7.7
Seed per siliqua	4.3-25.8	8.6-53.5	10.8-25.6
1000-Seed weight (g)	1.2-8.4	1.2-7.0	1.0-4.8
Days to maturity	112-132	-	61-130
Oil content (%)	24.1-46.11	35.1-47.0	35.7-45.6

Entire collection of *Brassica juncea* germplasm have been evaluated and characterized at NBPGR, New Delhi, DRMR, Bharatpur and at different AICRP centers and superior genotypes were screened out for various agro-morphological traits, biotic & abiotic stresses and quality traits (Table 6). Some genotypes were superior for multiple traits viz; IC58388, EC322093 for plant height, days to maturity; IC426383 for days to maturity (112 days), siliqua length (>5.0

cm), seeds/ siliqua (>17); EC766325 for siliqua on main shoot (>80), seed yield/plant; EC766198 for seeds/ siliqua (>17) and seed yield/plant.

The sources for resistance to pests and diseases were identified which can be utilized in breeding programmes. Indian mustard germplasm evaluation for various morpho-agronomic, quality traits, biotic (white rust, alternria blight and aphid) and abiotic stresses, were also carried out at hot spots. Some accessions were found resistant to white rust over the locations (Table 6).

Under quality analysis for oil content, EC766576 (46.11%), EC766557 (45.53%), EC766275 (45.15%) were found rich in oil content. *Brassica* germplasm were evaluated for phosphorus and phytic acid content. The phosphorus content ranged from 0.02-2.25 g/100g whereas phytic acid content ranged from 0.08 to 7.97 g/100g. The value rich accessions with low phytic acid content are given in Table 7.

Table 6. Promising Indian Mustard germplasm for Agronomic Traits across the locations

Traits	Promising germplasm over the Location
Day to 50% Flowering (<65 days)	IC491483, IC491554, IC521381, IC20167, IC560719, IC570287, IC570302, IC58388, EC322093, IC122414, IC267691, IC541052, EC199744, EC204233, EC206714, EC206724, EC322093, EC766084, EC766087, EC766134, EC766304, EC766306, EC766311, EC766312, IC491469, IC520747, IC426383
Plant Height (< 130 cm)	IC341108, IC546946, IC342749, IC355313, IC355348, IC491250, IC121667, IC58388, EC322093, IC122300, IC122346, IC122431, IC122442, IC253077, IC310804, IC520375, EC322093, EC620075
Days to Maturity (<130 days)	IC571687, IC491414, IC491135, IC570287, IC571669, IC571648, IC20167, IC58388, EC766560, EC766028, IC399809, EC766136 EC766141, EC766127, IC122414, IC267691, IC541052, EC199744, EC204233, EC206714, EC206724, EC322093, EC766051, EC766084, EC766087, EC766134, EC766304, EC766306, EC766311, EC766312, IC491469, IC520747, IC426383
Siliqua on main shoot (>80),	EC247855, EC347857, EC333564, IC12209, IC122235, IC122319, IC249624, IC253063, IC253066, IC296684, IC482968, IC589689, EC414319, EC620088, EC698998, EC699030, EC766325, EC766330, EC766444, EC766600, IC491200, IC491342, IC491461
Siliqua Length (>5.0 cm)	EC199744, IC342778, IC491438, IC329705, EC399293, IC121700, IC121715, IC121718, IC122197, IC122231, EC400082, EC766033, EC766205, EC766214, EC766234, EC766412, IC491294, IC491454, IC491580, IC426383, IC491457, IC491007, IC491211, IC121700, IC121715
Seeds/ siliqua (> 17)	IC491455, IC520754, IC491483, IC491565, IC495534, IC491548, IC491554, IC520767, IC482968, EC620075, EC699055, EC766198, EC766198, EC766234, EC766336, IC491114, IC491506, IC426383, IC570302, IC571646, IC571672, IC589669, IC589674, IC253063, IC296507, IC398765, EC720967, EC766037, IC491294
Seed yield/Plant	IC560700, IC491402, IC571668, IC426337, IC399853, IC589653, IC399797, EC766495, IC491096, EC766265, IC121718, IC122022, IC122288, IC122363, IC122441, IC249001, IC249624, IC491311, EC206712, EC491579, EC766190, EC766198, EC766258, EC766325, IC491147, IC491200, IC491342, IC491461, IC491510, IC589660

Cold tolerance	IC251661, IC261627, IC424755, IC447794, IC421293, IC571665, IC571668, IC961632, IC491085, IC491234, IC491203, IC355327, IC355456, IC361509, IC385632, IC401570, IC398025, IC424420, IC491527, IC491482, EC399308, EC399312, EC414315, EC491601, EC766383, EC766397, EC766433
White Rust	IC020167, EC657030, EC699003, EC766091, EC766133, EC766134, EC766136, EC766140, EC766142, EC766143, EC766144, EC766145, EC766148, EC766152, EC766164, EC766191, EC766192, EC766193, EC766230, EC766232, EC766402
High oil content (> 42 %)	EC766576, EC766557, EC766275, EC766064, EC766067, EC766070, EC766071, EC766097, EC766203, EC766286 EC766440, IC10963 IC267696, EC766487, IC491137, IC355327, EC491607, IC491115, IC491229, IC312524

Rapeseed-mustard accessions were also evaluated for amino acid profile. The mean values (mg/100mg) of different amino acids were aspartate (0.07), serine (0.11), glutamate (0.14), glycine (0.16), histidine (0.16), arginine (0.24), threonine (0.17), alanine (0.09), proline (0.12), cystine (0.04), Tyrosine (0.18), valine (0.09), methionine (0.11), Lysine (0.12), ssoleucine (0.08), leucine (0.15) and phenyl alanine (0.28). *B juncea* accession EC187213 had highest lysine content (0.1 mg/100 mg). *B. campestris* var. *yellow sarson* accession IC447740 had highest methionine content (0.19 mg/100mg). *B. campestris* var. *brown sarson* accession EC389888 and *yellow sarson* accession IC447740 had highest cystine content (0.09 mg/100 mg).

Promising germplasm identified over the years has also been registered with a view to give due recognition to the plant breeders associated with development / identification of novel genotypes/ germplasm/ variety for utilization in crop improvement programmes. Till now 51germplasm accessions have been registered for different traits like early maturity, high oil content, zero euric acid, high oleic acid, salinity resistance, low glucosinolate, CMS lines and tolerant to biotic and abiotic stresses.

Future perspective

For effective utilization of the genetic resources available, there is a need to intensify the research on genetic resources of oilseed brassicas in the country. The following priority areas of research have been identified:

- There is a need of extensive exploration and collection from unexplored areas / hotspots identified to broaden up the genetic base.
- Wild and weedy relatives/related species/taxa of rapeseed-mustard are very limited. There is an urgent need for strengthening the germplasm of wild and weedy relatives such as *Crambe, Sinapis* etc. from temperate, alpine region of Jammu & Kashmir, Himachal Pradesh and Uttarakhand.
- Introduction from the countries like Australia, Canada, China, Japan, Russia, Spain, Sweden; especially for quality, high heterosis (oil content, double zero types, yield), biotic, abiotic stress and wild species.
- Molecular characterization of germplasm and maintenance of gene pool for various traits such as quality, biotic and abiotic stresses.
- Development of a trait specific reference set and core or mini core of the germplasm for efficient handling and utilization of germplasm.

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Phenomics, the next generation phenotyping (NGP), for breeding climate resilient crops

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Introduction

Enhancing agricultural production with environmental sustainability is the major goal of agricultural research. To meet the food demand by 2050, the growth rate of yield gain must be doubled. This needs the efficient use of available genetic diversity and use of modern biotechnology to genetically enhance the resource (water & nutrient mainly nitrogen) use efficiency and crop productivity. The two pillars of analytical breeding are genotyping and phenotyping. Efficient use genomic information for crop breeding is potential solution to develop high yielding and climate resilient crop varieties. Genomic technologies such as Next Generation Sequencing (NGS) and SNP arrays have enabled the plant scientist to obtain genotypic information of breeding material with relatively low cost and shorter time. However, the principal goal of identifying specific genotypes that are associated with phenotypes progressed only slowly as development in phenotyping has not kept pace with genomics. The wet chemistry and other actual measurement of growth and physiological processes based phenotyping is inherently low throughput, labor-intensive, costly, time consuming and often destructive due to organism-wide phenotypic data for same plant cannot be obtained, which lead to genotype-phenotype gap (Furbank and Tester 2011).

Phenome is defined as expression of the genome as traits in a given environment. The human phenome project initiated in 1997 (Freimer and Sabatti 2003) led to the birth of phenomics (Bilder et al. 2009). Phenomics is multidisciplinary science of sensor aided non-destructive high throughput automated acquisition and analysis of high-dimensional phenotypic data on an organism-wide scale. Phenomics, the Next Generation Phenotyping (NGP), offers solution to discover the inner workings of living plants and thus bridge the phenotype-genotype gap. Phenomics involves 1) non-invasive sensors, 2) automated data processing to obtain phenotypic traits, 3) robotized delivery of plants to sensors or vice versa, 4) robotized plant culturing, and 5) automated analysis of processed data in a data management pipeline. Robotized delivery of plants to the imaging sensors is commonly used in controlled environment phenomics platform, while sensors are delivered to the plants in field phenomics platforms. Non-invasive sensors commonly used in non-destructive automated plant phenomics facility consists of various imaging cameras namely visual imaging, Hyperspectral imaging, IR thermography, NIR image analysis, Chlorophyll fluorescence imaging, bioluminescence imaging, fluorescence imaging, etc. Wide-range of phenotypic data on whole-plant during its entire life cycle can be acquired by using phenomics technologies that are not possible through conventional phenotyping methods (Kumar et al. 2016). In addition, Light detection and ranging (LIDAR) and laser triangulation sensors are used for assessment of plant growth, shoot biomass, leaf angle distributions and canopy structure, while magnetic resonance imaging(MRI)is used for three-dimensional imaging of roots to obtain spatial information on the root system architecture of plants (van Dusschoten et al. 2016).

IARI Plant Phenomics Facility

Realizing the potential of phenomics, Australian government invested $51 million in 2007 and established the Australian Plant Phenomics Facility (APPF) in January 2010 (http://www.plantphenomics.org.au/about/). Since then, several government Institutes have established automated high throughput phenomics facility for crop plants. Soon, the Indian Council of Agricultural Research, New Delhi also initiated the establishment of phenomics facilities in India recently. ICAR-IARI, New Delhi has established a state-of-art automated high throughput plant phenomics facility for non-destructive and accurate characterization of a large number of germplasm and recombinant inbred lines under defined environmental treatment conditions (Funded by NASF, ICAR, New Delhi-110012). The facility is designed with moving field with 1200 plant carriers in four different climate controlled greenhouses to grow plants with defined soil, nutrient and moisture conditions. The facility has the following imaging units:

1) ***Visual high resolution imaging:*** Reflectance in the visible (400-700 nm) range is captured by using high resolution camera from the top and side of the plants. Visual imaging is used to measure shoot/root growth, architecture, greenness, Leaf area, leaf rolling, senescence, growth rates, tillering, early vigor, plant height, phenology, biomass, convex hull, compactness, eccentricity, etc.
2) ***IR thermal imaging:*** The infrared energy (8 to 13 µm) emitted from plant is converted into an electrical signal by the imaging (microbolometer) sensor to measure tissue temperature. As tissue temperature is determined mainly by evapotranspiration, IR thermal images are used to infer stomatal conductance and plant health (biotic and abiotic stress).
3) ***Chlorophyll fluorescence imaging:*** Light absorbed by short wave length is emitted as long wave fluorescence depending upon the composition of plant tissues with molecules with innate (auto) fluorescence characters. Chlorophyll molecules absorb light at shortwave length and emit fluorescence at red/far-red wavelength (680 & 735 nm). This imaging system can measure chlorophyll fluorescence to calculate maximum quantum efficiency of PSII, photochemical quenching and non-photochemical quenching, which are highly sensitive to resource availability and stresses.
4) ***Near infrared (NIR) imaging:*** The reflectance of plants in the range of 900 to 1700 nm depends upon water content. Plants reflects large amount of 800 to 1400 nm light while soil reflectance is negligible. NIR shoot imaging system is used to measure water content and distribution in plants, leaf thickness and leaf area index, while NIR root imaging system is used to phenotype root soil moisture extraction pattern and root growth.
5) ***Visual-Near Infrared (VNIR) & Short wave Infrared (SWIR) - hyperspectral imaging systems:*** Spectral reflectance is imaged at nm resolution by VIS-NIR (400–1000 nm) and SWIR (1000–2500 nm) cameras. Several spectral indices are available to assess chlorophyll content, relative water content, nutrient status, chemical composition, plant health, photochemical reflectance index, genotype bar-coding

The automated weighing and watering stations will quantify the weight of pots before and after watering, in order to impose various drought/ waterlogging/ nutrient deficiency stresses, and to assess input use efficiency. Thus, critical physiological traits contributing to the yield and stress tolerance can be measured by phenomics platforms with high throughput for a large set of plants at defined intervals during crop growth. The depth of component phenotypic traits and the spatio-temporal dynamic phenotypic data generated in phenomics are enormous and unparallel to the conventional phenotyping. Some of the utilities of phenomics facility are (Kumar et al. 2016):

1. Dissection of complex traits into component traits
2. Germplasm screening to identify donors
3. Phenotyping of biparental population for Linkage mapping
4. Phenotyping of minicores for genome-wide association studies (GWAS)
5. Functional genomics, Forward & reverse phenomics
6. Gene function validation & selection of better transgenic events
7. Trait pyramiding in analytical breeding
8. Phenome-wide association studies (PheWAS)
9. Phenomic selection
10. Training of Genomic Selection models with deep phenotyping data
11. Development of ecophysiological crop simulation models for *in silico* phenotyping & ideotype design

Phenomics for gene/QTL mapping

Conventional phenotyping is often destructive and phenotypic data is obtained at few crop growth stages or at the end of the crop cycle. Automated NGP using phenomics technologies captures multiple phenotypic data throughout the crop growth stages and thus adds time-scale to the phenotypic data which is not available in the conventional phenotyping. Time-scale phenotypic data during different growth and development of crop is necessary for mapping the QTLs for component traits that contributes to crop development during specific growth stages. Some examples of biparental population based QTL mapping and genome-wide association (GWA) mapping using data from NGP phenomics are given in the Table 1.

Table 1. Examples of phenomics aided QTL mapping

Crop/ Model plant	Population	Phenomics platform	QTLs mapped	Remarks	Reference
Arabidopsis	162 RILs and 92 NILs derived from a Cvi) × Ler cross	Visual image every 2 min for 8 hr; Controlled environment	QTLs for mean tip angle at each of the 241 time points	Time-dependent QTL were detected on chromosomes 1, 3, and 4	Moore et al. 2012
Triticale	647 doubled haploid lines derived from four families; GWA mapping	A tractor pulled trailer equipped with two light curtains, three laser distance sensors, two 3D-Time-of-Flight cameras; Field conditions	23, 25 and 17 QTLs at 3 developmental stages; Two major QTLs	One major QTL on chromosome 5R is active throughout plant development while the other major QTL on chromosome 5A contributes strongly to biomass at the early stage	Busemeyer et al. 2013
Rice	171 RIL and parental plants Bala × Azucena	Visual imaging of root systems growing in nutrient-enriched gellan gum at days 12, 14, and 16 Post planting	89 univariate QTLs across all days of imaging for various RSA traits	Many univariate and multivariate QTLs that we identified colocalized with previously identified root trait and drought resistance hotspots	Topp et al. 2013
Barley	47 wild barley ILs of the S42IL library and the	RGB images; gravimetric measurement of	44 QTL for 11 traits;	Three QTL were identified for Absolute Growth	Honsdorf et al. 2014

	recipient parent Scarlett	water use, end point phenotypic data; Controlled environment		Rate Integral (AGRI); Two QTL were detected for WUE	
Triticale	647 DH lines derived from four families	phenomics data of biomass yield generated at three developmental stages; Controlled environment	10, 10, 9 QTLs were mapped for biomass at 3 stages respectively,	Of the several QTLs mapped, only 4 were common in all three stages, while 5, 4, and 4 were specific for biomass at satge1, 2 & 3 respectively	Liu et al. 2014
Triticale	647 triticale DHs derived from 4 families	Visual image based plant height (PH) measurement at 3 developmental stages (PH1, PH2 & PH3); Field conditions	15 QTL for PH1, 18 for PH2 and 8 for PH3	Only 3 QTLs common for all three stages suggesting that the genetic control of plant height undergoes rapid temporal changes	Würschum et al. 2014
Wheat	5000 RILs from a cross between Drysdale and Gladius	Conventional phenotyping in the field; Image based phenotyping in controlled environment	84 QTLs in Field; 21 QTLs for plant growth using the imaging platform	7 co-located QTLs were found for traits from the phenomics platform with that from the field	Parent et al. 2015
Arabidopsis	324 accessions; GWA mapping	Visual top-view imaging and end-point fresh weight determination; Controlled environment	22 QTLs for fresh weight (endpoint), projected leaf area (at 12 different growth stages) and modelled parameters	Many of the growth QTLs would not have been identified with only endpoint fresh weight data	Bac-Molenaar et al. 2015
Rice	378 diverse rice genotypes; Salinity tolerance; GWA mapping	Visible & Fluorescence imaging; Controlled environment	55 QTLs	Only 26 QTLs could be detected at one time point	Campbell et al. 2015
Rice	553 genotypes phenotyped for salinity tolerance; GWA mapping	Visible image (one top and two side views); Controlled environment	Several QTLs for RGR, TR and TUE at different intervals	The QTL on chromosomes 11 is strongest in the first interval after salt stress (2–6 days after treatment), but not in the last interval (9–13 days after treatment)	Al-Tamimi et al. 2016
Arabidopsis	324 accessions; GWA mapping	Visual top-view imaging, end-point fresh weight determination,	Twenty-one SNPs associate with FW, PLA over time, RWC and model	Six time-dependent drought-QTLs; Of these, for five QTLs, most likely candidate genes could	Bac-Molenaar et al. 2016

		gravimetric measurement of water use; Controlled environment	parameters	be identified	
Sorghum	97 RILs and the two parental lines BTx623, IS3620C)	RGB time-of-flight depth camera; Controlled environment	Five QTLs were mapped; alleles closely linked with the sorghum Dwarf3 gene, an auxin transporter, was found to play important role in shoot architecture.	Many of the QTLs identified via image-based phenotyping overlapped with QTLs for comparable traits discovered in prior field experiments	McCormick et al. 2016
Maize	167 RILs with its parents (B73 and BY804)	106 traits across 16 developmental stages using the automatic phenotyping platform in controlled environment; also phenotyped under field conditions	988 QTLs were identified for 42 phenotypic traits across 16 time points; 42 to 82 QTLs at each time point	Several dynamic development QTLs were identified	Zhang et al. 2017
Maize	252 diverse inbred lines; GWA mapping	Automated non-invasive phenotyping at 11 different developmental time points	Several QTLs mapped for different growth stages	Main effect loci detected show complex developmental phase-specific patterns of expression	Muraya et al. 2017

Conclusion and Perspectives

Recent advancements in use of NGP with phenomics platform enhanced the phenotyping capabilities as compared to few traits measured by conventional methods. Performance evaluation studies have shown that controlled environment as well as field phenomics is a suitable complementary approach, and in certain cases such as biotic stress, resource use efficiency and positional cloning phenomics can replace traditional laborious field-phenotyping. Besides GWA mapping, phenomics will be very useful in Phenome-wide Association Studies (PheWAS). Significant progress has been made in PheWAS to identify SNP-disease association in medical sciences. The availability of deep phenotypic data in spatial and temporal scale from NGP in phenomics is expected to accelerate PheWAS in plants. Besides, deep phenotypic data from phenomics will be very useful in training genomic selection models more accurately, and thus aid in genomic selection in crops. Further phenome features can also be used for phenomic selection (PS) in analogy with GS as complementary method (Kumar et al. 2016). We need to develop human resource in the area of image analysis and big data science to effectively use the phenomics for accelerated analytical breeding for crop improvement.

Acknowledgement

The work was supported by the funding from National Agricultural Science Fund, Indian Council of Agricultural Research, New Delhi.

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Phytotronics for *Brassica* improvement

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'Phytotron' is a kind of sophisticated laboratory where plants can be grown and studied under individually controlled conditions. It is far from a mere green house and hence the new name 'phytotron' was designed from the Greek word 'phyton', meaning 'plant' and 'tron', meaning 'device' (Went, 1949). Similarly, the word 'phytotronics' indicates the study of plants under controlled environmental conditions in order to determine the effects of a single, or known combination of environmental parameters. In the phytotron, the light period, light quality, temperature, relative humidity, and CO_2 can be regulated as per requirement of the plants. Thus, phytotron offers the requisite facilities to create conditions for studying interactions between plants and the environment.

The first phytotron in the world was built at the California Institute of Technology in 1949. It was funded by the Harry B. Earhart Foundation, and was officially known as 'Earhart Plant Research Laboratory'; however, subsequently it was christened as 'phytotron'. With precise control over growing environment with computers and other modern electronic devices, 'phytotron' promised an end to global hunger and political instability spreading around the world after World War II. In a shorter period, phytotron spread around the world including Australia, France, Hungary, Russia, and England. It also came up with variants such as *Climatron* at the Missouri Botanical Garden, the *Biotron* at the University of Wisconsin-Madison, *Ecotron* at Imperial College London, and the *Brisatron* at the Savannah River Ecology Laboratory (https://en.wikipedia.org/wiki/Phytotron). The North Carolina State University Phytotron, which was opened in 1968, was the second facility in the United States and one of the largest phytotron in the world. It houses 60 growth chambers, four green houses and other miscellaneous chambers.

In India, the first and the only 'phytotron' in the country, the 'National Phytotron Facility' (NPF) was established in 1997. Initially, it was started with financial support under the UNDP from Food and Agriculture Organization (FAO), Rome; subsequently, it was handed over the Govt. of India for its functioning and maintenance. It has a self-contained area of $2700m^2$ housing 22 growth chambers and 10 green houses. The facility is open to all plant scientists, students, commercial researchers, and agro-industries for conducting studies pertaining to plant-environment interactions.

The growth chambers of the NPF are primarily of two types' viz., reach-in chamber and walk-in chamber. The reach-in chambers offer unsurpassed accuracy and reliability in the control of temperature, light and humidity. In the walk-in chambers, the users can enter the chamber and perform desired activities.

The NPF has been used to conduct experiments of various disciplines including Plant Breeding, Genetics, Biotechnology, Physiology, Pathology, Entomology, Virology, Microbiology, Nematology, Horticulture, etc. Every year, 180-200 new experiments are being conducted here in various crops viz., rice, wheat, *Brassica*, lentil, green gram, soybean, chickpea, maize, brinjal, tomato, *Arabidopsis*, pea, pigeonpea, onion, etc.

In case of *Brassica*, experiments involving both biotic and abiotic stresses have been conducted in the NPF with satisfactory results. A new technique of screening *Brassica* genotypes for drought tolerance was optimized in the NPF. There were periodic increase and decrease of temperatures for the test. It could rapidly identify genotypes with tolerance to drought at the seedling stage. The technique was successfully used to map gene for drought tolerance. Similarly, molecular mapping of genes for white rust disease caused by *Albigo candida* was successfully conducted using the phytotron facility. Genetic studies for improved seed size in *Brassica* were also conducted using growth chamber facility of the NPF. Proper environment was created in the phytotron for successful inter-specific and inter-generic hybridization in *Brassica*. Growth of the plants was normal, seed development was proper and maturity was complete enabling harvesting of successful cross-seeds.

Arabidopsis thaliana is a model plant for oilseed crops. It is regularly grown in the NPF for multiplication and experimentation purpose. The condition of the glass house and the growth chambers has been adjusted in such a way that the *A thaliana* plant can grow well, flower profusely and produce seeds round the year. Several experiments of gene expressions are being conducted in the NPF involving *A thaliana*. Thus, the phytotron and phytotronics has been contributing immensely in improvement of various crops including *Brassica*.

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NICRA experiences towards making Indian agriculture climate smart

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Climate being central to agriculture production; any significant shift in climate variables may challenge the traditional production cycle. And, evidences over the recent past have conclusively established the climate change a reality. Accelerated and indiscriminate anthropogenic activities especially industrialization and destruction of natural environment raised the concentration of greenhouse gases (GHG) in the atmosphere that lead to global warming. It has been projected that by 2100 the earth's mean temperature will rise by 1.4 to 5.8^0C, while precipitation will decrease in the sub-tropical areas and the frequency of the extreme events will increase significantly (IPCC 2007). Although, the impacts of climate change are global, but countries like India are more vulnerable in view of the dependence of high population on agriculture.

Vulnerability of Indian Agriculture to changing climate

The climate change has become major concern for India to ensure food and nutritional security of growing population. It may cause most impending disasters to Indian agriculture due to its variable striking capacity. A gradual shift in climate variables viz. rainfall and temperatures may lead to creeping disaster, while increased extreme events viz. floods, hailstorm, cyclones, heat waves, frost etc. are resulting into impulsive disaster to farming. The creeping impacts of climate change could be modelled and predicted, while impulsive disasters being highly heterogeneous and location specific are difficult to quantify in advance. Further, these impacts gradually get accumulated over time and in spite of various mitigation measures and adaptation actions, it may lead to increasing residual losses and damages to farming. Here, the loss refers to negative impact for which reparation or restoration is impossible, while damage refers to negative impact for which reparation or restoration is possible (UNFCC, 2012).

The Government of India through the Indian Council of Agricultural Research (ICAR) initiated a National Network Project on Climate Change (2004-13) to assess the impact of medium term (2010-2039) changing climate on Indian agriculture especially crops. The study indicated average reduction in productivity by 4-6% in rice, 6% in wheat, 18% in maize, 2.5% in sorghum, 2% in mustard and 2.5% in potato besides significant regional variability (Naresh Kumar *et al.,* 2012).The crop yields are projected to be more vulnerable in Central and East India for wheat; Punjab, Haryana and Rajasthan for irrigated rice; Maharashtra, Odisha, Chhattisgarh and Assam for rainfed rice; Central India for mustard; and Punjab, Bihar, Jharkhand, Uttar Pradesh and West Bengal for potato. In total, agriculture makes up roughly 16% of India's GDP, an averaged 4.5-9.0% negative impacts on production implies a cost of climate change to be up to 1.5% of annual GDP. However, the study demonstrated that appropriate climate resilient interventions could greatly negate the impact of climate change.

Resilience of Indian Agriculture

Presently, the Indian agriculture is at cross-road; the hypotheses of green revolution are no longer valid. Of late, these technologies have started showing fatigue and widening risk to climate variability. This gives way for the adoption of climate resilient agriculture. In other words, green revolution technologies must be mutated into CRA practices to become relevant under changing climate scenario. CRA is not a new concept, but are sustainable technologies gradually disowned in favour of yield maximising green revolution technologies. However, changing climate brought CRA back to central place more as a necessity rather than an option. Technically, CRA means embodying adaptation, mitigation and other agricultural practices that enhance the capacity of the agro-ecosystem to relieve, resist, respond and recover from climate related disturbances. The CRA options available to Indian farmers could primarily be either adaptive or mitigating. The options that make farming adjusted to future climate are adaptive measures, while efforts that moderate variables contributing to climate change are mitigating measures. Some of the adaptation and mitigation options with emphasis on agronomic practices are briefly discussed here.

Adaptation Options to Climate Change

Adaptation refers to 'adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts' (Smit *et al.*, 2000). In other words, it represents adjustment in some practices directly reducing vulnerability of agriculture to climate change. The adaptation options include (1) technological developments, (2) Government programs and insurance products, (3) farm production practices, and (4) farm financial management (Smit and Skinner, 2002). These options are not mutually exclusive, and their typology depends on the scale and the level of involvement. The first two categories require efforts at macro-scale by public and agri-business agencies, while later two involve farm-level decision-making by producers. However, all adaption efforts are often interdependent but supplementary to each other.

Technological Developments

Adaptation technologies are primarily developed through research programs of public and/or private sectors, and often targets on development of tolerant crop varieties, strengthen real-time forecast system, and efficient management of resources to effectively deal with of climate-related risks. Tailoring crop varieties elastic to climate variables viz. temperature, moisture, wind etc. has great adaptation potential. Such varieties could fit well to new farming and weather conditions. The adaptability of varieties could further be augmented through bringing convergence with improved agronomic and crop management practices. Refined crop management practices such as adjustment in planting dates and cropping calendar could negate the effect of temperature, possibly escape extreme weather events and efficiently use the wet periods. In addition, crop rotations, intercropping, integrated weed and pest management, integrated nutrient management (INM), site-specific nutrient management (SSNM), agro-forestry etc. are important components of strategic adaptation to climate change in India.

The adaptation of farming to climate change could further be strengthened through adoption of resource conservation technologies (RCTs). The key RCTs for Indian context include *in situ* moisture conservation, rainwater harvesting and recycling, efficient use of irrigation water, conservation agriculture, energy efficiency in crop production and irrigation and use of poor quality water. However, these adaptations require thorough characterization of bio-physical and socio-economic resources.

Another type of technological advance is the development of information systems capable of forecasting weather and climate conditions. Weather predictions over days or weeks have relevance to the timing of agricultural operations such as planting, spraying or harvesting, while seasonal forecasts have the potential to aid risk assessment and production decisions over several months. In addition, information on longer-term climate projection can inform farmers about future norms and variability, and the probability of extreme events. Similarly, development of technological innovations in resource management also has the potential to address climate-related stimuli (Smit 1996).

Farm Production Practices:

It includes farm-level decisions with respect to farm production, land use, land topography, irrigation, and the timing of operations. Customizing farm production activities have capacity of reducing exposure to climate-related risks and increasing flexibility of farming under changing climate conditions. Adaptable production options include diversification of crops and crop varieties, changes in the intensity of production besides use of agro-chemicals, energy, capital and labour. Altering crop varieties, including the substitution of plant types, cultivars and hybrids designed for higher drought or heat tolerance has the potential to increase farm efficiency in changing temperature and moisture stresses (Smit *et al*., 1996; Chiotti *et al*., 1997). While, altering the intensity of chemical (i.e., fertilizers and pesticides), capital and labour inputs have the potential to reduce the risks in farm production (Hucq *et al*. 2000). Similarly, rotating or shifting production between crops and livestock, and shifting production away from marginal areas has the potential to reduce soil erosion and improve moisture and nutrient retention. Changing land topography through land contouring and terracing, and the construction of diversions, reservoirs, and water storage and recharge areas (Easterling, 1996), reduces farm production vulnerability by decreasing runoff and erosion, improves the retention of moisture and nutrients, and improves water uptake (de Loe at al., 1999). Water management could improve farm productivity and enable diversification of production with respect to climate-related changes. Changing the timing of operations involves production decisions, such as planting, spraying and harvesting has the potential to maximize farm productivity during the growing season and to avoid heat stresses and moisture deficiencies.

Mitigation to Climate Change:

Agriculture is both source and sink for greenhouse gases (GHG). Farming releases CO_2 largely through microbial decay or burning of plant litters (Smith, 2004; Janzen, 2004), CH_4through decomposition of organic materials under oxygen-deprived conditions, enteric fermentation in ruminants, stored organic manures and flooded rice (Mosier *et al.*, 1998), and N_2O through microbial transformation of nitrogen in soils and manures(Smith and Conen, 2004). Although, agricultural GHG fluxes are complex and heterogeneous, but could effectively be mitigated using available technologies for reducing emission, enhancing removals, and avoiding (displacing) emissions (Smith *et al*., 2007). Globally, technical mitigation potential of agriculture is expected to be 5500-6000 Mt CO_2equivalents per year by 2030 (IPCC, 2007). Agricultural mitigation measures often have synergy with sustainable development policies, and usually influence social, economic, and environmental aspects of sustainability. Many options also have co-benefits (improved efficiency, reduced cost, environmental co-benefits) as well as trade-offs (e.g. increasing other forms of pollution). It necessitates balancing these effects for successful implementation. Some of the mitigation options available for crop lands are briefly discussed here.

Crop management:

Improved agronomic practices that increase yields and produce higher carbon residue could augment soil carbon storage. Important agronomic practices include improved crop varieties, extended crop rotations especially with perennial crops that allocate more carbon below ground, avoiding fallows (West and Post, 2002; Lal, 2003, 2004), balance nutrition (Alvarez, 2005), reduced reliance on fertilizers (Paustian *et al.*, 2004), and catch/cover/intercrops to enhance soil cover (Barthes *et al*., 2004).

Nutrient management:

Nitrogen applied through fertilizers, manures, bio-solids, and other N sources is not always used efficiently by crops (Galloway *et al*., 2004; Cassman *et al.,* 2003). Improving N use efficiency can reduce N_2O emissions and indirectly reduce GHG emissions from N fertilizer manufacture (Scanhlesinger, 1999). Integrated Nutrient Management (INM) and Site-Specific Nutrient Management (SSNM) have the potential to mitigate effects of climate change. For example, adoption of INM and SSNM practices under flooded rice significantly improves the yield, net CO_2 assimilation, and nitrogen use efficiency while decreases GHG emission over traditional practices. Similarly, simultaneous application of urease inhibitor, hydroquinone (HQ), and a nitrification inhibitor, dicyandiamide (DCD) with urea is an effective technology to reduce N_2O and CH_4 emission from rice fields.

Tillage/residue management:

Soil disturbance tends to stimulate soil carbon losses through enhanced decomposition and erosion (Madari *et al.,* 2005), while reduced or no tillage agriculture often results in soil carbon gain (West and Post, 2002; Ogle *et al*., 2005) and usually lower N_2O emissions. Advances in weed control methods and farm machinery now allow many crops to be grown with minimal tillage (reduced tillage) or without tillage (no-till). These practices are now increasingly adopted throughout the world (Cerri *et al.*, 2004). In addition, recycling crop residues tends to improve soil carbon, while burning of residues promotes emissions of aerosols and GHGs

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Water management

Expanding area under irrigated agriculture or adoption of more efficient water management practices can enhance carbon storage in soils through enhanced yields and residue returns (Lal, 2004). For example, intermittent flooding in rice could reduce global warming potential by 25-30% over continuous flooding (Pathak, 2015). Similarly, aadoption of the micro irrigation technology will not only result in saving of water but also saving of energy (Shah, 2009) and reducing carbon emission. Resource conserving technologies (RCTs) like zero or minimum tillage (with or without crop residues), bed planting of crops and direct-seeded rice have a substantial scope in improving irrigation efficiency and saving energy for groundwater withdrawal. However, some of the gains may get neutralized due to energy used to deliver the water (Mosier *et al*., 2005) or from N_2O emissions from higher moisture and fertilizer N inputs (Liebig *et al*., 2005).

Agro-forestry

Agro-forestry systems buffer farmers against climate variability, and reduce atmospheric loads of greenhouse gases. Agro-forestry can both sequester carbon and produce a range of economic, environmental, and socio-economic benefits. However, the amount of carbon sequestered and other tangible benefits largely depend on the type of agro-forestry systems besides environmental and socio-economic factors that determines its composition. In general, the above-ground carbon sequestration rate in major agro-forestry systems ranges between 0.29-15.21 Mg/ha/year (Nair *et al.*, 2009).

Land cover and land use Change

Lands differ in their ability to grow plants and resilient capacity to weathering forces. Usually, a climax ecotype for a land use is thermodynamically the most efficient system that often leads to lowest GHG emission and maximum carbon sequestration. Any deviation from climax vegetation causes imbalances and accelerates entropy. Thus, reverting a crop land to another land cover, typically one similar to the native climax vegetation is one of the most effective methods of reducing emissions. However, such land cover changes often increases carbon storage, but comes at the expense of lost agricultural land. It is usually an option only on surplus agricultural land or on croplands of marginal productivity (Smith *et al.,* 2007).

Interaction of Adaptation and Mitigation Strategies

In farming, mitigation and adaptation action could be implemented simultaneously, but they differ in their spatial and geographic characteristics. Most mitigation measures are robust to future climate change (e.g. nutrient management). And, the benefits of mitigation measures to climate change are realized over decades. In contrast, the impact of adaptation actions to climate change is usually visible in short and medium term.

National Innovation on Climate Resilient Agriculture (NICRA)

The studies on climate change in India and abroad suggest possibilities of making Indian agriculture resilient through adaptation and mitigation measures. Thus, Government of India accorded high research and development priority towards climate resilient agriculture (CRA) and also identified agriculture as one of the eight national missions under the prime Minister's National Action Plan on Climate Change (NAPCC). The Government through ICAR launched mega project "National Initiatives on Climate Resilient Agriculture (NICRA) during 2010-11 for the XI Plan. The project aims at enhancing resilience of Indian agriculture to climate change and itsvariability through strategic research on adaptation and mitigation measures, their refinement and validation for local and regional needs; and extensive demonstration in dynamic mode.The project is continuing in XII plan as National Innovations on Climate Resilient Agriculture (NICRA)with special emphasis on arid regions, hill and mountain ecosystem, pollinators, hailstorm management, and socio-economic dynamics including adaptation financing. To achieve the goals, the project operates through four major components, namely, strategic research, technology demonstration, capacity building and sponsored/competitive grants for basic research.

The strategic research component aims at assessing the vulnerability of major agro-ecosystems, monitoring GHG emissions, pest dynamics, pest/pathogen-crop relationship; develop tolerant breed/varieties; evolve adaptation and mitigation options for climate change regulated abiotic and biotic stress on crops, livestock and fisheries; and real-time contingencies at leading ICAR research institutes in a network mode.The Technology Demonstration Component (TDC) deals with showcasing of proven adaptable technologies in in a participatory mode in selected vulnerable districts of the country by Krishi Vigyan Kendras (KVKs). Critical researchable issues like impact on plant pollinators, fisheries in esturian habitats, hail storm management, hill and mountain eco-system, small ruminants and socio economic aspects of climate change etc. are addressed under the Sponsored and Competitive Grants Component**.** Since climate change is an emerging area of science, capacity building of young scientists and other stakeholders is important component of the programme. Training to scientist on state of art technologies and subjects are being imparted in India and abroad, while more than 100 training programs have been organized across the country covering 50000 farmers to create awareness on climate change and appropriate adaptation and mitigation options.

NICRA experiences

Since 2101-11, NICRA efforts has resulted into generation of valuable information and technologies to address changing climate related issues of farming, brining convergence between technologies, and demonstrating capabilities of technology packages in 151 most vulnerable villages of the country. The results of most case studies have shown possibilities of resources conservation, sustainable production, and livelihood security of farmers. Some of the resilient NICRA experiences are discussed here.

Natural Resource Management

In a given land use condition, enhancing the availability of water is one of the important means for efficient use of available resources and bring resilience to farming. And, it could be achieved through means of adopting in situ water conservation measures and creating of ex-situ surface and sub surface storage structures. Thus at NICRA villages, farmers adopted multipronged approaches renovating creating community tanks, check dams, individual farm ponds besides in-situ conservation of rainfall through agronomic modification.

Renovation of traditional water reservoir 'Aahar' and conveyance channel 'Pyne' helped farmers of Nawada district (Bihar) to harvest additional 20,000 m^3 water for protective irrigation through drip irrigation in 24 ha area during kharif; enhance productivity by 20.7%, raised groundwater table by 20 cum; and improved availability of water for livestock. Similarly, renovation of irrigation channels (Mentepudi channel and VWS channel) in West Godavari district not only improved the water availability at tail end but also helped in safe disposal of excess rain water to avoid flooding and submergence of crops. Even during Neelam Cyclone, a flooding of just 42 cm against average 122 cm submergence (untreated areas) was observed, avoiding the yield loss upto 4.1 t/ha in paddy. Similarly, ex-situ rainwater harvesting and its efficient use brought perceptible change in kharif production at Nacharam Village (Khammam). Supplementary life-saving irrigation at critical crop growth stages gave mean additional yield of cotton (250 kg/ha), Chillies (150 and fodder (4.0 t/ha) and enhanced the income of farmers upto Rs.10900/ha.

Further, the rain water harvesting also proved boon to farmers of hilly regions. Even constructing a small community water storage tank of 200 m^3 at Chhoel-gadouri village (Kullu) is providing supplemental 5 irrigations to tomato crops in 2.2 ha area and improving the B:C ratio to 3.8. Likewise, availability of supplemental water through creation of small *Jal Kund* (capacity 30 m^3) and adoption of pressurised irrigation practices made vegetable production profitable and doubled the cropping intensity at adopted villages in NEH Regions.

In addition, adoption of in situ soil moisture conservation through improved planting methods and conservation agriculture practices proved beneficial to withstand the vagaries of climate. In situ rainwater management practices viz. ridge and furrow (R &F) method, broad bed furrow (BBF) method, and contour farming helped in conserving rainwater at field level and simultaneously draining excess water into community drain channels. These practices were found very effective in rainfed regions of Maharashtra, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, Telangana, Rajasthan, Odisha, West Bengal, Karnataka and Jharkhand. For example, adoption of R&F method improved average yield of cotton by 15%, while BBF or contour farming along with adoption of short duration variety (JS-93-05, 90 days) enhanced soybean productivity by 22%. Similarly, adoption of zero till technology supported reducing cost of cultivation, advancing sowing time by 10-15 days, escaping terminal drought stress, improving green water availability, increasing crop intensity, and thereby enhancing crop resilience. For example, adoption of zero-till practices made sowing of succeeding mustard crop feasible under rice-fallows in 80 ha land at Mizoram, and the practices gave additional mustard equivalent seed yield up to 1.24 t/ha.

Crop Production System

Adoption of location specific better management practices (BMP) including crop varieties has shown tremendous potential to bring resilience in Indian agriculture. Some of the important BMPs promoted through NICRA villages include adoption of short duration drought/flood tolerant varieties, improved soil health management, intercropping and agroforestry, crop diversification, and contingent crop planning to address creeping on cropping and impulsive disasters in farming.

During 2014, adoption of drought tolerant short duration varieties in many NICRA villages proved effective in alleviating the impacts of delayed monsoon without any yield loss. For example, replacing local maize cultivars with short duration varieties/ crops enhanced the seed yields by 18.4% at Umarani village (Nandurbar). Similarly, flood tolerant rice var. RG-2537 and MTU-106 under low inundation condition at Sirusuwada village (Srikakulam district) and lodging resistant var. MTU-1061 and MTU-1064 under cyclone prone areas at Undi village (West Godavari) proved better than traditional rice cultivars.

Location specific intercropping systems are another important adaptation measures for variable rainfall situations. Under NICRA, a number of intercropping systems has been identified and demonstrated at adopted villages. For example, soybean + pigeon pea (4:2) and cotton + green gram inter cropping were found superior to sole primary crops at Shetka village (Aurangabad). Further, diversification of traditional crops and cropping systems to more efficient and climate resilient crops/varieties proved advantageous in most NICRA village and served as an insurance against crop failures. For example, replacing vulnerable cotton with short duration for foxtail millet varieties (SIA -3085 and Suryanandi) ensured higher yields (upto 19.5 q/ha) and net returns (Rs.11820/ha) besides fodder at Yagantipalli village (Kurnool).

The NICRA studies further confirmed the opportunities to enhance resilience of Indian agriculture by adopting location specific soil health management practices. Rationalizing recommended fertilizer doses using soil test based nutrient application at Nalgonda, liming in acid soils at NEH region (Senapati, Manipur), integrated nutrient management at most centres, and introduction of summer moong in rice-wheat system of Punjab (Faridkot) are some of the NICRA experiences explaining optimization of resource use, improving soil health, enhancing system productivity and ensuring higher net returns to the farmers.

Contingent crop planning

Uncertainty of weather conditions is the most important factor causing instability in farming. Preparedness through contingent crop planning for weather aberrations could subjugate the yield losses and thereby enhance the resilience of Indian Agriculture. With this view NICRA in association with SAUs and State Department of Agriculture took major initiative to develop crop contingent plan for delayed monsoon onset/ deficit rainfall conditions prevailing at each rural districts of the country. These contingent plans involve appropriate crop/verities, soil moisture, nutrient management measures and plant protection strategies to face the impact of contingent conditions effectively. Till date, contingent plans for 614 rural districts of the country has been prepared and uploaded to the website of the ICAR, CRIDA and DAC&FW.

These contingent plans were taken up in NICRA villages where delayed onset/ deficit rainfall conditions were experienced. For example, contingency crops of sesame (Madhuri) and sunflower (PKV 559) produced higher yields than regular soybean crop under delayed planting (August) in Maharashtra (Takali village, Amravati district).Further, under delayed onset conditions, adoption of short duration pigeon pea var. BRG-2 over traditional cultivars enhanced the yield by 23.5%, while aerobic rice var. MAS-26resulted 14.4% higher yield than transplanted rice at Tumakuru district (Tamil Nadu). Many similar experiences at NICRA villages confirm the usefulness of dynamic contingent crop planning to enhance farmers' livelihood security.

Management of weather variability:

Unseasonal rains/ hailstorms cause un-predictable damage to standing crops. For example, widespread rains during March 2015 severely damaged wheat, mustard, chick pea, lentil and vegetable crops in many parts of the country. Effective management of such sudden aberration is difficult, but adoption of several pre- and post- event measures could minimize the damage and results into faster recovery. Several studies at NICRA villages have shown better feasibility to manage such weather extremes. During March 2015, zero-till wheat experienced less damage due to lodging and water-logging than conventional crop in Punjab and Haryana. Similarly yellow rust resistant varieties viz., WH-1105, HD-2967, HS-507, and HS-420 showed faster post event recovery and negligible disease infestation. Similarly, furrow irrigated raised bed (FIRB) planted wheat resulted into 70% lesser damage than conventionally sown wheat due to hailstorms at Kota (Rajasthan). Further, early maturing gram variety JG-14 escaped the damaged due to unseasonal rain (90 mm) in MP (Balaghat district). Such experiences at NICRA villages exhibit possibilities of effective crop management options to better withstand unseasonal rains /and hailstorms.

Summary

Impact of climate change on agriculture will be one of the major factors influencing future food security in coming decades. Adaptive responses are mainly related to technological interventions, management practices, sound governmental policy and political will to overcome the ill effects of climate change. The success of agronomic management interventions implemented under NICRA across vulnerable districts in India has demonstrated the ability of different low cost interventions at enhancing resilience to climate change for sustainable agriculture. These technologies have large potential for up scaling through supportive policies and programs. A convergence with developmental programmes operative at the village level could upscale and mainstream NICRA technologies to reduce the risk in farming under changing climate scenarios. The important Governmental schemes that need convergence with NICRA output includes Prime Minister Krishi Sinchai Yojana (PMKSY), National Mission for Sustainable Agriculture (NMSA), National Water Mission, Prime Minister Fasal BimaYojana (PMFBY) and Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). Such convergence will accelerate achieving India's Intended Nationally Determined Contribution (INDC) target for 2030 by reducing GHG emissions, enhancing resource use efficiency, and creating additional carbon sink in farming systems besides ensuring national food security.

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Development of salt tolerant Indian Mustard (*Brassica juncea*): Current status and future strategies

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Globally the total area of saline soils is 397 million ha and sodic soils 434 million ha. Out of 230 million ha irrigated land, 45 million ha (19.5 %) are salt-affected soils and almost 1500 million ha of dryland agriculture, 32 million (2.1%) are salt-affected (FAO, 2015). Out of global salt affected land, nearly 6.73 million hectare area is in India. Further, the arid and semiarid areas in different states are associated with saline underground water, which have to be used for irrigation, due to unavailability or diversion of good quality water to other than agricultural purpose. Use of such water is further rendering the soils unfit for crop cultivation. Salinity is currently one of the most severe abiotic factors, limiting agricultural production. In arid and semi arid lands, the plants are subjected throughout their life cycle to different stresses; some of these plants can tolerate these stresses in different ways depending upon plant species and type of stress. Excessive salinity reduces the productivity of many agricultural crops (Metternicht and Zinck, 2003), Salt stress has three fold effects which reduces water potential and causes ion imbalance and toxicity (de la Peña and Hughes, 2007). Salt stress affects some major processes such as germination, speed of germination, root/shoot dry weight and Na^+/K^+ ratio in root and shoot (Parida and Das, 2005). Salinity tolerance is critical during the life cycle of any species.

The *Brassicas* commonly known as rapeseed-mustard are important group of edible oils and vegetables crops belonging to *Brassicaceae* or *Cruciferous* family. This group comprises of six cultivated species, namely, *Brassica campestris/rapa* (2*n*= 20, AA), *Brassica nigra* (2*n*= 16, BB) and *Brassica oleracea* (2*n*= 18, CC) are diploids; *Brassica juncea* (2*n*= 36, AABB), *Brassica napus* (2*n*= 38, AACC) and *Brassica carinata* (2*n*= 34, BBCC) are digenomic tetraploids, which evolved in nature following hybridization between the constituent diploid species (Fig. 1).

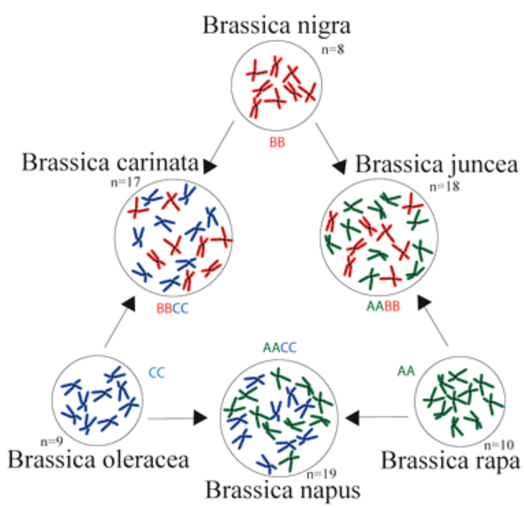

Figure 1: The Triangle of U diagram shows the genetic relationship between the six species of the genus Brassica. Three of the Brassica species were derived from three ancestral genomes, denoted by the letters AA (*rapa*), BB (*nigra*) or CC (*oleracea*). Alone each of these diploid genomes produced a common Brassica species.

Brassicas are the third most important edible oil source in the world, after soybean and palm and is grown in more than 50 countries across the globe. China, Canada, India, Germany, France, UK, Australia, Poland and USA are the major cultivators of its different species of *Brassica*. During 2013, the estimated area, production and yield of rapeseed mustard in the world was 30.74 mha, 60.43 mt and 1.95 tones/ha, respectively. Globally, India account for 21.7% area and 10.7% production (FAO, 2013). In India, oilseed *Brassicas* are being cultivated in around 2 million ha out of the 6.73 million ha salt affected soils, which comes under semi-arid region, affected with varying degrees of soil salinity (Singh *et al.,* 2014). *B. rapa, B. napus* and *B. juncea* are grown predominantly for oil and seed meal. India is the second largest country in rapeseed mustard production and more than 85% of its area under rapeseed mustard is occupied by Indian mustard *B. juncea* alone. The most common adverse effects of salinity on *Brassica* are the reduction in plant height, size and yield as well as deterioration of the product quality (Zamani *et al.,* 2011). Soil salinity markedly affected the lipid components of mustard seeds (*Brassica juncea*). With increasing salt levels, total and neutral lipids declined considerably, while phospholipids and glycolipids increased. The fatty acid profiles of total, neutral and polar lipid fractions were affected substantially. Erucic acid in total and neutral lipids decreased, while it was absent in the polar lipid fraction. In total and neutral lipids, oleic and linoleic acids increased. The amounts of linoleic and linolenic acids in the polar lipid fraction increased with rising salinity. Plant dry weight drastically declined at higher salinity levels (ECe 8 and 12) whereas the maximum weight was observed at ECe 4 (Parti *et al.*, 2003). Brassica cultivars showed comparatively lower percentages of oil content in seeds under saline sodic soil conditions (ECe=13.02 dS m and SAR=12.70). It might be due to an excessive absorption of toxic ions disturbing metabolic processes. Furthermore, nutritional imbalance as a result of depressed uptake of nutrients, shoot transport, chlorophyll breakdown and impaired distribution of mineral ions retarded the development of seeds and early maturity of plants under high salinity treatments might be responsible for the reduced oil content (Ali *et al.*, 2013; Mahmood *et al.*, 2007). In addition to a decrease in the mobilization of photosynthates towards developing siliqua, salinity also adversely affects the deposition of lipids. Fatty acid composition has revealed that erucic acid decreased marginally and this reduction was accompanied by an increase in linolenic acid and eicosenoic acid (Sharma and Manchanda, 1997, Sureena *et al.*, 1999). The irrigation of mustard with saline water (3500 ppm) raised the values of erucic acid followed by oleic acid to 40.98 and 20.49% respectively, as compared to 30.82 and 15.59% in the controlled treatment (Abd El-Wahab, 2013).

At higher salinity (EC >12 dS/m); oil, protein and crude fiber contents decreased by 5-7%, 15-20% and 29-34% respectively, whereas erucic acid content increased by 12-17% (Singh *et al*., 2014). Nevertheless, its growth and seed yield production have greatly decreased owing to salinity. This situation can be alleviated by an approach combining water storage and irrigation, crop management and plant breeding. There is great interest in breeding stress tolerant varieties, since significant inter and intraspecific variation for salinity tolerance exists within *Brassica*, which needs to be exploited through selection and breeding.

However, salt tolerance breeding programs have been restricted by the complexity of the trait, insufficient genetic and physiological knowledge of tolerance-related traits, and lack of efficient selection domain. Improved genotypes of mustard with tolerance to high salt along with consumer's acceptance and good oil quality are required for obtaining optimum yield and expansion of cultivated area under such stress situation.

Physiological and genetic studies on salt tolerance in *Brassicas*

Methods for evaluation of salt tolerance

Salt tolerance is a complex trait to study for the following reasons: (a) salt tolerance can only be evaluated under stress conditions, which can affect multiple physiological responses of the plants; (b) salt tolerance is a quantitative trait which requires an efficient and effective means to quantify the tolerance level; (c) the "salt" in "salt stress" is often ambiguous as it can be different mineral salts, such as NaCl, $MgCl_2$, and $CaCl_2$; despite the high-frequency use of NaCl for salinity, we cannot ignore the harm of other ions; and (d) other physiological stresses (e.g. drought, extreme acidity and alkalinity) are often associated with salt-stressed plants, which also makes this trait more difficult to study.

Therefore, efficient and effective methods, including plant culture under salt conditions, trait detection and grading to evaluate the salt tolerance degree, should be employed in the primary stage of study. Growing plants under some controllable conditions (e.g. hydroponics) is commonly used for salt tolerance studies because very few natural salty soils can provide a consistent and representative condition (Flowers, 2004). The model plant *Arabidopsis* is usually germinated and grown either on an agar medium and/or in pots, where it can complete its whole life cycle. For *Brassica* crops and radish, big-volume pots or containers in controlled conditions (potted soils or hydroponics) are necessary for growth. A few experiments for yield evaluation have been conducted in salty land. It is notable that salt tolerance of *Brassicaceae* species is likely controlled by different genetic components, which have been revealed by salt tolerance performances at different developmental stages (Almodares *et al.* 2007; Ashraf and Sharif 1998; El Madidi *et al.* 2004; Islam and Karim 2010). For example, *Arabidopsis* accessions with good germination rates showed more reductions in fresh weight and dry weight at the vegetative stage under salt stress than the poorly germinating ones. Therefore, salt tolerance tests in the entire life cycle or at the most salt-sensitive stages would be required for comparison of salt tolerance of different lines (Quesada *et al.,* 2002). Artificial salt stress methods, such as gradual stress and salt shock, may lead to outcomes different from those by field tests (Shavrukov, 2013). Imposition of salt stress by gradual exposure to NaCl rather than salt shock has been recommended for genetic and molecular studies because it reflects more closely natural incidences of salinity stress. However, the ideal type of gradual salt application is technically difficult (Katori *et al.,* 2010). Researchers are seeking an easy method or an ideal trait value to forecast the salt tolerance to enable more efficient selection of tolerant crop types or tolerant genotypes. Photosynthetic capacity, proline and glycine-betaine accumulation ability, and ion discrimination can be used as potential biochemical or physiological selection criteria for salt tolerance in canola (Munir *et al,.* 2013; Ulfat *et al.,* 2007). The transcript accumulation pattern for various salt overly sensitive (SOS) members after 24 hr of salt stress in various cultivars showed a strong positive correlation with salt tolerance among *Brassica* species (Kumar *et al.,* 2009). Relative cell membrane permeability and activities of antioxidant enzymes (superoxide dismutase, catalase and peroxidase) could be very effective in identifying canola cultivars with high salt tolerance. So far, there are no uniform criteria applied to the assessment of salt tolerance (Ashrasf and Ali, 2008).

Germplasm screening of Brassicaceae

Breeding for salt tolerance in crop plants is envisaged as one way to combat the worldwide problem of increasing soil salinity in agricultural land. Stresses under adverse soil conditions are highly complex and often compounded with climatic hazards. The stress varies from location to location and even from season to season. Soil stresses are often associated with nutritional imbalance (deficiency/toxicity). Kind of salt stress problems and strategies adapt by plants to overcome (Fig. 2).

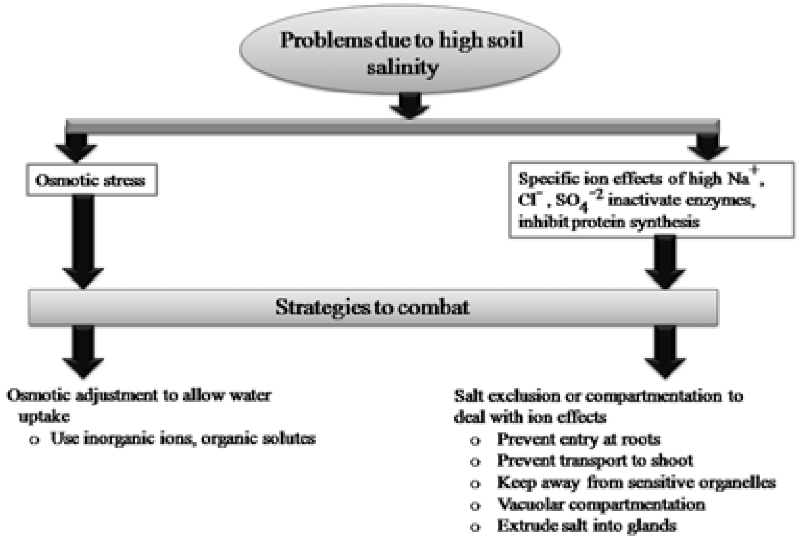

Fig. 2. Problems due to Salt stress and combating strategies in plants

The interaction between soil stresses and other environmental factors influence the plant's response to that stress. Such complexities are responsible for the slow adaptability of high yielding crop varieties in adverse edaphic environments. It is, therefore, necessary that crop genotypes must be screened at target sites having adequate stresses in order to identify dependable sources of varietal tolerance. Breeding crop varieties for increased salt tolerance is considered as a promising, energy-efficient and economical approach than major engineering processes and soil amelioration techniques which have gone beyond the limits of marginal farmers (Ashraf and McNeilly, 2004). For a successful breeding program, presence of a great magnitude of heritable variation in the gene pool of a crop is a prerequisite; such genepools are necessary to provide the variability needed. Genetic diversity provides parental material from well-adapted landraces to enhance local adaptation. It helps to overcome susceptibilities to problem soil and also provides the foundation for breeding for novel requirements. If the genetic variability has been totally utilized through continued selection, then variability may be sought through other means such as chemical and radiation mutagens, protoplast fusion, or recombinant DNA techniques. Using Conventional Breeding approaches researchers at Central Soil Salinity Research Institute (CSSRI), Karnal have generated three high yielding salt tolerant varieties of Indian mustard (*Brassica juncea*); CS 52, CS 54 and CS 56 (Table 1)

Assessment of salt tolerance has also been performed in *Brassica* and its closely related species. There is significant interspecific and intraspecific variation for salt tolerance. Comparing salt tolerance of amphidiploids and diploid *Brassica* species under salt stress revealed that shoot and root weights and seed yield of the three amphidiploid species were significantly greater than those of their ancestral diploids. It could be suggested that the salt tolerance of these species originated from A and C genomes (Ashraf *et al.,* 2001; Nazir *et al.,* 2001). Variation of salt tolerance within six common *Brassica* species plus *Eruca sativa* and *Brassica tournefortii* was explored by assessing the morphological, physiological and biochemical parameters. *B. juncea*, which had been thought to be the most salt-tolerant species, showed the least decrease of shoot length and root length, and lesser electrolyte leakage, higher proline content and higher K^+/Na^+ ratio than the other species (Kumar *et al.,* 2009).

Table 1: Salinity tolerant cultivars of Brassica species developed through conventional breeding

Parameter / Variety	CS 52	CS54	CS56
Year of release	1997	2005	2008
Parentage	Sel. from DIRA 343	B 380 X NDR 8603	RH 851 X Pusa Bold
Plant Height (cm)	170	160	202
Maturity duration (days)	135	121	132
Grain type	Medium	Bold	Medium
1000 seed weight (g)	4.0	5.3	4.4
Salinity tolerance (ECe dS/m)	6 - 9	6 - 9	6 - 9
Sodicity tolerance (pH)	9.3	9.3	9.3
Yield in Non stress(q/ha)	18-20	20-24	22-26
Yield in Salt stress(q/ha)	15-16	16-19	16-19
Time of sowing	Upto 15th October	Upto 15th October	Upto 15th November
Recommended States / Areas	Uttar Pradesh, Punjab, Haryana and Rajasthan		

Classical genetics of salt tolerance in Brassicaceae

Exploration of the heritable potential of a certain trait within the existing germplasm for a given crop would supply information on factors such as salt tolerance for breeders. The both additive and non-additive gene actions involved of in the inheritance of characteristics. High narrow-sense heritability estimates were observed for Ca^{2+}, K^+, Na^+, K^+/Na^+, Ca^{2+}/Na^+ and stress tolerance index, indicating the prime importance of additive effects in their genetic control (Rezai and Saeidi, 2005). Higher estimates of GCV, PCV, heritability and genetic advance (% of mean) under saline condition was observed for main shoot length, number of pods on main shoot and yield per plot, indicated that these characters might be controlled by additive genes (Sinha *et al.,* 2002; Kumar and Mishra, 2006). Salt tolerance was mainly controlled by dominant genes with an additive effect. The dominant effect played a major role and over-dominance might have existed in salt tolerance (Qiu and Li, 2009; Long *et al.,* 2013). The traits like main shoot length, number of pods on main shoot and yield per plot could be improved effectively by selection as these might be controlled by additive genes. Hence framing of selection criteria should be based on such traits on priority in the development of high yielding variety in Indian mustard for saline condition.

Molecular basis of salt tolerance in Brassicaceae

Molecular mechanism of salt tolerance revealed in the model plants will facilitate identification of candidate genes and development of transgenic plants with salt tolerance in *Brassica* crops. Over-expression of genes encoding enzymes related to abiotic stresses enhanced crop salt tolerance. The SOS signaling pathway governing salt tolerance in *Arabidopsis* well clarifies the mechanisms of salt tolerance (Fig.3). The SOS pathway comprises three family members, i.e., the plasma membrane Na^+/H^+ antiporter SOS1, the protein kinase SOS2, and the Ca^{2+} binding protein SOS3. An increase of Na^+ concentration leads to an elevation of intracellular Ca^{2+}, and SOS3 binds Ca^{2+} and activates SOS2 to form a compound which phosphorylates the plasma membrane-localized SOS1. Finally, over-expression of SOS1 results in an efflux of more Na^+ (Martinez-Atienza *et al.,* 2007). SOS1 and SOS3 are constitutively expressed in *Brassica* crops, while the expression pattern for SOS2 amongst *Brassica* species was found to be very unique (Kumer *et al.,* 2009). SOS2 may be upregulated by salinity stress in the roots of all the *Brassica* species except for *B. juncea*, which maintains high SOS2 transcripts even under non-stress conditions, indicating a very unique feature of *B. juncea* (Kumer *et al.,* 2009). Strong correlation between transcript abundance for SOS pathway related genes and salinity stress tolerance was observed in *Brassica* crops (Chakraborty *et al.,* 2012; Kumer *et al.,* 2009).

Recently studies of salinity tolerance in plants have ranged from genetic mapping to molecular characterization of salt induced genes. Increasing understanding of biochemical pathways and mechanisms that participate in plant stress responses has made it evident that many of these responses are common protective mechanisms that can be activated by salt, drought and cold, even if sometimes through different signaling pathways.

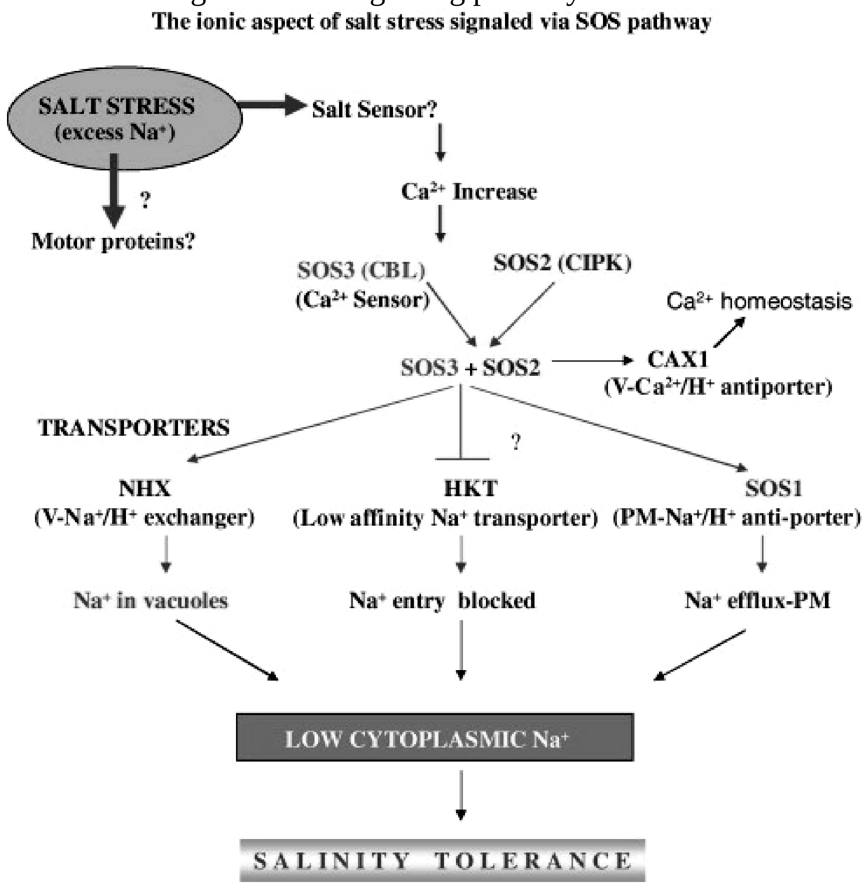

Fig. 3. ***Regulation of ion homeostasis by SOS and related pathways in relation to salt stress adaptation.*** *Salt stress is perceived by an unknown receptor present at the plasma membrane (PM) of the cell. This induces a cytosolic calcium perturbation, which is sensed by SOS3 and accordingly changes its conformation in a* Ca^{2+}*-dependent manner and interacts with SOS2. This interaction relieves SOS2 of its auto-inhibition and results in activation of the enzyme. Activated SOS2, in complex with SOS3 phosphorylates SOS1, a* Na^{+}/H^{+} *antiporter resulting in efflux of excess Na+ ions. SOS3–SOS2 complex interacts with other salt mediated pathways resulting in ionic homeostasis. This complex inhibits HKT1 activity (a low affinity* Na^{+} *transporter) thus restricting* Na^{+} *entry into the cytosol. SOS2 also interacts and activates NHX (vacuolar* Na^{+}/H^{+} *exchanger) resulting in sequestration of excess* Na^{+} *ions, further contributing to* Na^{+} *ion homeostasis. CAX1 (*H^{+}/Ca^{+} *antiporter) has been identified as an additional target for SOS2 activity reinstating cytosolic* Ca^{2+} *homeostasis (adopted from Mahajan and Tuteja, 2005).*

Currently, transgenic plants have been used to test the effect of over-expression of specific prokaryotic or plant genes, known to be up-regulated by salinity stress. Attempts have been made to raise transgenic *Brassica* with candidate gene approach only, making use of the genes having proven role in ion homeostasis, osmolytes accumulation etc., to make them more tolerant to salinity stress (Table 2). Transgenic *B. rapa* spp. *chinensis* plants expressing a choline oxidase (*codA*) gene from *Arthrobacter globiformis* showed a significantly higher net photosynthetic rate and a higher photosynthetic rate under high salinity conditions than wild-type plants (Wang *et al.* 2010). In addition, AtHKT1 is involved in the recirculation of Na^+ from shoots to roots, presumably by promoting Na^+ movement into phloems in shoots and translocation into roots. The function of AtNHX1 in salt tolerance through increased Na^+ compartmentation in the vacuoles (Berthomieu *et al.,* 2003; Apse *et al.,* 1999; Zhang and Blumwald, 2001; Zhang *et al.,* 2001).

Table 2: Salinity tolerant transgenic Brassica developed through genetic engineering

Species	Genes	Encoding protein	Phenotype	Reference
B. napus	*codA*	Choline oxidase	Moderate salinity tolerance and enhanced shoot growth	Huang, *et al*., 2000
	AtNHX1	Vacuolar Na^+/H^+ antiporter	Salt tolerance, growth, seed yield and seed oil quality	Zhang, *et al*., 2001
	PR10	Pathogenesis related (PR)	Enhances germination and growth in the presence of NaCl	Srivastava *et al*., 2004
B. juncea	*codA*	Choline oxidase	Tolerance to salinity stress, enhanced growth	Prasad *et al*., 2000
	PgNHX1	Vacuolar Na^+/H^+ antiporter	Tolerance to salinity stress, exhibited normal growth	Rajagopal *et al.*, 2007
B. oleracea	*betA*	Betaine aldehyde	Salinity tolerance	Bhattacharya, *et al*., 2004
B. campestris	*Lea*	Group3 Late embryo-genesis abundant	Salinity and drought tolerance	Park *et al*., 2005

Dalal *et al.,* (2009) proved that *LEA4-1* plays a crucial role in salt stress tolerance during the vegetative stage of *B. napus* and that transgenic *Arabidopsis* plants over-expressing *BnLEA4-1* have enhanced tolerance to salt stress. Glutathione (GSH) plays an important role in cell function and metabolism as an antioxidant. Bae *et al.,* (2013) developed transgenic plants by introducing the γ-*ECS* (*Glutamylcysteine synthetase*) gene from *B. juncea* (*BrECS*) into rice. Over-expression of *BrECS* confers plants with significantly enhanced tolerance to salinity by sustaining a cellular GSH *redox* state to avoid attacks from reactive oxygen species produced by salt.

QTL mapping of salt tolerance

Although QTL mapping remains the best method for identifying causal genes, it is quite laborious and time consuming. Association mapping, which utilizes a higher number of historical recombination events that have occurred throughout the entire evolutionary process of the population, enables mapping of the genes in smaller genomic regions (Nordborg and Tavaré, 2002).

Interesting results have been obtained by independent studies on salt tolerance in *Brassicaceae*, especially in *Arabidopsis*. Most of the mapped QTLs controlling the salt tolerance were different from each other, since the mapping populations were different and the investigated traits were not all the same. A common QTL for percent germination was detected at 20 cM on chromosome 1 which co-localized with the gene *RAS1*, a negative regulator of salt tolerance during seed germination and early growth (Ren, 2010). Another QTL located at 50 cM on chromosome 4 for candidate gene AT4G19030 (Lee *et al.* 2006), the expression level of which is reduced by ABA and NaCl, was predicted (DeRose-Wilson and Gaut, 2011). These results suggest a complicated genetic work controlling salt tolerance and that the genetic determinants are different in different accessions. Some QTLs for different traits were overlapped: for example, QTLs for root length and response on chromosome 1 and 3, indicating that these two loci may contain genes controlling root length and those for salt tolerance exhibited by root growth. However, genome-wide association studies with larger samples are considered to be more reliable and fruitful.

However, studies on QTLs or genes controlling salt tolerance in *Brassica* oil crops are still very limited. To date, the breeding practice of salt tolerance in *Brassica* crops has been largely unsuccessful due to non availability of salt sensitive line of brassica. The concerns prompted an intensive breeding program to develop high yielding cultivars with salinity tolerance at Central Soil Salinity Research Institute (CSSRI), Karnal which results in developed salt sensitive mutant lines of *Brassica juncea* CS 614-1-1-100-13 and CS 245-2-80-7 which are utilizing in development of recombinant inbred lines. Researchers and breeders endeavor to understand the mechanisms of salt tolerance and screen for stable salt-tolerant genotypes to use in breeding programs. Attempts have also been made to develop salt-tolerant transgenic *Brassica* crops with candidate genes with proven roles in ion homeostasis and osmolytes accumulation (Zhang *et al.,* 2004).

Conclusion

Today's agriculture certainly requires salt tolerant *Brassicas* for the very commercial purpose of the crop. Recent in-depth investigation sat physiological and molecular levels have identified many ways by which wild type plants cope with salinity stress. Thanks to close relationship and the significant inter and intra specific variation within *Brassica* species which shows huge potential for breeding for salt stress tolerance in Brassica crops. Nonetheless, it is clear that to link the salt tolerance trait with QTL position on the chromosome, a proper breeding program assisted with the markers is a prerequisite.

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Weed management in crops with special reference to rapeseed (*Brassica rapa* L.) and mustard (*Brassica juncea* L.)

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Weeds have been existing on the earth ever since the man started domesticating /cultivating plants and animals around 10,000 B.C. and recognized as a problem since then. The battle against weeds is a never ending one and often the costliest agronomic input for successful crop production. Weeds are most underestimated crop pests in tropical agriculture although they cause higher reductions in crop yields than other pests and diseases. Of the total annual loss of agricultural produce from various pests in India, weeds roughly account for 37%, insects for 29%, diseases for 22% and other pests for 12% (Yaduraju, 2006). Weeds decrease quantity and quality of the produces [food, fibre, oil, forage/fodder, animal products (meat and milk)] and cause health hazards for humans and animals. Therefore, weed control is very important for a successful crop production.

Rapeseed and mustard are fast growing crops with huge canopy coverage. They grow during winter season and, therefore, are seldom infested by repeated flushes of weeds. Once the initial flush of weeds is controlled by hand weeding, hoeing or interculture, a healthy crop can smother the growth of weeds coming up later. Grassy weeds like *Phalaris minor* and *Avena ludoviciana/fatua* are usually not rampant in tall vigorously growing rapeseed and mustard, but they may cast problem even in these crops, if they are in good number right from germination of crop and crop has poor growth. However, it is often recommended as a remedy that wheat may be substituted by mustard to eliminate/reduce *Phalaris minor* problem in course of time.

1. WEED FLORA (Das, 2008)

1.1 Annual Grass Weeds

Avena fatua/ludoviciana/sterilis, Agrostemma githago, Asphodelus tenuifolius, Bromus tectorum/ pectinatus, Cyanotis barbata, Eragrostis tenuifolia, Lolium temulentum/ multiflorum/ rigidum, Phalaris minor/paradoxa, Poa annua, Polypogon monspeliensis, Setaria pallidefusca, Snowdenia polystachya

1.2 Annual Broad-leaved Weeds

Chenopodium album, Chenopodium murale, *Melilotus indica/alba/parviflora, Anagallis arvensis, Argemone maxicana, Cannabis sativa, Carthamus oxyacantha, Cleome*(~*Gynandropsis*) *gynandra*, *Coronopus didymus, Daucus carota, Erucastrum arabicum, Fumaria parviflora, Gnaphalium luteo-album/indicum, Launaea asplenifolia, Malva parviflora* L.*, Medicago denticulata/polymorpha, Oenothera laciniata, Polygonum plebejum/ aviculare/ nepalense, Rumex dentatus/retroflexus, Sisybrium irio, Spergula arvensis* (narrow-leaved dicotyledonous weed), *Trigonella polycerata, Vicia hirsuta/faba/ sativa*, *Sonchus oleraceous*

1.3 Perrenial Weeds

Grasses : *Agropyron repens, Cynodon dactylon*; Sedges : *Cyperus rotundus/esculentus*; Broad-leaved weeds: *Convolvulus arvensis, Cirsium arvense, Launaea cornuta, Rumex crispus/ obtusifolius /acetosella* (simple perennial), *Sonchus arvensis* (simple perennial), *Plantago lanceolata* (simple perennial)

Chenopodium murale, Cannabis sativa used to grow earlier on the field bunds, have encroached to wheat and other winter crops in recent years, and are plenty in number. Recently two other species of *Chenopodium* (not identified) are growing in huge number in winter crops at IARI, New Delhi. *Parthenium hysterophorus* L. has also encroached to wheat and winter crops in some places of North and North-western India.

2. CRITICAL PERIOD OF WEED COMPETITION

Weeds do not cause harm to crops equally all through the growing period. There are certain stages in crop growth cycle when weeds are more damaging to crop growth and yield. Usually early season weed competition is most detrimental to crop and, therefore, early season weed control is indispensable, although weeds present at later stages of crop growth cause yield loss and other inconveniences. The critical period of weed competition (Table 1) may be defined as "the short time span in the life cycle of a crop, when weed causes maximum reduction in its yield or in other words, when weed control measure if adopted may fetch near maximal or maximum acceptable crop yield." It is, therefore, simply the specific duration of weed-free situation of a crop resulting into near maximal yield, which is sufficiently close or equal to that obtained by the season-long weed-free situation.

Table 1. The critical period of weed competition in crops

SN	Crops	Critical period (DAS)*
1.	Rice (upland) direct-seeded	15-45 DAS
2.	Rice (lowland transplanted)	30-60 DAT
3.	Rice (lowland direct-seeded)	40-60 DAS
4.	Dwarf wheat, barley, pea	30-45 DAS
5.	Tall wheat	35-50 DAS
6.	Maize	30-60 DAS
7.	Sorghum	15-45 DAS
8.	Pearl millet	30-45 DAS
9.	Soybean	First 60 days
10.	Groundnut	42-56 DAS
11.	Chickpea, lentil	30-60 DAS
12.	Green gram	15-30 DAS
13.	Black gram	15-30 DAS
14.	Cowpea	First 30 days
15.	Cotton (rainfed)	20-60 DAS
16.	Jute, mesta	15-45 DAS
17.	Sugarcane	30-60 DAS
18.	Potato	First 4 weeks
19.	Rapeseed & mustard	10-40 DAS

* DAS, days after sowing

3. HOW TO CONTROL WEEDS

Before recommending as well as adopting any weed control measure, a little knowledge about weed characteristics, morphology, life cycle/ontogeny, nature of competition, degree and duration of association with crops is pre-requisite for suggesting efficient weed control measures. Some common characteristics of weed species, which are clearly visible and easily understandable by farmers/users are to be exploited for making their classes/groups for possible recommendations. Many methods of weed control are available (Figure 1), but adoption of more than one method in a cohesive manner is always advisable. Integrated approach manages weeds better for longer periods. Integrated weed management although considered as a method of weed management, is basically a concept of weed management, which put together two or more methods, e.g. preventive, physical, cultural, biological, chemical, allelopathy in mutual and compatible way to work better and more efficiently towards weed management.

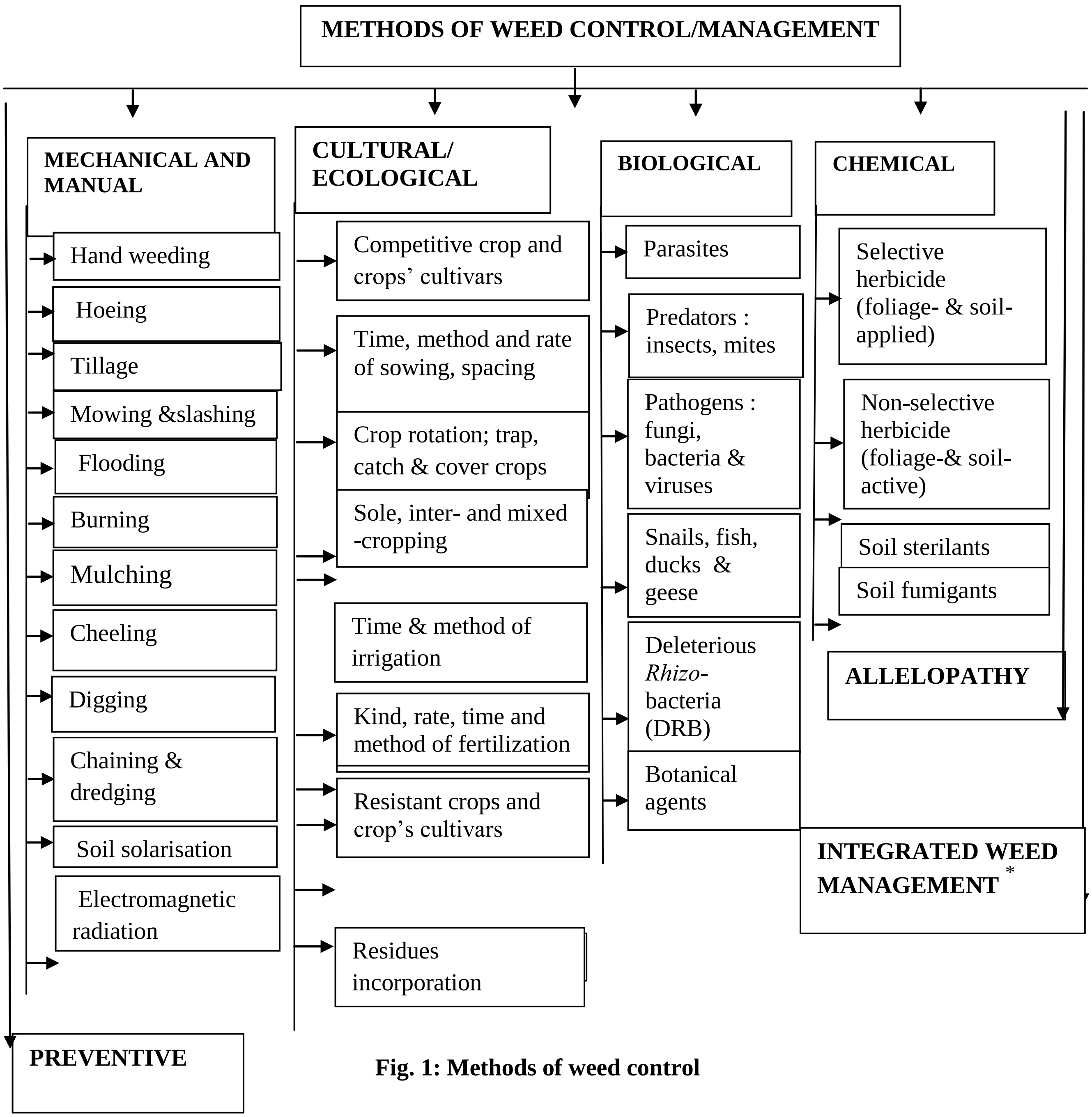

Fig. 1: Methods of weed control

3.1. WEED MANAGEMENT OPTIONS

i) Fine seed bed with enough moisture for smooth and even germination and early crop establishment.

ii) Row planting *versus* broad-casting: Broad-casting requires higher seed rate of rapeseed and mustard. Seed rate @ 10 kg/ha for line sowing with 40 cm row to row spacing, whereas 12-14 kg/ha for broadcasting is recommended. Notwithstanding broadcast crop appears usually poor competitor against weeds and less yielder than row-planted one because row planting maintains at least required or near required population of crops with uniform plant distribution and facilitates easy adoption/deployment of weed control measures like hand-weeding, hoeing, inter-cultivation etc.

iii) One hand weeding at 25-30 DAS as well as thinning at this time will facilitate rapeseed and mustard plants to pick up faster growth to smother weeds coming up later.

iv) Intercropping : Intercropping with wheat, barley, chick pea in India and with maize and sorghum and less frequently with teff in Ethiopia may be a good proposition for dual benefit – weed control and some extra yield from inter-crop. However, the sown proportion of main and intercrop has to be adjusted judiciously. Rapeseed and mustard should necessarily be the intercrop when grown with cereals (wheat, barley) and main crop when grown with chick pea.

v) Mulching : Waste residues of previous *kharif* crops may be spread in between the rows of rapeseed and mustard, which may control weeds, conserve moisture and produce organic matter. However, the residues need to be checked periodically whether there is any termite infestation/attack.

vi) Chemical control

a) Pre-plant incorporated treatment

i) Fluchloralin @ 0.75-1.0 kg/ha for controlling annual grasses and some broad-leaved weeds.

ii) Trifluralin @ 0.75-1.0 kg/ha for controlling annual grasses and some broad-leaved weeds. Grasses are usually not a problem in rapeseed and mustard, but in a specific field with history of annual grass weeds infestation, trifluralin at the above dose and post-emergence TCA @ 2.0-4.0 kg/ha may be advocated.

b) Pre-emergence treatment

i) Pendimethalin @ 0.75-1.0 kg/ha followed by one hand weeding at 30-35 DAS if at all required. Sufficient soil moisture is a pre-requisite for its efficacy.

ii) Alachlor @ 1.0-1.5 kg/ha can control many annual grasses along with some broad-leaved weeds. Soil should be moist at the time of application or moisture must be provided to soil within 10 days of application.

iii) Napropamide @ 1.0-1.5 kg/ha against annual broad-leaved and grass weeds.

iv) Oxyfluorfen is selective to mustard and rapeseed. It can be applied @ 0.20-0.25 kg/ha in 500 litres of water at 30-35 DAS of mustard, where *Orobanche sp* (Broom rape) poses problem.

iv) Dalapon @ 4-7 kg/ha may be applied if there grass weeds particularly perennial grasses are dominant.

v) Nitrofen @ 1.0–2.0 kg/ha for controlling broad-spectrum weeds may be advocated. It is, however, banned for use in India.

c) Post-emergence treatment

i) Isoproturon as early post-emergence @ 0.5 kg/ha at 4-5 leaf stage of crop for broad-spectrum control of weeds (both grass and broad-leaved weeds) particularly wild oats. Barban may also be used against wild oats.

ii) Nitrofen at 2-3 leaf stage of rapeseed and mustard may also be recommended.

3.2 *OROBANCHE/PHELIPANCHE* MANAGEMENT

3.2.1 *Orobanche* Species

There are about 140 species of *Orobanche*, which attack both cultivated crops and wild/ weed species. However, the most species of *Orobanche* have multiple hosts and similarly a crop host is infected by multiple species of *Orobanche*. The species usually occur in India are *O. cernua*, *O. ramosa, O. aegyptiaca, O. cumana, O. muteli* etc. They parasitize a large number of dicotyledonous crops like tomato, potato, tobacco, egg plant/brinjal, fababean, groundnut, sunflower, safflower, niger, lettuce, mustard & rapeseed, cabbage and linseed. *Orobanche* species have many wild hosts too. The wild hosts of *O. ramosa* are *Galinsoga parviflora* and *Solanum nigrum,* while that of *O. minor* are *Datura stramonium, Bidens biternata, Tagetes minuta* and *Xanthium sp*. A particular species of *Orobanche* (species not characterized) has also been found to occur on *Parthenium hysterophorus* in Ethiopia (Das *et. al.*, 2002). The species of *Orobanche* predominant across the world with their respective host range are:

i) ***Orobanche cernua*** (nodding broomrape): Tobacco, tomato, sunflower (mainly plants under solanaceae, lamiaceae).
ii) ***Orobanche crenata*** **:** Faba bean, broad bean and other legumes (plants under fabaceae, apiaceae).
iii) ***Orobanche ramosa*** **:** *Brassicas*, carrot, cotton, sunflower, safflower, potato, tobacco, tomato, brinjal & other solanaceous crops (under solanaceae, fabaceae, brassicaceae, cucurbitaceae, asteraceae, apiaceae, cannabinaceae, linaceae).
iv) ***Orobanche aegyptiaca*** (Egyptian broomrape): Almost same host range as in *Orobanche ramosa*.
v) ***Orobanche minor*** : Tomato, *Brassicas* (under brassicaceae, solanaceae).
vi) ***Orobanche muteli*** **:** Brinjal, tobacco, tomato (under solanaceae)
vii) ***Orobanche cumana*** **Wallr.** (sunflower broomrape) : Sunflower, clover, alfalfa (under asteraceae, fabaceae)

3.2.2 Biology

Orobanche is an achlorophyllous (devoid of chlorophyll), heterotrophic, phanerogamic, total-/holo-root parasite, annual plant with fleshy, pale, reddish-brown or yellowish-brown, pubescent stem bearing a simple spike or raceme of flowers. The spike is loosely flowered, interrupted below and continuous above. Flowers are 1-2 cm long with petals united into a broad tubular corolla, 2-lobed upper lip and 3-lobed lower lip. The leaves are scale-like, sometimes ovate or lanceolate, 6-20 mm long, acute and sessile. *Orobanche* usually grows to a height of 50-60 cm above the ground. Its most species are unbranched except *Orobanche ramosa*, which has branched stem. Inflorescence spike, flower colour varies with the species, fruit capsule which splits into two parts when ripe. It is cross-pollinated by bamble bee. It reproduces by sexual means with seed production potential of about 3,000-200,000 seeds per plant shoot in a short period of eight weeks. Seeds are minute (size 0.3 mm × 0.2 mm and test weight/1000 seed weight 0.1-3.0 g), ovoid, reticulate and dust-like, which are easily dispersed by wind, water, birds, farm animals, manure and others. Seed longevity varies from 2-20 years.

3.2.3 Germination, Infection/Attachment and Symptoms

Orobanche seeds require 1-2 weeks pre-conditioning period before it responds to host root exudates/stimulant and one week stimulation from host root exudates for germination. If pre-conditioning or stimulant exudation not proper, the seeds do not germinate and can remain dormant and viable in soil for about 10-12 years. Seed pre-conditioning followed by host root exudation induces germination of *Orobanche* seeds within soil up to 1 cm from the host roots. However, for attachment the seeds have to be within 2-3 mm from host roots.
Attachment must occur within a few days of germination. For attachment, the germinated seed produces a radicle up to 3-4 mm long with sticky papillae by which it sticks to the host root

surface. A haustorium is a nutrient sucking structure, which penetrates host cells by enzymatic action resulting separation of the host cells. The haustorium swells up and forms fleshy clone (base) from which several "tubercles" or "nodules" develop. On a "tubercle/nodule" after 1-2 weeks a shoot bud differentiates and elongates to produce a shoot. Thus several tubercles develop into separate shoots, which emerge rapidly through soil and produce flowers within a few days after emergence. Secondary attachment points can also develop to connect *Orobanche* rootlets with host roots. Optimum temperature for germination is 20-25^{0}C. Higher pH (alkaline range) may inactivate the germination stimulant and reduce *Orobanche* germination. Soil type usually has no influence on germination, but *Orobanche* infestation is likely more on less fertile soils. Unlike *Striga*, *Orobanche* emerges through soil soon after forming haustoria.

3.2.4 Crop Yield Losses

Crop yield loss varies from crop to crop and mainly based on the severity level (number of emerged *Orobanche* shoots) of infestation. *Orobanche* species also vary in their potential to cause damage since morphology, height/stature, infection ability varies across the species. In Upper Awash Agro-industries and South Wollo Zone of Ethiopia, yield losses to the tune of about 50-60% and 75-100% have been reported to occur in tomato and faba bean, respectively under heavy infestation (Personal Communication to NPPRC, Ethiopia). In Rajasthan, India, mustard encounters huge infestation of *Orobanche* and incurs heavy loss in yield. In Tamil Nadu, the loss to tobacco due to *Orobanche* infestation is placed at 30-35%. *Orobanche cernua* with 4 shoots per sunflower plant causes a yield reduction by 20% in sunflower (Stroud, 1989), whereas, its 7.3 shoots per tobacco plant causes 50% yield reduction in tobacco (Rao, 2000). Usually 4.3-7.3 *Orobanche cernua* shoots are found in tobacco. A single emerged *Orobanche* can reduce faba bean yield by 8% and a greater infestation can cause total crop loss (Stroud, 1989).

3.2.5 Orobanche Management

i) Preventive measure

Prevention is employed for minimizing the spread of *Orobanche* across and within the regions as well as to reduce its soil seed bank on gradual basis.

a) Clean crop seed should be used. *b*) Farm implements (ploughs, hoes) from an infested field should be cleaned before taking them to a new field. *c*) Quarantine should be followed properly. *d*) Avoid transfer of soil from infested area to a non-infested area. *e*) Avoid grazing animals in the infested area at least until the *Orobanche* has been removed. *f*) Destroy all pulled *Orobanche* plants by burning or burying immediately, otherwise, seeds may disperse from some plants if already matured. *g*) *Orobanche* growing on wild hosts/weeds in and around crop fields should be destroyed with contact herbicide, *e.g.* paraquat, diquat to prevent its seed production.

h) ***Application of natural/synthetic stimulants***

Ethylene does not stimulate *Orobanche* seed germination. However, several synthetic analogues of the natural stimulants, such as GR 7, GR 24 and GR 45 are available, which can induce *Orobanche* germination. They when applied well ahead of crop sown induce *Orobanche* germination, but the seedlings wither away in absence of a suitable host plant amounting to "suicidal germination." *Orobanche* plants those survived may be controlled by tillage, manual weeding or contact herbicide, *e.g.* paraquat, diquat. However, the combination of synthetic stimulants and trap crops towards *Orobanche* control would be the more effective ideal option, if the stimulants do not jeopardize the germination of trap crops.

Ground sunflower plants can also act as stimulant for *Orobanche* germination.

***ii*) Mechanical & manual measures**

a) **Soil solarization :** Soil solarization is an effective measure for controlling *Orobanche* (Das, 2008). Higher cost economics although puts doubt on its large-scale application, it can be adopted in seedling-raising nurseries on small plots of land and for growing profitable cash crops like vegetables. Solarization provided excellent control of *Orobanche aegyptiaca* (Abdel-Rahim *et*. *al*., 1988) and *Orobanche ramosa* & *Orobanche crenata* (Parker and Riches, 1993) and ensured higher yield. The population of *Orobanche* and other weeds reduced significantly in the subsequent crops planted 6-12 months later. The effect is likely to reduce if deep cultivation follows. Solarization controlled *Orobanche crenata* significantly and a yield increase to the level of 331%, 441% and 92% was recorded in faba bean, lentil and field pea, respectively in Syria (Linke *et*. *al*., 1991; cited in Parker and Riches, 1993).

b) **Hand pulling/mulching:** Usually periodical hand pulling of *Orobanche* shoots 3-4 times per season before seed setting is advocated in a bid to reduce maximum of its seed population for the coming years. Hand weeding although labour-intensive, is useful particularly under light infestations and should be practised as early as possible to avoid crop damage.

c) **Mulching :** Mulching is superior to fumigation as it cheaper and safer and involves no phytotoxicity or herbicide residues.

d) **Flooding :** Flooding for a long period destroys viability/longevity of *Orobanche* seeds. A continuous flooding for about 1-2 month(s) prior to planting of tomato reduces *Orobanche* infestation in tomato. Similarly flooding required for rice can be utilized for controlling *Orobanche* in tobacco if rice is included in the rotation.

e) **Deep ploughing :** Ploughing up to a depth of 20-25 cm during summer with normal interculture has been found effective towards reduction of *Orobanche* population and enhancement of tobacco yield in the following season (Khot *et. al.*, 1987).

f) Use implement **SPEAR** designed to remove tender *Orobanche* shoots.

***iii*) Cultural measure**

a) **Trap crops :** Trap crops stimulate *Orobanche* seed germination, but the infections die either during filamentous stage (germinating seed with whitish radicle attached to host roots) or during the sub-terranean button sized growth stage without subsequent emergence into flowering shoots. Generally trap crops for *Orobanche* are pepper, sesame, cotton, soybean, lucerne/ alfalfa, clover, castor, rapeseed & mustard, linseed, maize, finger millet, cowpea, hemp, chicory, horsegram, sorghum, niger, brinjal, chick pea, which may be grown in rotation with host crops towards *Orobanche* control. Pepper (*Capsicum annuum* L.) is regarded as a more effective trap crop for a number of species of *Orobanche* particularly *Orobanche cernua*. Several sunflower cultivars also show potential as trap crops. Even ground sunflower stalks stimulate *Orobanche* germination. Lucerne, maize, clover, rapeseed, mustard, pepper and castor could be effective trap crops for *Orobanche ramosa*; pepper for *Orobanche cernua*; and linseed for *Orobanche crenata*.

b) **Catch crops :** Acharya *et*. *al*. (2002) have used toria as a catch crop for *Orobanche* and observed 33.35 % reduction in seed bank of *Orobanche* with 2.1 g/m^2 of toria seeds.

c) **Time of sowing:** Late planting likely reduces *Orobanche* infestation in tobacco and other crop hosts.

d) **Crop rotation:** Crop rotation with trap crops (which promote *Orobanche* seed germination but do not support parasitism) or catch crops (which support parasitism but destroy *Orobanche* prior to flowering) can effectively hinder new seed production and hence reduce soil seed bank.

e) **Host plant's resistance (to *Orobanche* and herbicide) :** Enhancement of host plant's resistance by way of developing resistant varieties is one of the best methods of controlling *Orobanche*. Therefore, crop breeding and biotechnological researches for fostering *Orobanche* resistance in host crops should be more prioritized. Faba bean variety F-402, and pepper variety Maor & Odem are resistant to *Orobanche*. There are several herbicide-tolerant crop varieties developed in the world on which the respective herbicide can be used to control weeds including parasitic *Orobanche*. Several such crop varieties are chlorsulfuron-resistant tobacco, glyphosate-resistant rapeseed, asulam-resistant tobacco, glyphosate resistant tomato, asulam-resistant potato varieties.

f) **Maintain soil fertility :** *Orobanche* is believed to infest more in soils of low fertility. Heavy dose of N fertilizer and higher soil fertility reduce *Orobanche* population. Therefore, N should be applied at least at the recommended rate if not possible at the higher doses on the ground of affordability by farmers and cost economics. *In situ* on-season green manuring as per the feasibility and applicability may be undertaken to maintain soil fertility. Green house experiments in Jordan and USA have enough established that higher concentration of nitrogen drastically reduces *Orobanche* infestation in several host crops. *Orobanche* germination is not much affected by N concentration in the solution, but its radicle elongation is severely inhibited. As a result, the chances for attachment to the host root get reduced. NH_4^+-N is reported more inhibitive than NO_3^--N probably due to NH_4^+ has some herbicidal effects. It is acidic or acid-forming fertilizer. Acidity nearby root rhizosphere of the host may induce inhibition to haustorium development and radicle elongation of *Orobanche*.

_iv_) Biological measure

a) **Insects:**

Among a half-century insects feeding on the species of *Orobanche, Phytomyza orobanchae* Kalt (family - Agromyzidae; order - Lepidoptera)) offers a promise. It is native to the Mediterranean region, the main area of *Orobanche* infestation. It is highly efficient against *Orobanche* because:

i) it is multivoltine (2-7 generations per season), which ensures repeated attack of the insects;

ii) the occurrence of adult flies greatly coincides with *Orobanche* shoot emergence/ infestation in the field;

iii) Both adult and larvae are damaging to *Orobanche*. The adults lay eggs on the young *Orobanche* shoots and the larvae mine or tunnel through the stem and unripe seed capsules. As a result, *Orobanche* seed production is reduced to a great extent. However, several predators/ parasites/ parasitoids exist for *Phytomyza orobanchae*, which limit its utilization as a potential bio-control agent for *Orobanchae*.

b) **Fungi**

Almost 47 fungi species are isolated from the species of *Orobanchae*, but a few proved effective against *Orobanchae* under field conditions. One such fungus is *Fusarium oxysporum* f. sp. *orthoceras* (Appel & Wollenw.) Bilai from which "product F" was developed in the then USSR. It is mass reared on a medium of barley seeds and wheat straw and incorporated into the soil. It can cause massive damage to *Orobanchae*. Another important fungus is *Fusarium arthrosporioides*.

v) Chemical measure

Orobanche lacks chlorophyll and, therefore, photosynthesis-inhibitor herbicides should not be used for its control. For example, isoproturon, a PS II inhibitor, although selective to mustard and is recommended for post-emergence weed control at mustard's early growth stages, may not be much effective against *Orobanche*.

a) *Soil fumigation* : Soil fumigation with dazomet (DMTT) granules at 300-350 kg/ha about 30-40 days before transplanting of tobacco is found effective. Similarly, metham (Vapum®) @ 2000 l/ha (product) with narrow spacing of drippers is quite effective against *Orobanche* (Egyptian broomrape).

b) Glyphosate can have directed use in a few crops, for example, faba bean, if applied at low dose (0.2-0.5 kg/ha). Its directed application in wider-row sown crops is more useful.

c) Oxyfluorfen (200-250 g/ha as pre-emergence controls broad-spectrum of weeds along with *Orobanche* in mustard. Oxyfluorfen is selective to mustard and rapeseed. However, with regard to the control of *Orobanche* only, selective pre-emergence herbicide may not remain effective since *Orobanche* will germinate once mustard seedlings have developed some root system, but, by that time a sufficient time will elapse to reduce the effect of herbicide applied long back as pre-emergence. Therefore, oxyfluorfen, if applied as post-emergence @ 200-250 g/ha in 400-500 litres of water at 30-35 days after sowing of mustard would be more effective.

d) Linuron @ 0.5 kg/ha at 30 DAS caused complete control of *Orobanche*, but simultaneously posed severe phytotoxicity to mustard (Subhas Kumar, 2002). Therefore, pre-plant incorporation of linuron into the soil may be advocated, which could render selective control of *Orobanche* in tobacco and brinjal.

e) MH-T @ 1.5 % spray on established *Orobanche* shoots as post-emergence.

f) 2,4-D, dinoseb, TCA have also been found effective against *Orobanche* in different crops.

g) Post-emergence application of kerosene is effective, but highly non-selective.

vi) Integrated *Orobanche* management

Several feasible methods/options can be integrated to form a workable IWM/IOM (integrated weed or *Orobanche* management) module/schedule in a specific area or crop for a long-term basis. Biological control can be adopted on the basis of whole cropped and non-cropped area to manage *Orobanche* occurring on crop and wild hosts. *Orobanche*-resistant variety, if available should be adopted invariably in every situation or crop.

a) Soil solarization + optimum/ higher nitrogen fertilization + selective and effective pre-emergence herbicide + post-emergence herbicide or hand weeding/interculture at the later stages.

b) Soil solarization or one or a few trap crop(s) or crop rotation with rice where feasible or prolonged flooding if possible with high temperature (during summer) + optimum/ higher nitrogen fertilization + selective and effective pre-emergence herbicide + hand weeding/ interculture at the later stages.

Conclusion

A handful of weed control options are available now-a-days. They, however, individually are not a fool-proof strategy/technology. They have usefulness, as well as limitations. Therefore, a suitable integration of the relevant options for weed control available to the growers is necessary for achieving higher crop yields through improved weed management. Practices like summer tillage, stale seedbed, mulches/crop residues, herbicide along with other cultural/non-monetary options (appropriate variety; time, method & rate of sowing; row-spacing; proper fertilization, etc) may be integrated/combined in a compatible and mutually exclusive way to harness a better, efficient and longer weed management in crops and cropping systems.

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Climate change: Impact on pest scenario of oilseeds *Brassica*

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Climate change is of immense concern to India in view of its dependence on agriculture for food and nutritional security of its ever-growing population. Changing pest scenario due to climate change has warranted the need for future studies on such models which can predict the severity of important pathogens of major crops in real-field conditions. Climate change has direct effect on growth and multiplication, spread and severity/infestation of many plant pathogens / insect-pests, which in turn are affecting the pattern of incidence of pests (including insect-pests, microbial pathogens, weeds, etc.). Population dynamics of pests is dependent upon temperature and humidity among several weather factors. Small change in temperature can result in changed virulence as well as appearance of new pests in a region. Areas presently uncongenial for pests may become suitable due to rise in temperature. However, it needs to be borne in mind that insects (including insect-pests and beneficial insects) and microorganisms (including crop pathogens) could adapt to slow changes in the environment (*viz.,* increase in temperature) and thus their favourable thermal range could also shift. Any change in them, depending upon their base value can significantly alter the scenario, which ultimately may result in yield loss.

Magnitude of impact of climate change could vary with the type of species and their growth patterns. It may be assumed that the vegetation tolerating high temperature, salinity and having high CO_2-use efficiency could be better than other species. Intergovernmental Panel on Climate Change in its report of 1995 predicted that doubling the level of CO_2 could possibly increase yield in several crops by 30%. Observations of changing crop pest distribution over the twentieth century suggested that growing agricultural production and trade have been most important in disseminating them. But there is some evidence for a latitudinal bias in range shifts that indicates a global warming signal. The increased crop production could be off-set partly or entirely by the pests. It is, therefore, important to consider all the biotic components under the changing pattern of climate.

Climate change and pest scenario

In India, limited efforts have been made in this area for any disease of any crop. There is also thought about shorter winters, which may affect the oil yields of the rapeseed-mustard crops as also grain filling of other crops grown during similar period. Root rot is an emerging threat for rapeseed-mustard production system, recently reported from the farmers' field in some pockets of the country, which apart from the already established *Sclerotinia* rot is likely to increase, the latter with severe winters.

Climate affects the population dynamics and distribution systems of invertebrate pests like insects and mites. Climate change may affect the distribution of the insect-pests, their physiology, abundance, phenology and the major factors comprise CO_2 concentration, temperature, precipitation, natural enemies and their host plant. Severe weather events such as strong rainstorms, elevated temperatures or high wind also influence their continued existence. Climate change may include shifts in species distributions, changes in life cycles with phenology, rise in number of generations and population growth rates, alterations in crop-pest synchrony, change in migratory behaviour, natural enemy-pest interaction, and changes in inter-specific interactions. Extinction of some species and changes in community structure are also normal. Oilseeds *Brassicas* have been affected by the painted bug (*Bagrada cruciferarum*) in the western part of India whereas in the eastern India it has been affected by saw fly (*Athalia proxima*).

Overall, there is change in crop-wise pest scenario with several fresh introductions, which may be due to increased human activities that are triggering major pest outbreaks that may be inviting more sprays of chemicals coupled with higher risks of chemical pesticide residue as well. Apprehensions have been expressed towards adverse impact of climate change on pollinators and lac productivity as well.

We may have seen some changes in scenario of insect-pests, pathogens and attributed them to change in pattern of climate. However, establishing such correlation through research remains to be done in India. Due to variation in climatic situations and fitness of insect-pests, pathogens to such changes, there is possibility of their migration to their comfort zones, which could thereby trigger invasions to newer regions / countries and establishment therein. There is no clear indication on injury profile on attainable yield, changes thereof in course of any change in pest scenario and hence we are not sure about the fitness status of any pest vis-á-vis the changed climatic situation apart from the status of our readiness to encounter the same. Research to assess change in pest scenario crop- and region-wise need to be addressed to estimate the impact of climate change on crops, pests, crop-productivity and sustainability of farming. The pest diagnostic systems need to be simple, autonomous, rapid and enrichment-free, field operable, inexpensive, real-time, sensitive and specific with abilities for early detection. There should be systems for untoward situation for pest management with actions, roles and responsibilities identified in advance and duly linked with information flow in decision framework from pre-border checks and pest-risk analysis in relation to present and future climates.

Plant Protection Approaches

Changing pattern of disease and insect-pest scenario due to climate change has warranted the need for improved novel agricultural practices and use of eco-friendly approaches for sustainable crop production. A knowledge gap exists in understanding pathogen survival, the timing of spore release to infect subsequent crops as different responses to the climate by the pathogen and crop could lead to more or less infection. More research is also needed to understand impacts of climate change on soil microbes, particularly those that mitigate root diseases. Generally warmer conditions will increase severity of root and stem rots which could advance with earlier crop growth in view of higher temperature. However, yield losses from pests could increase as also higher and earlier transpiration stress caused by heat or drought. Effects of increased carbon-dioxide concentrations on plant pathogens also require further research. Increased carbon-dioxide may trigger denser crop canopies, which could encourage a range of foliar diseases. Due to change in climate there is shift in seasons, cropping pattern, pest scenario, and hence, the choice of crop management practices based on the real-time situation is very important. In such scenarios, weather-based pest (inoculums/population) monitoring, and rapid diagnostics would play a significant role for accurate information on level of pest condition for their coordinated management at regional, national and global levels. There is need to adopt novel approaches to respond to the resurgence of pests under scenario of changed climate. Thus, there is need to devise better ways for data compilation (*viz.,* e-pest surveillance, use of satellite-based information for tracking pest mobility, etc.) with cognizance of migratory behaviour of crop pests duly aided by international cooperation at regional and global scale, to improve understanding of criticalities in dynamics of crop pest interaction, impact through a thorough understanding of agro-ecological analysis (including alternate hosts of crop pests), yield loss, economics and ultimately enhance forewarning capabilities for pest risk under enhanced level of unpredictability in temporal and spatial interactions among weather, cropping systems, and pests to enable a closer-to-reality forecast of doom and gloom scenarios. Educating farmers towards maintaining records on farming practices undertaken date-wise may enable experts to guide on decision making as per need of the hour apart from equipping policy makers, crop health institutions and field functionaries with updated information. Integrated pest management strategies would undoubtedly be the only solution to cope with complex pest scenario. It includes multiple approaches like use of healthy pest-free seeds with durable disease resistance, and various types of cropping systems that promote the conservation of native bio-control agents whereas early warning systems and monitoring for forecasting pest epidemics / epizootics should also be developed for important ones, which have a direct link on the crop production, income generation of the farmers and food security. Use of biocontrol agents of plant origin such as neem oil, karanja seed extract and neem cake may also facilitate in mitigation of climate change because it helps in the reduction of nitrous oxide emission by nitrification inhibitors. Biological control studies in several field crops are lacking which need to be addressed to reduce the reliance on chemical pesticides and consequent development of pest resistance to the target-pests and / or resurgence thereof. Holistically, there is need to improve resilience of production systems to withstand shocks from increased incidence of pests for which required research and developmental efforts are required (eg. pre-emptive breeding for shock-tolerant varieties), etc. Unfortunately, appropriate expertise and financial support has been declining over the years in several sectors, more so in the arena of diagnostics and taxonomy of fungi, bacteria, nematodes, mites, insects, weeds, etc. and also in the area of extension services. Thus, the education system is immediately required to take a serious view to enable train students, the future experts and thus reverse the decline in skilled crop protection specialists in India. Overall, under extremes of uncertainties, extension workers should be prepared for worst-case-scenario that uncovers the crop of resilience vis-à-vis pests apart from capability to face disasters through all possible means of cooperation.

Conclusion and further approach

Climatic changes provide challenges and opportunities for Indian agriculture. Though the effect of climate change is vast, only limited research on impact of climate change on pests has been done under real-field conditions. However, some assessments are being done in few countries, regions, crops and particular pests under field condition to counter the current as well as upcoming problems of crop pests. Emphasis must shift from impact assessment to developing adaptation and mitigation strategies as also options thereof with special attention towards outbreaks. We need to thoroughly assess the efficacy of current chemical, physical and biological control tactics, including pest-resistant cultivars under climate change, and to include future climate scenarios in all research aimed at developing new tools and strategies. Research on host response and adaptation should be conducted to know how forthcoming change in the climate could affect crop pests; pest risk analyses need to be done regularly based on host-pests' interactions. In case of oilseed Brassica crops, many issues needs to be addressed in future like

- Injury profile as relevant to major pests of oilseed Brassica crops vis-a-vis attainable yield with special reference to sucking pests (aphid) need to be worked out.
- Biotype-wise study of major pests (insect-pests, pathogens) should be taken up for fitness to future climate scenario.

- Since it is expected that there could be higher vulnerability to biocontrol agents and also higher losses due to pathogens having wider host range viz., the cellulase-producing rot-causing fungi (eg. *Sclerotinia*), reduced efficacy of chemical management, thus greater emphasis on working out better biocontrol strategies against rot-causing (soil-borne) pathogens should be focussed as major component of IPM for the crops and cropping systems. This needs to be addressed not in isolation but keeping in view the entire soil microflora (pathogens and beneficial microbes) vis-à-vis the impact of elevated CO_2 and temperature.
- Pest risk analysis vis-à-vis climate change profile of the country / region for different oilseed *Brassica* crops should be done regularly with special reference to invasive pests. There are a few isolates of *Alternaria brassicae* and *Sclerotinia sclerotiorum*, which have earlier been reported as capable of adapting under high temperature situations. Further, it would be interesting to observe the behaviour of white rust causing *Albugo candida* isolates in general, particularly those from the North of India and Karnataka as relevant to future climate scenario. *Erysiphe criciferarum,* the pathogen causing powdery mildew is expected to be more damaging in coming times with increase in its window of occurrence both in terms of crop stage and region.
- Knowledge-empowerment of farmers about integrated crop health management practices and on cluster approach of farming need to be advocated.
- Validation of findings on downy mildew, white rust, *Alternaria* blight, *Sclerotinia* rot, *Rhizoctonia solani*, etc. need to be carried out for better preparedness to future climate.

Today's challenge is to 'produce more from less'. In the era of climate change, diagnostics of pests and diseases and capacity building of farmers, extension and even research personnel for adaptation to changed pest scenario under future climates assumes significance, wherein Integrated Crop Management in Private Public Partnership mode could be very effective. Farmers' decisions are of vital importance for good yields of crops. Forecasted weather products and area-wide weather networks are becoming more prevalent. Crop loss models, representing a dynamic interaction between pests and host, are essential for forecasting losses thereof. Accurate information concerning possible yield losses due to occurrence of a pest is needed by growers or plant protection specialists to decide on cost-effective control measures. India is fortunate enough to have such a diverse climate suitable to grow various types of crop plants with varied pest populations (for innovative experimentations under natural situations), which can help counter the pest problems in the changed climate scenario to enable farmers cope with such uncertainties with confidence and comfort. Thus, future research and education in Crop Protection in India does need to address the issue of future climates in pest management, for which fund requirement would certainly be lesser than many ambitious ones.

Diseases scenario in rapeseed-mustard and management strategies in India

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In response to changes in the cryosphere, hydrosphere, biosphere and other atmospheric and interacting factors, the earth's climate has always changed. From last 250 yeras, global emissions of radioactively active gases, including CO_2, have increased rapidly, a trend that is likely to accelerate if increase in global emissions is not be restricted effectively. It is now established that human activities are increasingly influencing changes in global climate. Climate change affects plants in natural and agricultural ecosystems throughout the world. Little work has been done to estimate the effects of climate change on plant disease epidemics. A weather-based disease forecasting model combined with a climate change model predicting temperature and rainfall under high- and low-carbon emissions is essential to demonstrate such effects,. Temperature is projected to increase by 3·4°C and CO_2 concentration to increase to 1250 p.p.m. by the net 70-75 years, accompanied by much greater variability in climate and more extreme weather-related events. Underlying these trends is much spatial and temporal heterogeneity, with projections of climate change impacts differing among various regions on the globe. Some of this is clear in the outputs from models that take into account geographic criteria such as land mass distribution, topography, ocean currents and water masses, and known meteorological features such as air streams. However, historic data show seasonal and regional variation not accounted for in model processes that have major implications for practical processes such as crop sowing, harvest or pest and pathogen infection and therefore all the activities that derive from these effects. Defining uncertainty is important in all areas of climate change research, not only in assumptions for stochastic or deterministic models, but also in biological processes where knowledge or understanding is lacking. However, uncertainties are perhaps greater when the implications of climate change on food security are considered. Food security can be defined as "when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2003). To realize how best to control plant diseases to improve food security in the framework of climate change, plant protection professionals must work with societal change, defining its key processes and influencers to effect change. Plant pests and diseases could potentially deprive humankind of up to 82% of the realizable yield in the case of cotton and over 50% for other major crops and, pooled with postharvest spoilage and deterioration in quality, these losses become significant, especially for resource-poor regions. Climate change will most likely influence the occurrence, prevalence and severity of plant diseases. This will also affect disease management with regard to timing, preference and efficacy of chemical, physical and biological measures of control and their utilization within integrated pest management (IPM) strategies. Prediction of future requirements in disease management is of great interest for agro-industries, extension services and practical farmers. A comprehensive analysis of potential climate-change effects on disease control is difficult because current knowledge is limited and fragmented.

Climate change is of great concern to India in view of oil and nutritional security of its ever growing population. The impacts of climate change are global, but Indian subcontinent is more vulnerable due to dependence of its increasing population on agriculture. Climate change has direct effect on agriculture due to 0.74°C average global increase in temperature in the last

100 years and atmospheric CO_2 concentration having increased from 280 ppm to 400 ppm over the years. These changes have direct effect on growth and multiplication, spread and severity of many plant pathogens, which in turn are distressing the pattern of incidence of diseases. Changing disease scenario due to climate change has warranted the need for future studies on such models which can predict the severity of important pathogens of these crops in real-field conditions. Simultaneously, disease management strategies may be reoriented to manage with changing situation for sustainable oil production in the country.

Effect of climate change on diseases of rapeseed-mustard crops is multi-dimensional. Magnitude of this impact could vary with the type of species and their growth patterns. It may be assumed that the plants tolerating high temperature, salinity and having high CO_2-use efficiency could be better than other species. It has been predicted that doubling in the level of CO_2 could possibly increase yield in several crops by 30%. The increased production could be off-set partly or entirely by the biotic stresses. It is, therefore, important to consider all the biotic components under the changing pattern of climate. There is also contemplation about shorter winters, which may affect the oil yields of the rapeseed-mustard crops.

Development of diseases is strongly dependent upon the temperature and humidity. Any change in them, depending upon their base value, can significantly alter the situation, which ultimately may result in yield loss. With an increase in concentration of CO_2, the nutritional status of crop will change and the net effect on agricultural production will depend upon interaction between pests and crops. Gradual climate warming will lead to changes in the composition of pathogen fauna in different areas. The high population growth rate of many species will ensure changes in pathogen distribution. If the rise in winter temperature takes place, the duration of hibernation of pathogen may decrease, thus increasing their activity. Uncongenial areas for pathogens due to low temperature at present may become suitable due to rise in temperature. However, we should not forget that pathogens could adapt to slow changes in the environment and with increase in temperature, their favourable range of temperature may also shift.

Climate change and disease scenario

In India, limited efforts have been made in this area for any disease of any crop. However, at the genomic level, advances in technologies for the high-throughput analysis of gene expression have made it possible to begin discriminating responses to different biotic, abiotic stresses and potential trade-offs in responses. Ecologists are now addressing the role of plant disease in ecosystem processes and the challenge of scaling-up from individual infection probabilities to epidemics and broader impacts. The numbers of diseases on the same crops were much higher in tropics than under temperate conditions to indicate how rising temperatures could impact occurrence of plant diseases on agricultural crops. Root rot is an emerging threat for rapeseed-mustard production system, recently reported from the farmers' field in some pockets of the country, which was initially identified as stand-alone bacterial or fungal incidence or in combinations (*Erwinia carotovora* pv. *carotovora, Fusarium, Rhizoctonia solani* and *Sclerotium rolfsii*). In view of the fact that some isolates of *Alternaria brassicae* sporulated at 35°C and several isolates had increased fecundity under higher RH, it seems that as per recent changes towards warmer and humid winters, existence of such isolates could pose more danger to the oilseed Brassicas due to Alternaria blight in times to come. The immense variation available among only thirteen representative isolates of *A. brassicae* also indicates their ability to adapt to varied climatic situations. In Germany, rapeseed-mustard pathogens such as *A. brassicae*, *Sclerotinia sclerotiorum*, etc. are predicted to be favoured by average warmer temperatures.

Due to rise in maximum temperature in post-rainy (*Rabi*) season and shortening of cold period, powdery mildew incidence on oilseeds *Brassica* (*Erysiphe cruciferarum*) has been observed appearing earlier (December) than usual time (late Jan, Feb) quite frequently in non-traditional crop growing areas of Madhya Pradesh, Haryana, central Uttar Pradesh, parts of Rajasthan and Bihar possibly due to shortening of cold spell during the crop period.
Routine monitoring at surface for weather and by remote sensing could help predict epidemic well before first appearance of the disease on the crop, giving a positive edge to make accurate decision related to disease management. It has also been possible to detect Sclerotinia rot-affected mustard using remote-sensing technology. These successful experiences could certainly be effective boosters for any future endeavour. But the potential benefits of short-to-medium range weather forecast from numerical weather prediction (NWP) models or future climate projections have been least harnessed in India for regional crop protection services. On-line decision support systems to forecast different diseases are in use across the globe viz., canola light leaf spot (*Pyrenopeziza brassicae* on http://www.rothamsted.bbsrc.ac.uk/Research/Centres/Content.php?Section=Leafspot&Page=llsforecast) and Phoma stem canker (*Leptosphaeria maculans, L. biglobosa* on http://www.rothamsted.bbsrc.ac.uk/Research/Centres/Content.php?Section=Leafspot&Page=phomaforecast). Models of plant disease have now been developed to incorporate more sophisticated climate predictions.

In view of changing climate, the devised and to-be-born models need to be oriented to dynamic mode. The models already developed are based on some observations on meteorological parameters, pathogen severity levels recorded in the past and hence are based on previous pest-weather correlation. However, with change in climate, the pest-weather relationship is also bound to change apart from behaviour of the hosts, newer varieties, cropping practices, etc. The assumption is that more and better data will make prediction more accurate and/or reliable. Dynamic models incorporate the recorded data of each crop season for a particular pest to suitably revise itself and thus remain stable, relevant enough to continue providing accurate forecast.

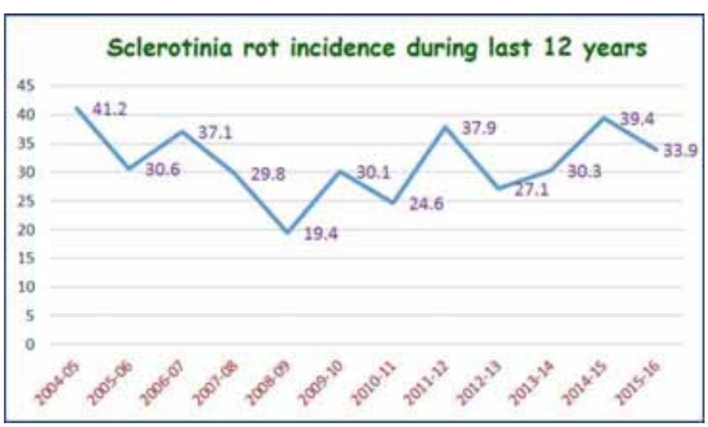
Because of inadequacies in hard-core data, the vital questions still haunt – what are the possible impacts of climate change on diseases and insect-pests of major crops or any shift in pathogen status with change of climate in the agro-ecological region growing rapeseed-mustard in India? We may have seen some changes in scenario of pathogens and ascribed them to changed climatic patterns. However, establishing such correlation through research remains to be done in India. There is no clear indication on injury profile on attainable yield and changes thereof in course of any change in pest scenario and hence we are not sure about the fitness status of any pest vis-á-vis the changed climatic situation apart from the status of our readiness to encounter the same. Monitoring of variability in major pathogens affecting oilseed brassica crops to keep track of upheaval of 'sleeper races' becoming severe under changed climate, modelling future enemies of plants and designing crops with resistance to such would-be menaces as also modifying IDM strategies suitably to enable them be more climate-resilient and pest smart may need emphasis.

Major diseases of oilseed *Brassica*

Rapeseed-mustard crops are challenged by numerous biotic and abiotic stresses. Fungal diseases are the most important barrier in achieving higher productivity per unit area. The exhaustive cultivation of the crop with higher inputs has further compounded the problem and now the incidence of diseases has become more frequent and wide spread. Severe outbreak of diseases declined the quantity, quality of seed and oil content drastically in different rapeseed-mustard crops. Expression of full inherent genetic potential of a genotype is governed by inputs that go in to the production system. This can be very well illustrated with examples that involve disease management of rapeseed-mustard. The losses in oilseed crops due to biotic stresses is about 19.9%, out of which diseases cause severe yield reduction at different growth stages. Different plant pathogens are reported to distress the crop, and among them, 18 are considered to be economically important in different parts of the world. Among various diseases, 5 diseases *viz*; Alternaria blight (*Alternaria brassicae*), white rust (*Albugo candida*) downy mildew (*Hyaloperonospora brassicae*), white rot (*Sclerotinia sclerotiorum*) and powdery mildew (*Erysiphe cruciferarum*) are of great economic importance, whereas among a number of other relatively less important diseases, seedling blights/ damping-off (*Rhizoctonia solani*, *Sclerotium rolfsii* and *Fusarium solani*), phyllody (caused by Sesame phytoplasma), bacterial rot (*Xanthomonas campestris pv campestris)*, club root (*Plasmodiophora brassicae*), mosaic (Turnip Mosaic Virus) and *Orobanche* (a phanerogamic parasite) appear to become important only under specific agro-ecological conditions in certain geographical areas and hence are assumed to be of regional and sporadic importance.

Sclerotinia rot

Sclerotinia sclerotiorum (Lib.) de Bary, the causal organism of stem rot of *Brassica* and over 400 host plants is distributed worldwide. In India, this disease is very serious since 1999 when upto 40% yield losses were reported. Sclerotinia rot is a menace to cultivation of oilseed *Brassica* crops in the world. Infection occurs on leaves, stems and pods at different developmental stages, causing seed yield losses of up to 80%, as well as significant reductions in oil content and quality. The initial mycelial infection at the base of the stem is an appearance of elongated water-soaked lesions that expand rapidly. Ascosporic (carpogenic) infection is quite general and occurs on the leaves or leaf axil. Effective pathogenesis by *S. sclerotiorum* requires the secretion of pathogenicity factors including oxalic acid and extracellular lytic enzymes. Germination of over-wintered sclerotia, and release, survival and germination of ascospores are important factors for the development of disease and in the life cycle of this pathogen. Isolates of *S.sclerotiorum* show a high level of morphological variability and molecular diversity. Management of *S. sclerotiorum* is a major challenge, and the best being the integration of various IPM measures. Partial resistance has been identified in some *Brassica napus* and, *B. juncea*, genotypes, though, wild *Brassicas* show better resistant reactions. The Sclerotinia rot is now wide spread and occuring in more or less sever form in all the brassica growing states of the country. During the last 12 years the mean disease incidence was recorded 31.7%.

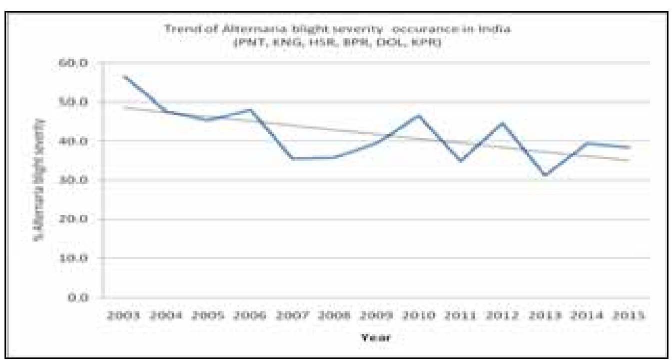


Alternaria blight (*Alternaria brassicae & A. brassicicola*)

Alternaria blight or black spot, the most common, widespread and destructive disease is causes 35% yield losses mainly by *Alternaria brassicae* (Berk.) Sacc. and *A. brassicicola* (Schwein) Wiltshire infecting all above-ground parts of the rapeseed-mustard plant. There are over 4000 *Alternaria* /host associations including a wide range of crops. The disease is generally prevailing severely in states of Himachal Pradesh, Haryana, Rajasthan, Uttar Pradesh, Uttara Khand, Bihar, and Madhya Pradesh but appear in almost all the parts of the rapeseed-mustard growing areas. Usually, disease becomes visible at 40 - 45 days after sowing and most critical stages for initiation and peak of severity has been reported 45 and 75 days of plant growth.

Several sources of tolerance against Alternaria blight have been reported. A short stature *B. juncea* cultivar Divya is reported to be tolerant to Alternaria blight. Among the different species of oilseed *Brassica*, *B. juncea* and *B. rapa* are more susceptible than *B. carinata* and *B. napus*. Only PAB 9511 (IC 546946) of Indian mustard is the registered donor for Alternaria blight in India. While, other lines also found tolerant to the disease in *B. juncea* included RC 781, PHR-2, PAB-9534, JMM-915, EC-399296, EC-399301 and RN-490, those in *B. carinata* are HC-1 and Kiran (PBC 9221) and of *B. napus* happen to be PBN-9501, PBN-9502, PBN-2001 and PBN-2002.

Severity of Alternaria blight on leaves and pods were higher in later sown crops. A delayed sowing results in coincidence of the vulnerable growth stage of plants as indicated earlier with warm (maximum temperature: 18-26^{o}C; minimum temperature: 8-12^{o}C) and humid (mean RH >70%) weather. Severity of Alternaria blight disease on leaf was favoured by a maximum temperature of 18-27^{o}C in the preceding week, minimum temperature of 8-12^{o}C, mean temperature >10^{o}C, >92% morning relative humidity (RH), >40% afternoon RH and mean RH of >70%. Disease severity on pods was positively influenced by 20-30^{o}C maximum temperature, >14^{o}C mean temperature, >90% morning RH, >70% mean RH, >9 h sunshine and >10 h of leaf wetness. The regional and crop specific models devised thereby could predict the crop age at which Alternaria blight first appears on the leaf, pod, the peak blight severity on leaf, pod and the crop age at peak blight severity on leaf, pod at least one week ahead of first appearance of the disease on the crop, thus allowing growers to take necessary action.



In both the year, 2002-03 and 2003-04, the *A. brassicae* spores started getting trapped on 23 Oct and in 2002-03 remained in the atmosphere till early April or the time when the crop got harvested from fields surrounding the trap and the daily mean temperatures rose beyond 35^{o}C. During October-April, there was no major variation in daily total count of trapped spores noted after it reached a level following appearance on trap. However, a uniform diurnal variation in spore trap count was noted throughout the crop period. The spore count on the trap was noted to rise gradually in the initial (0-6) hours of the day, which reached its peak between 2 PM-3 PM before climbing down. This seemed to vary directly with the diurnal variation of temperatures and inversely with that of RH. This could be due to the production of spores during the night, which remained adhered to plant surfaces or spore producing lesions due to high RH or leaf wetness then. With rise in temperature and fall in RH (reduction of leaf wetness), the spores become free from the spore producing surfaces and are found to get trapped from the atmosphere. Sporulation of *A. brassicae* has been reported to be favoured by darkness.

White rust (*Albugo candida*)

White rust caused by *Albugo candida* (Pers. Ex Fr.) Kuntz. is an obligate pathogen of all cruciferous crops. Plants of 241 species in 63 genera of cruciferae family have been reported to be infected by *A. candida* all over the world. Disease appearing on leaves is characterized by the appearance of white or creamy yellow raised pustules up to 2 mm in diameter, which later coalesce to form patches. The part of upper surface corresponding to the lower surface is tan-yellow, which enable recognition of the affected leaves (Saharan *et al*., 2014). Swelling and distortion of the stem and floral parts results in 'stag head.' In humid weather, mixed infection of white rust and downy mildew can develop on stag head structures. Each, per cent of disease severity and staghead formation causing reduction in seed yield of about 82 kg/ ha and 22 kg/ ha respectively. Resistant for white rust (*Albugo candida*) has been developed with few varieties like JM-1, Basanti with some good source BIOYSR and NRCDR 515 etc. Severity of white rust disease on leaves was favoured by >40% afternoon (minimum) relative humidity (RH), >97% morning (maximum) RH and 16–24^{o}C maximum daily temperature. Staghead formation was significantly and positively influenced by 20–29^{0}C maximum daily temperature and further aided by >12^{o}C minimum daily temperature and >97% morning (maximum) RH.

Emerging diseases in rapeseed-mustard

A new disease stem blight, caused by *Nigrospora oryzae* (Berk. & Broome) Petch, first time reported from rapeseed-mustard growing regions of India during 2012. This minor problem may become serious problem as the disease severity of more than 70% has been recorded in some of the mustard fields. Initially, small (2–7 mm), circular to irregular, dark grey to black lesions with a slight bluish cast are formed on stem. Soon it become discolored as numerous separate, irregular blotches are formed. In the advanced stages of disease, lesions reached a length upto 120 cm on stems and spread onto the petioles and midribs also. The pathogen survives on diseased plant debris in soil. Bacterial stalk rot, caused by *Erwinia carotovora* pv. c*arotovora* (Jones) Bergy, has recently become a threat to successful cultivation in some parts of Haryana, Uttar Pradesh and Rajasthan states. The incidence of disease has been reported up to 60-80% at farmer's field.

Novel Plant Protection Approaches

Changing pattern of disease scenario due to climate change has warranted the need for improved novel practices and use of eco-friendly approach for sustainable crop production. Due to change in climate, there is shift in seasons, cropping pattern, insect-pest and disease scenario, etc. Therefore, the choice of crop management practices based on the real time situation is very important. In such scenarios, weather-based disease monitoring, inoculums/population monitoring, and rapid diagnostics/systematic would play a significant role. There is need to adopt novel approaches to counter the resurgence of diseases under changed climatic scenario. Educating farmers towards maintaining records on farming practices undertaken date-wise may enable experts to guide on decision making as per need of the hour. Integrated disease management strategies would undoubtedly be the only solution to cope with complex disease scenario. It covers multiple approaches including the use of healthy disease free seeds with innate forms of broad and durable disease resistance, and various types of cropping systems that promote the conservation of natural/native bio-control agents. In addition, monitoring and early warning systems for forecasting disease epidemics should be developed for important host–pathogens, which have a direct link on the crop production, income generation of the farmers and food security. Use of botanical pesticides and plant-derived soil amendments such as neem oil, neem cake and karanja seed extract also help in mitigation of climate change because it helps in the reduction of nitrous oxide emission by nitrification inhibitors such as nitrapyrin and dicyandiamide.

Management strategies

In this context, a system approach needs to be considered for a better crop health management. Through adaptive researches at respective AICRP-RM centre's and in frontline demonstrations, component-wise and in-whole package, the following measures may be combined for designing location-specific packages depending upon demand of the area.

- Sowing time is important as it affect the disease incidence/intensity significantly.
- Deep summer ploughing.
- Application of recommended balanced doses of N, P and K fertilizers with split application of nitrogen,
- Disease resistant/tolerant or early maturing disease escaping varieties.
- Quality seeds of varieties.
- Seed treatment with biocontrol agents *viz.*, *Trichoderma viride* or botanicals like *Allium sativum* bulb extract (1% w/v) or carbendazim @ 0.1% or mixture of carbendazim with metalaxyl (Apron 35 SD @6 g/ kg)
- Optimum plant population with recommended spacing.
- Clean cultivation, elimination of weeds and stubbles. Rouge out diseased plant to avoid secondary spread of disease.
- Identify the right crop for rotation and also for non-crop season as sequence crop in order to discourage the pathogen build-up. Choose a suitable intercrop as per the pathogen to be countered.
- Avoid over irrigation, preferably only two, depending on the stage of crop growth, soil type and rainfall availability.
- Prophylactic spraying of botanical/ bioagent/ fungicide/ antibiotic when conditions become favourable for disease occurrence. Timing the application of such prophylactic sprays should be based on data bank, expert systems and epidemiological research findings. Disease forewarning/ forecasting model ensures a cost-effective management of rapeseed-mustard crops. There is need to ensure that the pesticidal sprays are to be avoided or minimized during peak activity period of the biocontrol agents.

To make disease management successful, ecofriendly and economical there is a need for integration of seed treatment with recommended chemicals, with available biocontrol agent(s) having well tested delivery systems followed by recommended foliar sprays with chemicals for each disease.

Conclusion

Though the effect of climate change is very vast, only limited research on impact of climate change on plant diseases has been done under real field conditions. Most of the recent plant protection technologies have been developed either in the laboratory or artificial condition. However, some assessments are now being done in few countries, regions, crops and particular pathogens under field condition to counter the current as well as upcoming problems of crop diseases. Now, emphasis must shift from impact assessment to developing adaptation and mitigation strategies and options. We have to systematically evaluate the efficacy of current physical, chemical and biological control tactics, including disease-resistant cultivars under climate change, and to include future climate scenarios in all research aimed at developing new tools and tactics. Disease risk analyses based on host–pathogen interactions should be done, and research on host response and adaptation should be conducted to understand how an imminent change in the climate could affect plant diseases. India is fortunate enough to have such a diverse climate suitable to grow various types of crop plants with diverse pest population, which can help to counter the pest/disease problems in the changed climate scenario.

Today's challenge is to "more produce from less input". In the era of climate change, diagnostics of diseases and capacity building of farmers, extension and even research personnel for adaptation to changed disease scenario under future climates assumes significance, wherein Integrated Crop management in Private Public Partnership mode could be very effective. Farmers' decisions are of vital importance for good yields of crops. Forecasted weather products and area-wide weather networks are becoming more prevalent. Now, the challenge is to bring continuous improvement in productivity, profitability, stability and sustainability of major farming systems, wherein scientific management of plant pests holds a pivotal role. Crop loss models, representing a dynamic interaction between pathogens and host, are essential for forecasting losses thereof. Accurate information concerning possible yield losses due to occurrence of a disease is needed by growers or plant protection specialists to decide on cost-effective control measures. With an increasing concern for cleaner environment and discouragement for pesticide use, there is need to approach pest management through knowledge on their dynamics as an art of living with them. Thus, future research and education in Plant Pathology in India does need to address the issue of future climates in disease management, for which fund requirement would certainly be lesser than many ambitious ones.

Screening techniques for plant resistance to insects under changing climatic scenario: Special emphasis on mustard aphid

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Host plant resistance is one of the most important, effective, economic, environmentally safe, and more over highly compatible component of pest management with other control measures. Therefore, it should be included as one of the essential and basic component of integrated pest management in order to increase production and productivity of crops. The insect resistant varieties have been deployed as principal method of insect control in many crops in several parts of the world. Since last two decades, the quest to break yield plateau for sustainable increase in crop productivity of field crops through use of hybrid technology has diluted the emphasis on development of insect-resistant cultivars. Moreover, the levels of insect resistance in most of the recently released varieties/hybrids are inadequate, and therefore recent years have observed a paradigm shift in advocacy and deployment of techniques to diversify the bases of resistance through gene pyramiding from cultivated germplasm, closely related wild relatives of crops, and transfer of insect resistance genes in parental lines for developing insect-resistant hybrids. There has been slow progress in screening and breeding for resistance developing, mainly due to variations in insect populations in space and time, influence of environmental factors on behavior and biology of insects, and plant growth and biochemical composition of host plants. Thus, it is important to develop techniques to screen for resistance to insect pests under optimum levels of infestation and under similar environmental conditions. Therefore, there is a need to develop/refine techniques to screen for resistance to insect pests, and develop standardized procedures for assessing insect populations and damage (Fig. 1). The following techniques/protocols may be followed for evaluation of the test material for resistance to insects:

A. Screening techniques for plant resistance to insects under natural infestation conditions

Rarely a researcher is able to grow and evaluate insect damage accurately under natural infestation due to certain reasons, such as either there are insufficient insect numbers to cause adequate damage or insects occur at an inappropriate phenological stage of crop growth. Field infestations are normally used to evaluate a large number of genotypes at an early stage of resistance-breeding program. Major advantages of screening under natural infestation are the convenience and low cost. However, seasonality, unpredictability, interference by non-target insects, and uneven distribution makes screening under natural conditions to be unreliable, time consuming, and less effective. Moreover, screening for resistance to insects under natural conditions is a long-term process because of the variations in insect populations across seasons and locations. In addition, there are large differences in the flowering times of different genotypes. Genotypes flowering at the beginning and the end of the season are exposed to low insect infestation, while those flowering during the mid-season suffer heavy damage. As a result, it is difficult to identify reliable and stable sources of resistance under natural infestation.

Therefore to mitigate such problems, it is highly desirable to follow certain need based options such as use of hot spot locations, adjust planting dates, planting of infester rows, grouping of material according to height and maturity, sequential planting, augmentation of insect populations, etc. to have reliable information on genotypes with resistance to target insect pests.

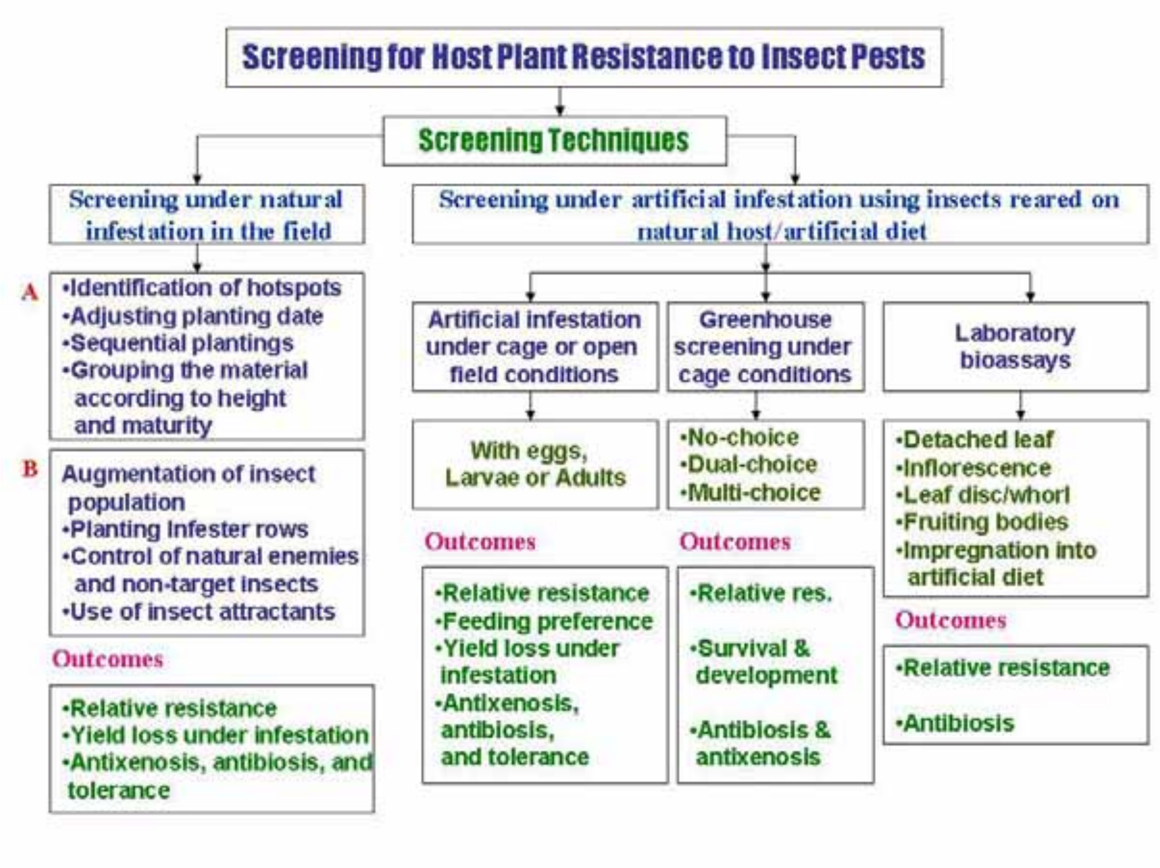

Fig. 1. Schematic diagram to screen host plants for resistance to insect pests.

Use of hot-spot locations

Hot-spots are the locations where the insects are known to occur regularly in optimum numbers across seasons. Hot-spot locations can be used for large-scale screening of the germplasm, segregating breeding material, and multi-location testing of the test genotypes. Several insect species are known to occur in high numbers every year at several locations. As far as possible, efforts should be made to select locations where appropriate attention can be paid for managing the trials and evaluation of the test material for resistance at the appropriate stage.

Adjusting planting date

The test material should be planted such that the most susceptible stage of the crop is exposed to maximum or optimum levels of insect infestation. Fortnightly or monthly plantings of a susceptible cultivar during the cropping season can also be used to determine the optimum time for planting the test material. Most of the crops planted 20 to 25 days later than the normal planting times are exposed to heavy insect damage. Similar planting times should be determined for different insect pests and their crop hosts in each region to maximize the chances for obtaining adequate levels of insect infestation for resistance screening.

Planting infester rows

Planting susceptible cultivars as infester rows along the field borders or at regular intervals in the field can be used to increase insect infestation in the test material. The infester rows may be planted 20 to 25 days earlier or an early flowering crop or cultivar can be used as infester rows so that the flowering in the infester rows occurs earlier so that the test material in case of insects feeding on the reproductive parts. There should be sufficient time for the insect to multiply on the infester rows, and then move to the test material. Insects collected from nearby fields can also be released in the infester rows. Insects can also be attracted to the infester rows by kairomones. The infester rows should be removed after infestation of the test material has taken place so that it does not compete with the test material. Trap crops that are attractive to the target insect species can also be used to increase insect infestation in the test material. When the main crops reach the susceptible stage, the trap crops are either allowed to senesce or chopped off so that the insects migrate to the test material.

Grouping the material according to maturity and height

To screen for resistance to insect species that feed on reproductive structures, it is important to group the test material according to maturity and height as there are large differences in the flowering times of different genotypes within a crop. Because of fluctuations in insect populations over the crop-growing season, it becomes difficult to obtain uniform insect pressure on genotypes flowering at different times. Genotypes flowering at the beginning and end of the cropping season escape insect damage, while those flowering in the mid-season are exposed to heavy insect damage. As a result, it becomes difficult to make meaningful comparisons between the resistant and susceptible genotypes. To overcome this problem, it is important to group the test material according to maturity and height. It is equally important to include resistant and susceptible checks of appropriate maturity in different trials for proper comparison.

Sequential plantings

Even with the best of insect forecasting models, it is not possible to pinpoint the periods of maximum abundance of an insect under field conditions. At the same time, it is not possible to take up timely planting of the test material because of certain valid reasons. As a result, it becomes difficult to stager susceptible stage of the crop with maximum insect abundance due to changes in weather conditions, and effect of environment on both insect and crop. Therefore, the test material should be planted 2 to 3 times at an interval of 15 to 20 days so that one of the plantings is exposed to adequate/optimum insect pressure. Such an approach also helps to reduce the chances of escape from insect damage as the late-flowering genotypes in the first planting and the early-flowering genotypes in the second planting are most likely to flower during the mid-season, and are exposed to maximum insect abundance.

Augmentation of insect populations

Insect infestation in the screening nursery can be increased by collecting indigenous insect populations from the surrounding areas and released in the test plots. Insect abundance in the screening nursery can also be augmented by placing non-destructive traps in the field.

B. Screening techniques for plant resistance to insects under artificial infestation

Mass rearing of target insects

Insects can be reared in large numbers on natural or artificial diets in the laboratory or collected from the field to screen the test material in the field or in the greenhouse under uniform insect infestation. Many insect species can be reared on the natural diets, and many species of aphids can be reared in the greenhouse on their natural host plants. Protocols for mass production of insects on artificial diets for infestation of the test material under greenhouse or field conditions have also been described for several insect species. Insect rearing should be planned such that the appropriate stage of the test insect is available in adequate numbers for infesting the test material during the susceptible stage of the crop. One of the major constraints to large-scale production of insects on artificial diets is the high cost of infrastructure, particularly when special equipment and facilities with appropriate control over temperature, relative humidity, and photoperiod are required. Continuous production of insects on artificial diet also decreases their genetic diversity, which might lead to outcomes dissimilar to that of the natural populations. This problem can be overcome by infusing insects from the field periodically or fresh culture can be initiated at the beginning of each season. This will also avoid the build up of pathogen infections such as bacteria, fungi, protozoa, and viruses in the insect colony.

Infestation techniques

Standardization of techniques to infest the material at the susceptible stage with uniform insect density is essential for successful evaluation of the test material under greenhouse or field conditions. Several techniques have been used for infestation and evaluation of the test material in the field. While devising techniques to infest the test material, it is important to take into consideration the:

- Stage of the insect and application procedure.
- Number of insects required and time of infestation.
- Number of infestations.
- Susceptible stage of the crop and the site of infestation.

Efforts should be made to obtain uniform infestation at the most susceptible stage of the crop in a manner closer to natural infestations. The amount of food available to the insects and the insect density also influence the expression of resistance to insects, and therefore, efforts should be made to use optimum and uniform infestation to result in maximum differences between the resistant and susceptible genotypes. The following protocols/techniques may be followed for evaluation of the test material for resistance to insects:

Caging the plants with insects

Caging the test plants with insects in the greenhouse or in the field is another dependable method of screening for insect resistance. In this method, considerable control is exercised on maintaining a uniform insect pressure on the test entries, and plants are infested at the same phenological stage. This protects the insects from the natural enemies and also prevents the insects from migrating away from the test plants. Cages can be designed to cover the whole/part of plants that are damaged by the insects. Cage size and shape are determined by the type and number of test plants needed for evaluation. For valid comparisons, resistant and susceptible checks of appropriate maturity should also be included and infested at the same time as the test genotypes.

Greenhouse screening

Screening for resistance to some insects can be carried out at the seedling stage in the greenhouse under no-choice, dual-choice, or multi-choice conditions, and has been utilized successfully in several crops. The test material can also be infested with insects under multi-choice, dual-choice, or no-choice conditions using cages of appropriate size. The test material can also be infested with insects at the susceptible stage without a cage. This approach is more appropriate to evaluate seedlings or small sized plants, etc.

Bioassay with excised plant parts

Artificial infestation in the field and in the greenhouse requires a large number of insects, and there is no control over the environmental conditions. Differences in flowering times of the test material add another variable to the screening process. Cage screening in the field and in the greenhouse at times may be cumbersome as a number of large sized cages may be required to complete the screening process. To overcome some of these problems and to screen large numbers of lines rapidly, excised plant parts can be used successfully to evaluate the test material for resistance to insects. Excised plant part assays have been successfully used in several crops for many insect species. However, excision of plant parts at times lead to a change in physico-chemical properties of the plants, and the magnitude of resistance can either decrease or increase, depending on the nature of insect plant interactions.

Diet impregnation assay to assess antibiosis

Antibiosis to insects in general is mainly because of poor nutritional quality or secondary plant substances. Antibiosis effects of secondary metabolites can be measured in terms of survival and development of insects on host plant tissues incorporated into inert materials or artificial diet. To assess the antibiosis component of resistance through diet impregnation assay, the test material can be grown in the greenhouse or field conditions. No insecticide should be applied on the test material, but care should be taken that there is no heavy incidence of any disease or non-target insect species.

C. Techniques to screen rapeseed-mustard against aphid, *Lipaphis erysimi* Kalt.

Since this is especially with reference to screening and breeding for resistance to aphids in rapeseed-mustard, following techniques can be suitably used to evaluate test genotypes for resistance to mustard aphid, *L. erysimi*:

- Use of hot-spot locations
- Adjusting planting date
- Sequential plantings
- Grouping the test material according to maturity and height
- Caging the plants with insects

The population and damage by aphid, *L. erysimi* in rapeseed-mustard varies across seasons and regions, and is difficult to identify genotypes with resistance/tolerance to this pest under natural conditions. Therefore, it was highly desirable to develop/standardize a dependable technique to evaluate rapeseed-mustard for resistance to aphids under field conditions. Thus, we standardized artificial screening technique for aphid resistance in rapeseed-mustard under field conditions:

Artificial screening technique to evaluate rapeseed-mustard for resistance to mustard aphid, *Lipaphis erysimi*

We standardized artificial screening technique for aphid, *L. erysimi* resistance in rapeseed-mustard under field conditions. We used six diverse genotypes for each infestation technique as test materials in randomized complete block design, and there were three replications. The test genotypes were sown in four rows of 5 meter row length each. Three different screening techniques viz., twig cage, plant cage and plot cage were designed along with natural infestation control. The twig and plant cages were designed using wire rings (6 inches dia. × 24 inches ht. for twig cage; 18 inches dia. × 36 inches ht for plant cage covered with muslin cloth), while plot cage with iron pipes (20 ft. long and 6 ft. height) covered with mosquito net. Ten randomly selected plants from each test genotype from middle two rows were infested with 20 aphids (nymphs and adults) at flowering initiation. The observations were recorded on aphid damage score (1-5), aphid population score (1-5), aphid resistance index (1-5), and aphid multiplication rate (X times) after 21 days of inoculation. Among the three screening techniques, twig cage technique showed significant and consistent variability in aphid damage score, aphid population score, aphid resistance index and aphid population multiplication rate among the test rapeseed mustard genotypes, was found most reliable, economic, and easy to manage for screening of rapeseed and mustard genotypes under artificial infestation conditions in the field.

Protection of Plant Varieties and Farmers' Rights Act and the status of Registration of Rapeseed Mustard Varieties

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Introduction

The history with respect to protecting Intellectual Property (IP) in Plant Varieties in the globe traces back to eighteenth century, where various attempts were made by different countries in Europe to extend the intellectual property protection (IPP) in agricultural innovations. However the first attempt to recognize the intellectual property right (IPR) of plant breeder was the enactment of the Plant Patent Act in USA during 1930. Such legislation was subsequently enacted in Germany, Hungary, Italy, Netherlands, Austria *etc.* in 1930s which led to private monopolization of plants and business.

In 1961, five European countries initiated *sui generis* IPR protection to plant varieties and formed the International Union for the Protection of New Varieties of Plants [Union International Pour la Protection des obtentions Vegetables International (UPOV)] and entered into force in 1968. The Convention aimed to ensure protection of plant breeder's rights (PBR) by the grant of an exclusive right in the protected new plant variety on the basis of a set of uniform and clearly defined principles: distinctiveness, uniformity, stability (DUS) and novelty. The UPOV convention was revised in 1972, 1978, 1991 and 1998. At present, there are 71 members and other countries are either its observers or in the process of becoming its members.

This development in developed countries was followed by a concern for farmers' rights, in particular by the developing world, under the auspices of Food and Agriculture Organization (FAO). As a result the Convention on Biological Diversity (CBD) came in force on 29th December, 1993. This is perhaps the most comprehensive inter-governmental agreement concerning conservation, sustainable utilization of plant genetic resources (PGR) and sharing benefits arising out of such use in equitable way. Article 8 (j) of CBD recognizes contributions of local and indigenous communities to the conservation and sustainable utilization of biological resources through traditional knowledge, practices and innovation and provides for equitable sharing of benefits with such people arising from the utilization of their knowledge, practices and innovations. Further in harmony with CBD to promote the conservation of PGR and to protect the farmers' rights to access and have fair and equitable sharing of benefits arising out of their sustainable use to achieve food and nutritional security, an International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), a legally binding instrument, was adopted in 2001. At the same time, it highlights the necessity of promoting farmers' rights at National and International levels, established multi-lateral system (MLS) for facilitated access to a specified list of PGRFA including 35 crop genera and 29 forage species for food security and inter-dependence, balanced by benefit-sharing in the areas of information exchange, technology transfer, capacity building and commercial development. Nagoya Protocol, came into existence on 29 October 2010, is a new International Agreement, which aims at sharing the benefit arising from the utilization of genetic resources in a fair and equitable way, thereby contributing to the conservation and sustainable use of biodiversity. It advances the CBDs third objective and creates greater legal certainty and transparency for both provider and user of genetic resources. The communities will benefit from the use of their knowledge, innovations and practices.

Another important international agreement in Trade Related Aspects of Intellectual Property Rights (TRIPS) under World Trade Organization (WTO) was ratified by the Convention Countries in 1994. As the agreement on TRIPS requires WTO members to introduce an effective system for the protection of plant varieties, this commitment by WTO member countries implies that the countries which hitherto had not extended IPR to their agricultural sector would have to do so.

Notwithstanding the fact that the UPOV system is the first system of Plant variety protection (PVP), India evolved its own *sui generis* legislation for protection of plant varieties, the rights of farmers and plant breeders and to encourage the development of new varieties of plants the "Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001. The PPV&FR rules were notified in September 2003 and the Act came into force from November 2005. This legislation provides a more comprehensive framework for the PVP containing several deviations from the UPOV model. This is the only Intellectual Property (IP) law in India that gives dual proprietorship of IP on variety and its denomination. Another special feature of this legislation is that the protection accrues to a person from the date of filing of application for it gives priority and provisional protection.

The PPV&FR Act, 2001 is unique to befit the national situations yet matching with the larger global commitment. It attempts to optimize and balance claims for protection by both plant breeders and the farmers and is first of its own kind in the world. India is the first country to provide substantial rights to farmers and the registration of their varieties is one of them. The PPV&FR Act recognizes the multiple roles played by farmers in cultivating, conserving, developing and selecting varieties. With regard to developing or selecting varieties, the Act refers to the value added by farmers to wild species or traditional varieties/ landraces through selection and identification for their economic traits. Accordingly, farmers' rights encompass the roles of farmers as users, conservers and breeders. A farmer is entitled to save, use, sow, re-sow, exchange, share or sell his farm produce including seed of a protected variety in the same manner as he was entitled before operation of the PPV&FR Act, provided that he shall not be entitled to sell branded seed of a protected variety.

Objectives of the Act

- To establish effective system of plant varieties, rights of farmers and plant breeders and to encourage increased breeding activity and encouragement of new types of breeders such a private breeders, researchers and farmer breeders
- To accelerate agricultural development in the country, protect plant breeders rights, stimulate investment for research and development both in public and private sector for the development of new plant varieties to facilitate the growth of seed industry which will ensure the availability of high quality seeds and planting material to farmers
- To recognize and protect the rights of farmers in respect of contribution made at any time in conserving, improving and making available plant genetic resources for development of new plant varieties

Various Rights under the Act

(i.) Breeder's Rights

The Act, provides an exclusive right on the breeder or his successor, or his agent or licensee, to produce, sell, market, distribute, import or export the variety registered under the Act. A breeder may authorize any person to produce, sell, market or otherwise deal with the variety registered under this Act.

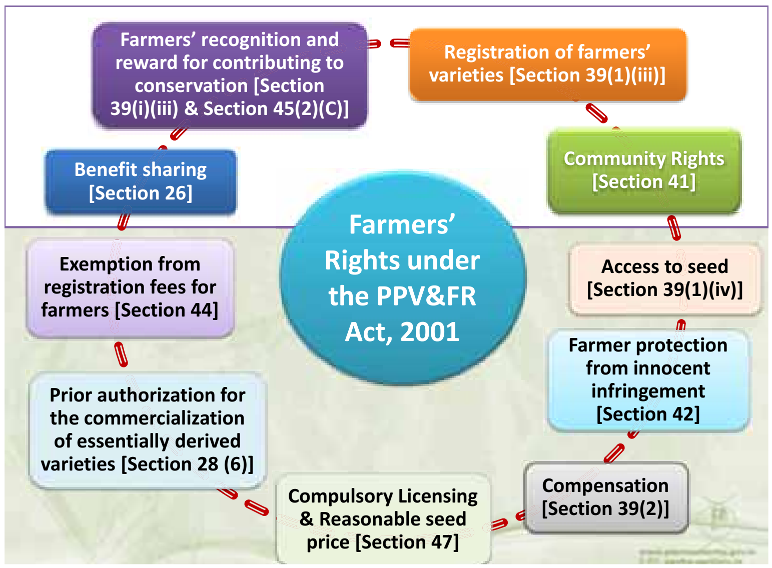
(ii.) Researcher's Rights

A researcher can use any of the variety registered under this Act for conducting experiment or research. However, authorization of the breeder of a registered variety is required where repeated use of such variety as parental line is done for commercial production of other newly developed variety.

(iii.) Farmers' Rights

The Act treats the farmer also as plant breeder so far as the farmers' variety is concerned and they can register them under the Act. The other provisions related to farmers' rights are presented in Fig.1. Farmers are entitled for recognition and reward from the Gene Fund provided that the material so selected and preserved (land races and wild relatives) has been used as donors of genes in varieties registrable under the Act.

Fig.1: Provisions related to the Farmers' Rights



(iv.) Community Rights:

If any village or local community has made a significant contribution in the evolution of any variety and if such variety is registered by any other person then the said village or local community can claim compensation.

Other Provisions

Compulsory license: Compulsory license is granted by the Authority to a competent person when a registered variety falls short of public demand after three year of its registration.

Benefit Sharing: When genetic material of any person or group of persons who are citizen of India and any firm or governmental or non-governmental organization formed or established in India is used in the development of a registered variety such community can claim benefit sharing from the registered breeder.

Registration of plant variety

A variety is eligible for registration under the Act if it essentially fulfills the criteria of Distinctiveness, Uniformity and Stability (DUS) which means that the candidate variety must be distinguishable by at least one essential characteristics from a variety which is a matter of common knowledge in any country at the time of filing application, sufficiently uniform in expression of its essential characteristics which should remain unchanged even after repeated propagation. The variety should also have a single and distinct denomination.

The Authority has established 78 DUS test centres for different crop species which are responsible to conduct DUS test of varieties applied for registration and to maintain, multiply and characterize reference/example varieties as per DUS descriptors. In case of new variety, DUS Test is carried out for two years at two locations and for Extant variety, DUS testing is for one year only. When the DUS Test result is found to be satisfactory, certificate of registration is issued to the applicant and its details are published in the Plant Variety Journal of India.

Notification of crop species for registration of plant varieties

The Central Government has notified 114 crop species for the purpose of registration (Table 1). For these crop species PPV&FR Authority has developed “Guidelines for the Conduct of Species Specific Distinctiveness, Uniformity and Stability (DUS)” tests or “Specific Guidelines” for individual crop species. The purpose of these specific guidelines is to provide detailed practical guidance for the harmonized examination of DUS and in particular to identify appropriate characteristics for the examination of DUS and production of harmonized variety descriptions.

Table 1: Crop species notified for registration.

Group	No.	Crop Species
Cereals	11	Bread wheat, Rice, Pearl millet, Sorghum, Maize, Durum wheat, Dicoccum wheat, Other Triticum species, Barley, finger millet, foxtail millet
Legumes	7	Chickpea, Mungbean, Urdbean, Field pea, Rajmash, Lentil, Pigeon pea
Fibre Crops	6	Diploid cotton (two species), Tetraploid cotton (two species), Jute (two species)
Oilseeds	11	Indian mustard, Karan rai, Rapeseed, Gobhi sarson, Groundnut, Soybean, Sunflower, Safflower, Castor, Sesame and Linseed
Sugar Crops	1	Sugarcane
Vegetables	17	Tomato, Brinjal, Okra, Cauliflower, Cabbage, Potato, Onion, Garlic, Ginger, Bottle gourd, Bitter gourd, Pumpkin, Cucumber, Paprika, Chili, Bell Pepper, Vegetable Amaranth, Ridge gourd, Spinach beet
Flowers & Ornamentals	17	Rose, Chrysanthemum, Bamboo Leaf Orchid, Spray Orchid, Vanda or Blue Orchid, Orchids (Cattleya, Phalaenopsis), Bougainvillea, Orchid (Oncidium), Canna, Gladiolus, Jasmine, Tuberose, China Aster, Carnation, Orchid (Paphiopedilum), Mogra
Spices	6	Black pepper, Small cardamom, Coriander, Fenugreek, Turmeric,

		Jaiphal
Fruits	23	Mango, Almond, Walnut, Cherry, Apricot, Apple, Pear, Pomegranate, Grape, Ber, Acid lime, Mandarin, Sweet orange, Banana, Muskmelon, Watermelon, Papaya, Peach, Japanese Plum, Strawberry, Beal, Jamun, Sitaphal
Medicinal and Aromatic plants	7	Isabgol, Menthol mint, Damask Rose, Periwinkle, Brahmi, Noni, Kalmegh
Plantation crop	8	Coconut, Eucalyptus (two species), Casuarinas (two species), Tea (three species)

Categories of varieties eligible for registration under the Act

New Varieties

A new variety shall be registered for breeder's right if it conforms to the criteria of Novelty, Distinctiveness, Uniformity and Stability. The variety should also have a denomination in accordance with the provisions of PPV&FR Act, 2001. Novelty criteria is, if, at the date of filing of the application for registration for protection, the propagating or harvested material of such variety has not been sold or otherwise disposed of by or with the consent of its breeder or his successor for the purposes of exploitation of such variety in India, earlier than one year; or outside India, in the case of trees or vines earlier than six years, or in any other case, earlier than four years.

Extant Variety

Extant Variety is defined as a variety available in India which is notified under Section 5 of the Seeds Act, 1966 (54 of 1966); or Farmers' Variety; or a Variety about which there is Common Knowledge; or any other variety which is in public domain;

Farmers' Variety

"Farmers' variety" is defined as a variety which has been traditionally cultivated and evolved by the farmers in their fields; or is a wild relative or land race or a variety about which the farmers possess the common knowledge.

As per the Act, "farmers" means any person who cultivates crops by cultivating the land himself; or cultivates crops by directly supervising the cultivation of land through any other person; or conserves and preserves, severally or jointly, with any other person any wild species or traditional varieties or adds value to such wild species or traditional varieties through selection and identification of their useful properties.

Variety of Common Knowledge

Variety of Common Knowledge (VCK) refers to a variety which has not been released and notified under the Seeds Act, 1966, have been sold or otherwise disposed of in India for more than a year from the date of filing the application. The variety which is under cultivation in a State/region/country, even as "truthfully labeled" variety, finds a entry in official list/register of varieties in any country granting Plant Variety Protection (PVP), including filing of an application for PBR, Inclusion in a recognized publicly accessible collection, including an accession in a National/International Gene Bank and adequate description of the variety in a publication that may be considered a part of the public technical knowledge may find their eligibility under the VCKs.

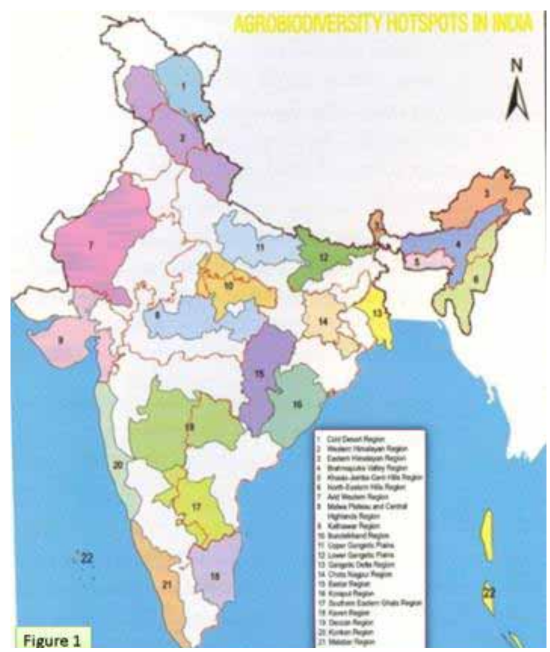
Essentially Derived Variety

A variety (the initial variety), shall be said to be Essentially Derived Variety (EDV) from such initial variety when it is predominantly derived from such initial variety, or from a variety that itself is predominantly derived from such initial variety, while retaining the expression of the essential characteristics that results from the genotype or combination of genotypes of such initial variety; is clearly distinguishable from such initial variety; and conforms (except for the differences which result from the act of derivation) to such initial variety in the expression of the essential characteristics that result from the genotype or combination of genotype of such initial variety.

National Gene Fund for promoting PGR activities

On the basis of richness of agro-biodiversity i.e. number of crop species, crop varieties, wild relatives of various crop species cultivated, social relevance and ancientness of the agriculture, wild relatives of crop species occurring in the region, number of species domesticated and the uniqueness of the agro-ecosystems, the Authority has identified 22 agro-biodiversity hotspot regions in India. (***Fig. 2***).

Fig.2: Agro-biodiversity hotspots regions of India



Farmers' who have been engaged in conservation and preservation of plant genetic resources (PGR) of land races and wild relatives of economic Plants and their improvement through selection and preservation in these identified 22 agro-biodiversity hotspots, receive recognition and rewards from the National Gene Fund. This provision, when taken in conjunction with the provisions relating to the farmers' privilege, is similar to the concept of Farmers' Rights contained in the International Treaty on Plant Genetic Resource for Food and Agriculture (ITPGRFA).

The National Gene Fund receives contributions from central government, national and international organizations and other sources [section-45 (1-d)]. The gene fund also receives funds from benefit sharing [section-45 (a)] from the breeder of the variety or an essentially derived variety registered under the Act or propagating material, the compensations deposited [section-41 (4)] and the annual fee payable to the Authority by way of royalty [section-35 (d)]. The expenditures of the fund are earmarked to support the conservation and sustainable use of PGR including *in-situ* and *ex-situ* collections. Thus, in this way it can be considered to be a national equivalent to the global benefit-sharing fund operating within the ITPGRFA.

Supporting Plant Genome Saviour Awardee Communities, PGR conservation, protection and promotion for sustainable use is being practised by farmers and their families since ancient time. This has allowed them to cultivate a large number of different local varieties in different crop species of economic importance. This is how India has been regarded as one of the 12 mega bio diversity centres in the world. To support the activities of PGR, the Authority has selected the Genome Saviour Awardee Communities to support their efforts of saving local varieties and land races. As climate change has a significant impact on agricultural production, growing local varieties which have a high degree of genetic diversity is highly important because these varieties have the ability to better withstand and adapt to environmental stresses and change setting up community seed banks may help farmers to acquire varieties that are adapted to local conditions; these varieties may not be accessible through formal seed systems, may be costly or may suffer from erratic supplies. To make available the quality seeds of popular local varieties through informal seed chain, the Authority is promoting "Community Seed Bank Concept" at different Agro climatic bio diversity hotspots where improved varieties have not made impact on production and productivity. Authority has identified regions in agro biodiversity hotspots and mainstreaming of farmers' varieties is being taken up.

Progress in filing applications and PVP certificates issued

Applications which have fulfilled all requirements and have been finally accepted by the Registrar for registration are issued PVP certificates. Details of applications received (Table 2) and PVP certificates issued (Table 3) are indicated hereunder. The certificate of registration issued will be valid for nine years in case of trees and vines and six years in case of other crops. It may be reviewed and renewed for the remaining period on payment of renewal fees subject to the condition that total period of validity shall not exceed eighteen years in case of trees and vines from the date of registration of variety, fifteen years from the date of notification of variety under Seeds Act, 1966 and in other cases fifteen years from the date of registration of the variety.

Table 2: Applications received year-wise/applicant-wise

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Public	287	322	193	31	125	129	141	136	89	325	10	**1788**
Private	143	220	368	505	295	266	534	420	420	262	13	**3446**
Farmer	2	5	127	4	941	304	1002	1964	1957	1808	43	**8157**
Individual Breeder	0	0	0	0	0	0	0	0	2	0	0	**2**
Total	**432**	**547**	**688**	**540**	**1361**	**699**	**1677**	**2520**	**2468**	**2395**	**66**	**13393**

Table 3: Registration Certificate Issued year-wise/applicant-wise

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
Public	-	-	149	49	95	154	154	250	64	113	1028
Private	-	-	16	-	21	55	104	124	121	145	586
Farmer	-	-	3	-	-	3	46	459	200	340	1051
Total	**0**	**0**	**168**	**49**	**116**	**212**	**304**	**833**	**385**	**598**	**2665**

Progress in the Registration of Rapeseed Mustard Varieties and the PVP Certificates Issued

The central government vide notification no. S.O.993(E) dated April 30, 2010 notified Indian Mustard (Sarson), Indian Mustard (Karan rai), Rapeseed (Toria) and Gobhi Sarson for registration to obtain IPR. In the beginning the receipt of applications was quite low (Table-4). From the year 2013, series of awareness programmes were organized at SAUs/ICAR Institutes and KVKs to bring literacy on IPR. As a result from the year 2013, large number of applications were received for grant of IPR (Table-4). Maximum number of applications (185) were received in Indian Mustard (Sarson) followed by Rapeseed Toria (12), Rapeseed Gobi Sarson (5) and Indian Mustard Karan Rai (2) respectively.

Table 4: Applications received Rapeseed Mustard crops year-wise/applicant-wise

Applicant Category	2010	2011	2012	2013	2014	2015	2016	2017	Total
Farmer	-	1	3	8	54	46	61	3	176
Private	2	4	9	6	4	7	1	-	33
Public	2	-	9	44	3	-	8	-	66
Total	**4**	**5**	**21**	**58**	**61**	**53**	**70**	**3**	**275**

The details of IPR certificates granted is presented in table-5. More number of certificates (58) were granted to public institutes mainly because the public institutes submit extant notified varieties for registration which does not require DUS tests. Maximum number of certificates (61) were issued in Indian Mustard (Sarson) followed by Rapeseed Toria(12), Rapeseed Gobi Sarson (5) and Indian mustard Karan Rai (2) respectively.

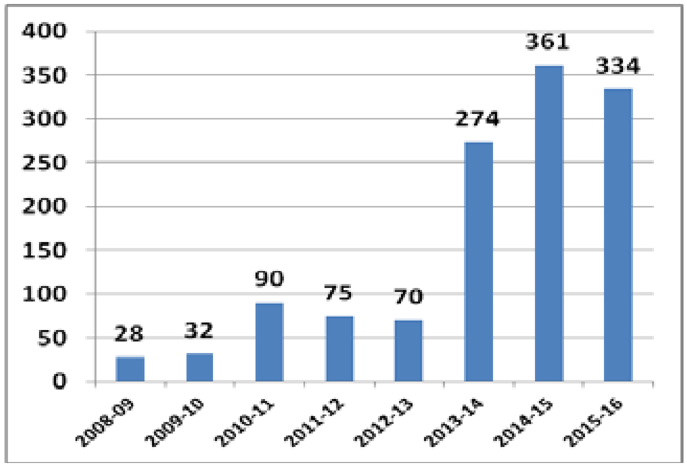
Table 5: Certificates issued in Rapeseed Mustard Crops year-wise/applicant-wise

Applicant Category	2010	2011	2012	2013	2014	Total
Farmer	-	1	-	-	5	6
Private	2	4	8	2	-	16
Public	2	-	11	43	2	58
Total	**4**	**5**	**19**	**45**	**7**	**80**

Training and Awareness Programs

The Authority, since inception, took initiatives to popularize its provisions in the civil societies and grass-root workers. There exists a close linkage of the Act with the farmers, researchers, plant breeders, intellectuals, scientists, students, NGOs, and public and private organizations active in this area. The Authority has been releasing funds for training, awareness and capacity building on the provisions of the PPV&FR Act, 2001 including Farmers Rights, Breeders Rights, and Researchers Right involving different stakeholders viz. ICAR Institutes, SAUs, KVKs, NGOs and other Govt. Departments for the farmers, researchers, plant breeders, intellectuals, scientists and students etc. and also for creating awareness through participation in agricultural fairs, kisan melas, kisan utsav, farmers' forum etc.

Fig 1- **Details of PPV&FR Awareness programs organized by the Authority**



Introduction of IPR courses in the colleges

Plant breeder / researcher spend huge financial resources, time and the University infrastructure for the development of improved genetic stocks / varieties. Unless these important improved genetic resources are not protected legally, we may lose the ownership of the variety. The University bred varieties might be registered by others in some other denomination for IPR. Once the IPR is obtained, the ownership goes to the one who registers the variety first. Hence awareness about the Act is very much needed and all teachers in the farm University / Colleges should be provided with capacity building in IPR.

In the Undergraduate and Postgraduate degree programs, one course on IPR is to be introduced as a compulsory subject. The Diploma courses on IPR on plant varieties should also be started. In all Universities campuses / colleges, opening of IPR cells will enable, proper co-ordination with respect to IPR issues.

As Farm Science Centres (Krishi Vigyan Kendras - KVKs) are the Agricultural knowledge dissemination centres in rural areas, the subject matter specialists (SMS) of KVKs be trained as trainers for IPR. These KVKs should in turn impart capacity building to farmers.

Role of PPV&FR Authority

Every year, the PPV&FR Authority is providing financial as well as human resource support for capacity building in the form of awareness programs. The Authority also organises exhibitions, farmers' dialog and Kissan Melas. The Authority also promotes IPR related theme for the organization of conferences, seminars and workshops and awareness programs.

In the eyes of law, innocence and ignorance are not the excuses. One has to protect PGR through IPR and harvest the benefit of new innovations and also century old efforts of farmers / farming community.

Brassica in Farming Systems

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India is the fifth largest vegetable oil economy in the world, next to USA, China, Brazil and Argentina, and has an annual turnover of about Rs 80,000 crore. India contributes about 10% of the world oilseeds production with 19% of world oilseed area. Out of 9 oilseed crops cultivated in the country, only 7 produce edible oils (soybean, groundnut, rapeseed-mustard, sunflower, sesame, safflower and niger) and remaining are non-edible in nature (castor and linseed). Among the seven edible oilseeds cultivated in India, rapeseed-mustard contributes 28.6% in the total oilseeds production and ranks second after groundnut sharing 27.8% in the India's oilseed economy. India ranks first in the production of most of the minor oilseeds (castor, niger, safflower and sesame). During 1951–2010, the area, production and productivity of annual oilseeds in India showed a compound annual growth rate of 1.57%, 3.01% and 1.42% respectively. Due to launch of Technology Mission on Oilseeds in the year 1986, India's oilseed production surpassed the fixed target of oilseed production (18 Mt) under the 7th Five Year Plan with an annual growth rate of nearly 6%. Though during later part of 1990s to tackle domestic edible oil demand the country had to depend on imports from outside which led to more than Rs 26,485 crore import bill of edible oils.The mustard growing areas in India are experiencing the vast diversity in the agro climatic conditions and different species of rapeseed-mustard are grown in some or other part of the country. Under marginal resource situation, cultivation of rapeseed-mustard becomes less remunerative to the farmers. This results in a big gap between requirement and production of mustard in India. Therefore, farming systems approach is essential for enhancing the farmer's income.

Cropping Systems

Under AICRP on Integrated Farming Systems, rapeseed and mustard were evaluated in different regions for its productivity and profitability. Gobhisarson and mustard were evaluated in maize-gobhisarson and groundnut-mustard systems as a part of front line demonstrations. At Amritsar (Punjab), 19.2% increase in gobhisarson yield was recorded by maintaining 45 x 10 spacing by thinning as improved practice. In groundnut-mustard cropping system at Fathepur (Rajasthan), 24.1% and 27.1% increase in the yield of groundnut and mustard was seen owing to the improved practice over the farmers practice. Enhancement in yields of maize and gobhi-sarson (85.3% and 88.26%, respectively) was observed at Kangra (Himachal Pradesh) due to improved management practice. For gobhi-sarson this increase was due to the replacement of Kanchan with the new improved variety HPN-3. In semi-arid agro-ecosystem of Amritsar (Punjab), maintenance of 45 x 10 cm spacing by thinning in gobhisarson has reduced the cost of cultivation and increased gross and net returns by 19.2 and 26.4% respectively. At Fathepur (Rajasthan) in groundnut-mustard cropping system, replacement of local varieties of groundnut and mustard with improved groundnut variety (HNG-10) and mustard variety (Laxmi) has resulted in 76.22% increase in cost of cultivation of groundnut and 72.45% increase in cost of cultivation of mustard but 103 % increase in gross returns and 98% increase in net returns was observed.

Farming System involving Brassicas

Marginal and small categories of farmers, representing more than 86% of Indian farm families with holding size below 1.2 ha are living in risk prone diverse production conditions. Small and fragmented land holdings do not allow farmers to have independent farm resources like draught animals, tractors, bore wells/tube wells and other sophisticated farm machineries for various cultural operations. Most of them are illiterate or poorly educated, economically poor and unaware of advancements made in the field of agricultural sciences. In the past, the focus had been on maximization of crop yields only and that to for well-endowed resource rich farmers. To fulfill the basic needs of households including food (cereals, pulses, oil seeds, milk, fruit, honey, fish, meat etc.) for humans, feed, fodder, fuel and fiber, a well-focused attention towards Integrated Farming System Research was initiated. A farming system model involving Gobhisarson was evaluated at Ludhiana (Punjab) in which land allocation made for different enterprises are given in Table 1.

Table 1: Allocation of one hectare irrigated farm land for livelihood improvement

Farm commodities	Minimum family needs (7 persons) (kg/ton)	Land allocation for basic food and feed commodities (ha)	Distribution of left out land area under high value crops/enterprises (ha)
Cereals	1550 kg	0.35	-
Oilseeds	130 kg	0.11	-
Pulses	200 kg	0.17	-
Sugarcane	1600 kg	0.03	0.14 (Cash crop)
Green fodder	40 ton	0.67	As a part of cropping system
Fruits	200 kg		0.20 (Fruit orchard of guava and lemon)
Vegetables	900 kg		No separate area allocated. Vegetables grown as intercrops in fruit orchard and kitchen gardening.
Milk	1120 Litres		No separate area allocated for green fodders as these are integral part of cropping systems.
Meat/fish	160 kg		0.10 (in the fish pond)
Mushroom			0.01
Apiary			0.01

To meet minimum basic food and fodder requirements of the family a farmer need 1.33 ha gross cultivated area. Under irrigated conditions, more than two crops per year are taken from the same piece of land. Considering an average 250% cropping intensity the net cultivated area required comes to 0.54 ha only. Now the remaining land area of 0.46 ha (out of 1 ha) is available for diversification of the prevailing farming systems either with high value crops(sugarcane in this case) or by integrating some additional more paying enterprises (fruits & vegetables and fishery to make the system holistic and also more profitable and sustainable too. Vermicompost and boundary plantations are mandatory and most essential for all type of IFS models

Table 2. Economic analysis of cropping system module involving Gobhisarsondurig 2014-15 (0.08 ha)

Cropping System	Economic Yield kg/800 m^2	Gross return (Rs)	Input cost (Rs)	Net return (Rs)	Total man hours	B:C ratio
Maize-GobhiSarson-Bajra Fodder	386-138-2480	12985	4626	8359	84	1.81

Rate (Rs/q):; maize-1310; gobhi sarson-3150; fodder -150

Recycling of residues: The residue of other crops *viz.,* rice were utilized for bedding in the cattle shed during winter months and then these rice residues were decomposed in the pit alongwith cowdung. The remaining residues of various crops (4834 kg) were utilized for mulching. Gobhisarson residues were used as nutrient source (Table 3). On an average these residues contained 0.6, 0.4 and 1.2 per cent N, P and K, respectively which amounts to 29, 19.3 and 58 kg N, P and K, respectively. These residues contained N, P and K amounting Rs 346, 989 and 1628. In nut shell these residues contained fertilizer amounting Rs 2963 which upon recycling improved soil health also.

Oil and sarson cake: From 138 kg of gobhisarson, 46 litres of oil was extracted for domestic consumption and remaining 92 kg sarson cake (Table 2) was used in dairy feed.

Table 3: Straw/stover produced (kg/800 sq m area) and utilized in IFS

Cropping System	Straw/stover (kg/800 sq m area)				
	Kharif	Rabi	Summer	Used as input in IFS	Used as nutrient source
Maize-GobhiSarson-Bajra Fodder	668	532	0	668	532

Livelihood improvement

IFS approach not only fulfilled the household needs but enriched the diet of human being and animals both and simultaneously keep the people away from the hazards of residual toxicity of the chemicals being used in agriculture on a large scale. Further, diversified nature of the model provides huge employment opportunity for unemployed rural youths (Table 4). Economic and livelihood analysis of the system revealed that beside household food and fodder security, the system generated a sizable amount of rupees 247523/ha as net family savings which will assist to meet other liabilities of the family including education, health and social obligations and overall improvement in livelihood of small farm holders. This shows the soundness of the IFS approach and its utility for small and marginal land holders of the region having dominance cereal-cereal system.

Table 4 : Livelihood analysis of the IFS Model involving Gobhisarson at Punjab Agricultural University, Ludhiana

Farm Enterprises	Value of all the farm commodities produced (A) (Rs.)	Value of Farm commodities consumed In family (B) (Rs.)	Value of all Farm commodities Recycled within the system (C) (Rs.)	Marketable surplus (A-B-C)=D (Rs.)	Family savings (If any) (D-Cost of Production) (Rs.)
Crops/Cropping Systems (Including vegetables/flowers)	164555	18088 (cereals) +7682 (pulses) +3294 (oilseeds) =29064	7104	128387	67018
Dairy (Milch Animals)	465713	26022	33089	406602	124991
Horticulture (Fruit crops)	59620	3340	0	56280	39432
Agroforestry	4498	0	191	4307	1907
Fishery	19450	0	2000	17450	14875
Others (Kitchen gardening) (Supplementary/complementary)	9300	9300	0	0	-1300
Boundary plantations	1600	200	4400	-3000	-3000
Mushroom	8000	2000	400	5600	3600
Total of all the farm produces (GR)	732736	69926		128387	247523

Other advantages of brassicas in farming systems

Bio-fumigation: Biofumigation refers to the suppression of soil-borne pests and pathogens by biocidal compounds, principally isothiocyanates (ITCs) released from Brassicaceous rotation and green manure crops when glucosinolates (GSLs) in their tissues are hydrolysed. Brassica and mustard cover crops are known for their rapid fall growth, great biomass production, and nutrient scavenging ability. However, they are attracting renewed interest primarily because of their pest management characteristics. Most Brassica species release chemical compounds that may be toxic to soil borne pathogens and pests, such as nematodes, fungi and some weeds. The mustards usually have higher concentrations of these chemicals. Like most green manures, brassica cover crops suppress weeds in the fall with their rapid growth and canopy closure. Recent research in Australia has investigated the potential for biofumigation to contribute to the control of soil-borne pathogens in broad area cropping as well as high value horticultural crops. In broad acre cropping, brassica oilseeds such as canola are thought to be superior break-crops for subsequent cereal crops, partly due to their biofumigation effects on cereal pathogens. In horticultural systems, a wide range ofBrassica green manures can be used; they can be grown immediately prior to commercial crops, and both shoot and root material can contribute to biofumigation. Bio-fumigation using brassicas as intercropping in horticulture plantations and other crops can be a viable option for integrated management of cereal pathogens.

Soil management: Brassicas can provide greater than 80% soil coverage when used as a winter cover crop. Some brassicas (forage radish, rapeseed, turnip) produce large taproots that can penetrate up to 6 feet to alleviate soil compaction. This so-called "biodrilling" is most effective when the plants are growing at a time of year when the soil is moist and easier to penetrate. Their deep rooting also allows these crops to scavenge nutrients from deep in the soil profile. As the large tap roots decompose, they leave channels open to the surface that increase water infiltration and improve the subsequent growth and soil penetration of crop roots. Smaller roots decompose and leave channels through the plow plan and improve the soil penetration by the roots of subsequent crops. Most mustard have a fibrous root system, and rooting effects are similar to small grain cover crops in that they do not root so deeply but develop a large root mass more confined to the soil surface profile.

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Mustard based Nutri village concept for popularization of value added products and strategies for faster dissemination of improved technologies

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Inspite of record food grain production, 265.57 mt (2013-14), the level of nutrition in our country is disturbing. According to NFHS 3 (2005-06) survey, in India, about 30 percent of all adults have BMI<18.5. More than one third (36%) of women have a BMI below 18.5; About 36 percent women suffer with chronic energy deficiencies; 56 percent women are anaemic; It shows that food security does not directly translate into nutritional security. There is a disconnect between agriculture, nutrition and health, which needs to be bridged.Many studies proved that improving food production system through biofortification will aid in better nutritional outcome. In addition to innovation in agri food production system, maintenance of nutrient quality is of very much essential to ensure not only nutrient security but health security for world populations (Kaput*et al*., 2015). The challenge to maintain and improve nutrient quality is magnified by the need to produce food locally and globally in a sustainable and consumer-acceptable manner for current and future populations.

In this context, to address the problems of malnutrition by connecting agriculture with nutrition and health, a project "Enhancing Nutritional Security and Gender Empowerment" was initiated during 2014 in the Division of Agricultural Extension, ICAR-IARI, New Delhi. This project comprises of two components such as research and establishment of agri-nutri (A2N) smart village model and analyzing the macro trend on linkage between agriculture and nutrition across the states by secondary as well as primary survey.A2N model has been conceptualised and is being experimented in project villages of Baghpat district, U.P. and Sonipat, Haryana, India. In A2N model, agriculture innovations to improved food production system are being experimented through field demonstrations on nutri rich crops and varieties, field days,farmers-scientists interface, awareness campaigns and capacity building programmes such as exposure visits, streaming of videos on healthy practices, minimal processing techniques of oil seeds, pulses, fruits and vegetables.This paper describes brief summary of agriculture interventions in mustard crop for nutrition security.

Nutritional and health benefits of Pusa Mustard 30

Mustard oil is the mixture of various acids like, linoleic acid and linolenic acid, which have beneficial properties and is a perfect blend of saturated and unsaturated fatty acids.The mustard oil has a distinctive pungent taste, characteristic of all plants in the mustard (*Brassica)* family. The pungency is due to glucosinolate, which has anti-bacterial, anti-fungal and anti-carcinogenic properties and account for many medicinal utilities of the oil.Mustard and its oil have been used as a topical treatment for rheumatism and arthritis, as a foot bath for aching feet, and in the form of plasters over the back and chest to treat bronchitis and pneumonia. It contains a high amount of selenium and magnesium, which gives it anti-inflammatory properties. It also helps stimulating sweat glands and helps lowering body temperature. In traditional medicines, it is used to relieve the pain associated with arthritis, muscle sprains and strains. A study by WHO recommends N3/N6 ratio of 4:5 which is almost closer to mustard oil. Hence, mustard oil is the safest edible oil for our heart. It is also an important medicine in the indigenous Ayurveda system of healthcare. It is used for therapeutic massages, muscular and joint problems. Oil with garlic and turmeric is used for rheumatism and joint pains. Mustard oil is also used as a mosquito repellent. Table 1 describes the saturated and unsaturated fatty acids present in the mustard oil.

Table 1. Fatty Acid Composition of Mustard oil

S.No.	Fatty Acid composition	Per centage
1.	Erucic acid	40-55%
2.	Oleic acid	12-24%
3.	Linoleic acid	12-16%
4.	Linolenic acid	7-10%
5.	Eicosenoic acid	3.5-11.6%
6.	Palmitic acid	1-3%
7.	Behenic acid	0.6-2.1%
8.	Arachidic acid	0.5-2.4%
9.	Lignoceric acid	0.5-1.1%
10.	Stearic acid	0.4-3.5%

But, it is banned in EU, USA and Canada, for edible consumption principally due to its erucic acid content. Even though, mustard oil has beneficial fat composition, it contains on an average 47% erucic acid (the normal mustard varieties possess erucic acid more than 40%). The health risks associated with erucic acid in mustard oil are: accumulation of triglycerides in the heart; development of fibriotic lesions of the heart; increase in risk of lung cancer; and anaemia. Higher erucic acid content leads to diseases like myocardial fibrosis in adults and lipidosis in children. {According to ToI (2012) report, it was even banned for human consumption in New Delhi in 1998, because of alarming increase of dropsy}

Initiative by ICAR-IARI

A mustard oil that is healthy and yet retains its characteristic pungency is the ideal cooking oil and which is something many consumers especially in northern India want. Indian Council of Agricultural Research (ICAR) has given due emphasis to improve the nutritional quality traits of various crops including mustard. ICAR - Indian Agricultural Research Institute (ICAR-IARI), New Delhi has developed a low erucic acid Indian mustard variety namely Pusa Mustard-30 (PM-30) using conventional breeding method, by making the ideal combination real. **It (LES-43)**is a **single zero (<2% erucic acid of** total fatty acids**).** The normal Indian mustard (Brassica juncea) typically have over 45 per cent erucic acid, linked to increase in risk of cardiac muscle impairment.The high erucic acid levels in Indian mustard have led to a growing market for imported rapeseed or canola oil (*Brassica napus*), which in 2014-15 (November-October), was amounted to over 14.4 mt valued at $10.5 billion.

Apart from good production potential, it is beneficial for health as it has low erucic acidand has the best combination of other desirable fatty acids. Besides, the two other two essential fatty acids viz., linoleic and linolenic acids, which are not synthesized by human body are supplemented by diet only, are also present in very balanced proportion. The quantity of such important essential fatty acids has also improved in this oil (Oleic acid 45%, linoleic acid 29%, lenolenic acid 14% and ecosenoic acid, 3 %.) to make it healthier with enhanced shelf life. The new variety possesses oil content of 38% oil and composition of fatty acids iserucic acid less than 2%. Belonging to the same Brassicaceae family, but of a different species (napus), in addition to the advantage of low erucic acid (below 2 per cent), it lacks in glucosinolates, an organic compound that catalyse reactions in the broken seeds imparting the pungent taste associated with mustard oil. While the glucosinolates content in Indian mustard is about 150 micromoles per gram of seeds, in PM 30, it is less than 30.

This variety was released in the year 2013 and recommended for Uttar Pradesh, Uttrakhand, Madhya Pradesh and eastern Rajasthan and suitable for timely sown irrigated condition. The Seed rate of the crop is 4.0-5.0 kg/ha; Spacing is 30 * 10-15 cm and depth of sowing is 2.5 cm. It is a medium maturing variety, which matures in 137 days and is about one week early to all released quality mustard varieties. The approximate day of harvestable maturity is 107 days. It has high yielding properties. Its average seed yield is 18.24q/ ha with potential seed yield of 31. 25 q/ha. Average yield of this variety is 18.24 q/ha, range is 12.90 q to 37.78 q/ha. Its seeds are dark brown in colour, medium in size (5.38 g/ 1000 seeds) with 37.7% average oil content across locations.

To produce and market the oil extracted from Pusa Mustard-30 commercially, a separate venture, Arpan Seeds Pvt. Ltd under public-private-partnership has been started in the year 2015 under the brand name 'Lifegard'. It is first of its kind effort by ICAR-IARI under public-private-partnership mode to develop a new edible oil brand which is one of very essential component under Make in India initiative of Govt. of Indiaand launch it as an indigenously developed health value product with improved oil quality.

Agriculture interventions for nutrition security

In Baghpat, U.P., being the mustard growingarea, there was a scope for introducing Pusa Mustard 30. Hence, under the project, Enhancing Nutritional Security and Gender Empowerment, a number of field demonstrationswere conducted from 2015 onwards to the farmers on this variety**low erucic acid content Pusa Mustard 30**. And so far, 200 acres of land has been covered for ensuring healthy consumption of mustard oil as it is the majorly consumed cooking oil in this area. Total number of beneficiary farmers were 130.Apart from this, field day on Pusa 30 (mustard) variety of IARI (with <2% erucic acid content) was organized in the project village to create awareness among farmers about its health benefits.A **video on low erucic acid Pusa Mustard 30** in hindi (local language) has already been prepared by using Windows Movie Maker and was streamed through computers, laptops and pico projectors to a group of farmers to aware them about PM 30 and its importance in health perspective. As, it was in local language, it helped in better understanding of the content by the farmers.

The feedback from the farmers to who cultivate this variety includes the following: The plant height of Pusa Mustard 30 is 195- 205 cm having vigorous growth. The farmers who cultivate this crop perceived that it is very good in taste; fiber enriched; oil content of the variety is equal to others and taste of oil is pleasant; They also perceived that it is good in production, yield and low disease was visible in the crop. Yield of this variety in farmers' field was approximately 17.5 qtl/ha. In total, the farmers are satisfied with the performance and yield of this variety.

In addition to taking Pusa Mustard-30 from the IARI to farmers' fields,these mustard growers will be linked with oil seed companies to market their products and get an additional income in future. The project area is having twenty eight women self help groups. In future , the scope for linking the SHG members for entrepreneurial activities will be explored. As it is predominantly mustard growing area, entrepreneurship in value addition in terms of oil will be a profitable venture. It will not only increase the income and livelihood security of villagers but also will pave a way for nutrition and health security.

The present government is focusing more on Made in India and Skill India. In such condition, it is an golden opportunity for entrepreneurs to join their hands with private partners to produce premium healthy Indian mustard oil. The policy measures should be directed to get additional incentive/premium over the market price of regular mustard to incentivize farmers to grow this variety. Having roughly 40 per cent oil content, mustard is the most suitable crop to usher in a 'yellow revolution', similar to the contribution by wheat and paddy in 'Green Revolution', by reducing India's reliance on edible oil imports.To reach the Sustainable Development Goals (SDGs), new technologies and approaches having health and nutrition in mind should be taken to the farmers' field tohelp address the problem of nutritional and health security.

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Technology Commercialization under National Agricultural Research System: Opportunities and Challenges

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Agriculture sector is predominant in the overall socio-economic developmentin agrarian economies.Under the climate change scenario, these countries are expected to face more challenges in production, processing and trade sectors. Their trade competiveness and regulatory capacities are further challenged under the world trade regime. India has potentials of becoming theagriculture powerhouse, and through right policies and technology, could contribute to feeding many in the developing world besides sustainably ensuring food security in the country.

Successful technology transfer from labs to farmers' fieldshas become a habit since the green revolution days. Of course, international agreements and treaties implemented in the past two decades have also influenced this change. The research institutions now focus on cooperation with related research and development agencies, industry partners and private enterprises for developing and transfer of safe, productive, and sustainable agricultural technology. This paper discusses strategic opportunities and challenges in public research and technology sector.

Technology Development, Transfer and Diffusion under NARS

Research outcomes have been historically treated as public goods in the National Agricultural Research System (NARS) as per their mandates i.e.catering to social obligations and welfare objectives on priority. Technological information were disseminated via traditional Extension systems like National Demonstration Scheme (1964) to demonstrate the production potentiality of major crops in the farmers' field, Lab-to-Land programme (1970) to transfer low cost technologies in agriculture and allied enterprises, Institution –Village Linkage Programme (1995), Agriculture-Technology Information Centre (ATIC) to make available of technology inputs & products (limited), information and advisory services under one roof.

New technologies are embodied in products like improved seeds of crop varieties and hybrids, farm machinery, agrochemicals, bio-agents, etc. and the challenge is to ensure their availability to farmers at right time, at reasonable price and in sufficient quantity. Here comes the role of private sector, which can create, manufacture and sell/ distribute technology. Within Indian Council of Agricultural Research (ICAR),idea to collaborate with industry was initiated in late 1980s and sporadic transfer of technologies (TOT) begun. IARI established business cell within institute and transfer of technology happened through NRDC in late 90s. Later on,the new trends of globalization in trade and intellectual property protection have compelled ICAR institutesand state agricultural universities (SAUs) to build adequate capacity for the development of new technologies and products, for licensing and commercialization of new technologies, and for building a culture of intellectual property (IP) protection.

Three-Tier IP Management Mechanism at ICAR

ICAR recognizes that research in frontier sciences, such as agro-biotechnology will require IP protection through patents, plant variety protection and other forms of IPR. In 2006, ICAR launched its key IP management policy elements together with well-versed guidelines for "Intellectual Property Management and Technology Transfer/ Commercialization". Under these guidelines, commercial ethos in transfer of skills and products were institutionalized through a 3-

tier IP management mechanism: 1) Agro-Technology Management Center (ATMC) at ICAR level; 2) Zonal Technology Management Centers (ZTMC); and 3) Institute Technology Management Units (ITMU) at each one of its institutes. This 3-tier mechanism ensures a decentralized and empowered system with handholding opportunity for weaker institutes by the ZTMCs, an upward-downward back and forth decision support capability for commercialization and public-interest decisions in TT, and that ICAR keeps all IP assets and other activities/records related to IP and TT and commercialization in various ICAR institutes.

ATMC serves as the apex unit that facilitates, coordinates and monitors the implementation of IPR and TT policies across the ICAR establishments. ZTMCs handle pre-defined zones through their Business Planning and Development Unit (BPDU) and have regional roles in managing ICAR's IP and TT activities. ITMUs, created in each ICAR institute are headed by the institute's director and provided with decision support system through the respective ITMCs. Researchers at ICAR institutions are encouraged to disclose their inventions to ITMU, which evaluates the novelty of research, patentability of the invention or respective criteria of other IPR protection (e.g. plant variety protection, trademark, design protection, etc.) and pursues IPR protection and maintenance accordingly.

ICAR's IP policy gives edge to IPR protection over publication. ITMU arranges to file IPR applications while PME Units oversee publication of the research results. All IPR applications are filed by and on behalf of "Indian Council of Agricultural Research" as applicant and the inventors assign their research results to ICAR. The patent/IPR applications contain all the names of all concerned ICAR scientists who contributed to the invention or the development of plant variety. ITMU facilitates commercialization of innovative technologies via licensing agreements.

AgriInnovate India Pvt. Ltd: For Profit Company of DARE

In 2011, ICAR and Department of Agricultural Research & Education (DARE), Ministry of Agriculture and Farmers' Welfare took a step forward to secure, sustain and promote agricultural development in the country and international collaborators. DARE set up a for profit company, the Agri-Innovate India Ltd., for TOT and acting as an effective interface between ICAR and the stakeholders of agricultural development at the national, regional and global levels.

IPR Portfolio of ICAR

After the establishment of its regular IPR Unit in 2001 at ICAR headquarters,a huge IPR portfolio has been built by 2015-16. This includes a cumulative 980 patent applications filed by its 69 institutes, 170 granted patents, 167 titles granted to plant varieties, 21 registered trademarks, and 94 copyright applications filed. A patent for rapid detection of Bt cry toxin in cotton is granted in 4 countries (China, South Africa, Uzbekistan and Mexico) and the four Bt-detection kits developed and commercialized became popular all over the country with sales of over Rs. 6crore until March 2009. Bt based biopesticide formulation developed by ICAR institutes were licensed to over three dozen licensees in 4 major cotton growing states. Many more technologies have been successfully commercialized.

Technology commercialization at ICAR/IARI:

ICAR has, so far, commercialized around 500 agricultural technologies, including 300 agricultural engineering products through its 3-tier mechanism of managing IP and TT. Show-how, know–how clauses of licensing agreement and inventor's involvement at all stages of product development have contributed to success in these licensing agreements.

About 30 per cent of ICARs licensed technologies, including neem-based agrochemicals and engineering products came from the Indian Agricultural Research Institute (IARI), one of the ICAR institutes and the country's oldest, premier national Institute for agricultural research, education and extension. In the last six years, IARI through the ZTM& BPD Unit has successfully commercialized around 196 agricultural technologies ranging from crop varieties, bio-fertilizers, post-harvest technologies, agri-chemicals, farm implements and diagnostic tools as per Fig 1to 365 agro-based companies and generated the revenue of Rs. 622.31 lakhs (Fig 2 & 3).

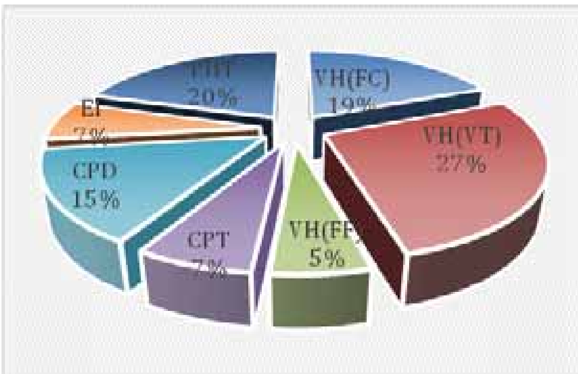
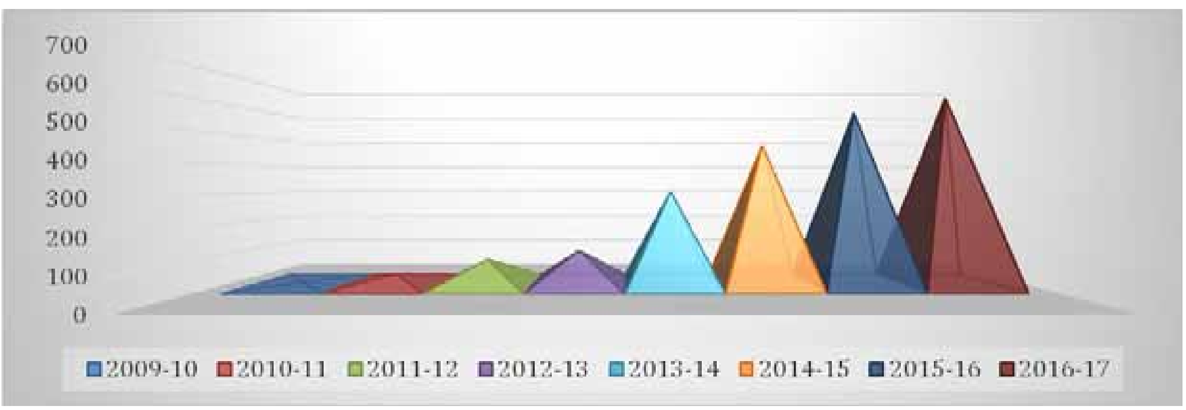


Fig 1 and Fig 2: Technology commercilaization from IARI from 2009 to 2016



* Revenue in Rs Lakhs

Fig 3: Revenue Generated through Technology Commercialization

***Pusa gautami*: HD 3086:**

IARI has executed licensing agreements with 199 seed companies for its climate resilient wheat variety HD 3086 in the shortest period of 2 years. The wheat variety HD3086 is the fastest adopted crop improved varieties of IARI that has covered an area of approx. 2 million hectares in 2014-15 and contributed approx. Rs. 15,822 Crores to farmer's incomewithin a record 3 years of its release. In the past, it usually required 5- 7 years for a new variety to reach farmers' field under the conventional system of varietal dissemination. The impact of timely delivery of new seed variety i.e. HD 3086 can be measured by the level of adoption and increased in farm productivity and production, which is obvious in the productivity gain of wheat in Punjab and Haryana. Out of 199 seed companies, 57 seed startup companies were supported, guided and nurtured by ZTM & BPD Unit. In a way, this initiative has nurtured the entire seed value chain from LAB TO LAND via industry participation and created around 5000 new employment opportunities in the last two years.

Soil Testing and Fertilizer Recommendation Meter (STFR meter):

A portable STFR meter designed by the institute's inventors, IP protected and then commercialized to fourteen industry partners for providing the soil testing services at the farmer's doorstep. Three startup companies took up this technology for manufacturing and marketing of STFR meter. This portable machine created many benefits to the farmers and created employment opportunities to the rural youth.

Zero Erucic Acid Indian Mustard Varieties:

Most of the popular Indian mustard varieties have >40 % of erucic acid which leads to diseases like myocardial fibrosis in adults and lipidosis in children, thereby affecting the human health.The team of scientists at ICAR-IARI has developed Indian mustard variety PUSA 30 with <2% erucic acid using conventional breeding method. Besides, the quantity of other essential fatty acids like Oleic acid has also improved to make the oil healthier with enhanced shelf life.The two other two essential fatty acids viz., Linoleic and Lenolenic acids, which are not synthesised by human body, hence are supplemented by diet only, are also present in very balanced proportion.

To disseminate these varieties, ZTM & BPD Unit registered Mustard varieties with PPVFRA as per table No 1.

Table 1: List of Mustard Varieties Registered under PPVFR Act

S.No.	Variety Name	Reg. No.	Reg. Date
1	*PusaAgrani*	REG/2013/522	04.10.2013
2	Pusa Mustard 21	REG/2013/523	04.10.2013
3	Pusa Mustard 26	REG/2013/524	04.10.2013
4	Pusa Mustard 27	REG/2013/525	04.10.2013
5	Pusa Mustard 28	REG/2013/526	04.10.2013
6	Pusa Mustard 22	REG/2013/527	04.10.2013
7	*PusaKarishma*	REG/2013/528	04.10.2013
8	PusaMahak	REG/2013/529	04.10.2013
9	Pusa Mustard 30	REG/2013/530	04.10.2013
10	Pusa Mustard 29	REG/2013/531	04.10.2013
11	*Pusa Vijay*	REG/2013/532	04.10.2013
12	Pusa EJ-9912-13	REG/2013/533	04.10.2013
13	Pusa Mustard 24	REG/2013/534	04.10.2013
14	Pusa Mustard 25	REG/2013/535	04.10.2013
15	VSL-5	REG/2013/536	04.10.2013
16	*Pusa Aditya*	REG/2013/537	04.10.2013
17	*Pusa Swarnim*	REG/2013/538	04.10.2013

Simultaneously, marketing campaign were launched and created partnership with seven industry partners as per table 2.

Out of seven, three are start up companies. Two of them took the incubation support under ABIC programme and facilitated to get Grant in aid under project entitled "MSME Scheme for supporting Startup Company with innovative Ideas" funded by Ministry of MSME, GoI, New Delhi. Ananya Seed Pvt. ltd. Took up the seed production of Pusa Mustard 30 to provide certified/TL seed to the farmers. \

Nano-biotechnology based bio fertilizers and micronutrients have been scaled up and launched for test marketing by a licensee, and PUSA varieties and Hydrogel are similarly meeting commercial success with huge benefits to user farmers and agro-industry. With World Bank financed National Agricultural Innovation Project support the ZTM & BPD Unit IARI has executed end-to-end deals with Indian MNCs and other agro companies, including the post NAIP R&D agreements.

Table 2: List of Industry partners for different Mustard Varieties

S.No.	Mustard Variety	Name of Licensee
1	Pusa Mustard 25	Dayal Seeds Private limited, New Delhi
2	Pusa Mustard 26	*Bestech Seed India Pvt. Ltd., Rajasthan
3	Pusa Mustard 27	Nuziveedu Seeds Ltd, Telangana
4		Dayal Seeds Private limited, New Delhi
	Pusa Mustard 28	Nuziveedu Seeds Ltd, Telangana
5	Pusa Mustard 29	Nuziveedu Seeds Ltd, Telangana
6		Malwa Enterprises, Punjab
		M/s Ajeet Seeds Ltd, Aurangabad, Maharashtra
		*Ananya Seed Pvt Ltd, Karnataka
	Pusa Mustard 30	*M/S Arpan Seeds Pvt. Ltd, Rajasthan

* Startup companies

Recently, IARI, to innovatively reach out through the large number of mobile users in the country, has launched a mobile application "Pusa Krishi" to promote its technologies for licensing to various stakeholders from corporates to individual farmers, all served by the three tiers.

Agri-Business Incubation Centre (ABIC)

On the line of our national campaign of Start-up India and stand-up India, to further strengthen our efforts, new dimension of agribusiness incubators has been added to facilitate start up in agri sector that is difficult one in a no.of ways mainly on technical side.Currently, ZTM& BPD Unit, IARI is implementing 'Arise 2016- launch Pad for Agri Starts ups' programme in collaboration with Central Ministry of MSME to push agri-biotechnology and agribusiness.

Way Forward

Valuation of technologies is a huge challenge as it depends upon a number of factors. At present, we are deciding on it based on the experience and keeping in consideration the strength of local industry. In coming times, we have to be much more systematic and new tools have to be designed and required.Effective use of ICT tools is imperative for technology commercialization. Virtual marketing place will be required. Farmer enterprises, either in the form of FPO, cooperatives, startups, have to be taken up in a very systemic approach to address the value chain development as well as the processing part.

- Tech Transfer Integration with Incubation for Startups /FPO/ Woman or Farmer enterprises/ cooperatives
- Market led Agri technology Transfer/value chain/processing segment
- More Emphasis on PPP
- Capacity Building at all levels/ Hand holding/ Consortia/Networking
- Trained professionals: Technical, business, legal knowledge
- Demand Driven v/s Supply Driven
- Technology readiness
- Linkage with industryYouth has to attracted in agriculture sector.

Conclusion

The innovative 3 tier structure created by ICAR in the form of ATMC, ZTM & BPD unit and ITMU has led to increased and specialised focus on IP protection and their licensing. These centres have tried to bring in specialization and expertise in the arena of Intellectual Property Regime, as necessitated by fast changing environment in this sector. This has added to Indian agriculture 's shift from resource or input-based growth to knowledge or science-based growth. In this paradigm shift, the flow of knowledge and innovations plays a critical role. R&D activities, new inventions and their protection through patents and IP tools of plant variety protection are going to assume more importance in future because it is a cost-effective method for promoting growth with sustainability while attaining competitiveness. Thus it is high time for the scientists and researchers of NARS to make IPR an integral part of the curriculum so that the public research and education system in agriculture can take on new challenges effectively by becoming contemporary, compatible and competitive, as envisioned by ICAR.

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THEME 1

CROP IMPROVEMENT STRATEGIES UNDER CHANGING CLIMATE

Induction and utilization of desirable mutations to tailor plant architecture of *Brassica juncea* for enhancing yield potential

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Genetic variability has extensively been utilized in hybridization to develop high yielding varieties. However, productivity of Indian mustard has been stagnated to 1100kg/ha. To enhance yield potential, novel germplasm needs to be generated and/or explored. Mutation breeding has been successfully employed to enhance the production and productivity of crop plants. Through mutation breeding technique, more than 3200 varieties have been released globally. We have isolated desirable mutations like dwarf and early, yellow seed coat, fasciation, non-locular siliquae, light green leaf and reduced erucic acid. Dwarf mutation has early maturity, yellow seed coat and yield potential equal to the parent Varuna and could be the best candidate to isolate desirable transgressive segregants. Yellow seed coat has more oil content. Fasciation has more number of siliquae per plant and non-locular siliquae has more number of seeds per siliqua. Both these character along with dwarf could be the best plant architecture. Light green leaf mutation has less chlorophyll content but high biomass and seed yield. It is a good indicator for developing high yielding hybrids. Mutations for reduced erucic acid could be novel source to develop zero erucic acid varieties. High yielding mutations can be directly released as variety, whereas, mutations for specific character can be introgressed in high yielding background to isolate desirable plant type. Using mutation breeding technique, total 31 high yielding varieties comprising 12 in *B. juncea*, 14 in *B. napus*, 2 in *B. rapa* and 3 in white mustard have been released for cultivation worldwide. BARC has developed three high yielding varieties using induced mutagenesis.

Model plant type in Ethiopian mustard (*Brassica carinata* A. Braun)

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Despite the great genetic potential, a major break-through in yield has not been achieved in rapeseed-mustard. It is certainly true that various factors affect the yield to a larger extent but the role of plant type cannot be given less weight. Efforts have been made to define a model plant type in rapeseed-mustard by improving yield and its component characters and bringing them together in one plant type. Breeding for a model plant type which is expected to give maximum yield can be carried out with the help of correlation and path coefficient analysis.The present study was carried out in 18 mutant lines of Ethiopian mustard to identify the morphological framework of model plant type through character association and path coefficient analysis. Data were recorded on seed yield and its component characters; analysis was done as per standard statistical procedures. High heritability coupled with high genetic advance was observed for number of secondary branches and harvest index, whereas plant height, 1000-seed weight and biological yield showed high heritability with moderate genetic advance. Correlation analysis showed that days to 75% maturity, number of secondary branches, siliquae per plant, biological yield and harvest index had significant positive correlation with seed yield per plant.

Path analysis revealed that harvest index had the highest direct positive effect on seed yield per plant followed by biological yield, seed per siliquae, plant height and number of secondary branches. According to character association and path coefficient analysis, such a model plant was characterized by plant type having the higher number of secondary branches, siliquae per plant, biological yield and high harvest index. Two mutant lines showed the desired characteristics of model plant type.

Success story of PT-303 variety of *toria*: Revisiting development and its sustenance in performance through maintenance breeding

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Toria (*Brassica rapa* var. *toria*) is an important *Brassica* oilseed cultivated largely rainfed in north-eastern states and in the northern parts of the country. It is cultivated as a catch or mixed crop due to its short duration. A large number of improved varieties of *toria* have been developed during the past four decades. Of these PT 303, released at national level has been most successful as a widely adapted high yielding variety. Various aspects of its success viz. development, performance as national check in multi-location All India Coordinated trials, DAC indents for breeder seed production and post-release maintenance have been analyzed. PT 303 was developed from a cross between B-54 (Agrani), an early maturing self incompatible and cross pollinated variety of *toria* from West Bengal suitable for both irrigated as well as rainfed situations and DSH17MD is a strain of *tora* type brown *sarson* which is self compatible possessing compact plant type and bold seeds with high oil content. Thus, PT-303 combines desirable characteristics of both *toria* and brown *sarson*. It was released by CVRC in 1985 for all *toria* growing areas of the country on the basis of its superiority over T-9 (check) by a margin of 12.51% in multilocation coordinated trials with increased tolerance of PT-303 to major diseases viz. Alternaria blight, white rust and downy mildew. Ever since its release, PT 303 has regularly figured in DAC indents for breeder seed production. During the last 17 years (1999-2k to 2015-16), breeder seed indents for PT 303 ranged from 0.55q in 2005-06 to 3.45q in 2015-16 with a total of 21.77q sharing 12.56% of the indents for all *toria* varieties. The share of this variety in actual quantity of breeder seed produced was almost double (24.24%) of the indented quantity. Time series analysis of check varieties using AICRP on Rapeseed-Mustard multilocation trial data across six zones over six years (1994 to 1999) by Yadava *et*. *al*. (2000) showed that superiority in yield of PT-303 was invariably associated with low variability (CV%) which reflects its stability in performance. Performance of this variety as a check in various coordinated trials during six years (1986-87, 1992-93, 1998-99, 2004-05, 2010-11 and 2015-16) as percentile of top ranking entry in the respective trials was 83.26 to 100% in Zone-III and 0.72 to 100% in Zone-II. Consistent superiority in performance of PT 303 may be attributed to the most favourable combination of genetically divergent parental lines and to maintenance breeding actually practiced at Pantnagar. Large population size (invariably covering >1ha area), regular supply of genetically pure nucleus seed produced as bulk of progenies selected on the basis of multiple row plots and long isolation distance (>500m) are integral part of maintenance breeding at Pantnagar. From the above it is explicitly clear that PT 303, even after three decades of its release has been the most successful variety for its wider adaptability and consistently superior performance which is mainly due to technique of maintenance breeding followed with greater emphasis on large population size and longer isolation distance in addition to the follow up of other recommended seed production practices. In the view of climate change, PT 303 is becoming more important in hilly tract which is reflected from its certified seed allocation of 65q for 2014-15 and 56q for 2015-16 for hill districts of Uttarakhand by the State Department of Agriculture.

GDM 5: A High yielding, high oil content and abiotic stress tolerant variety of Indian mustard [*Brassica juncea* (L).Czern & Coss]

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Rapeseed-mustard is an economically important multipurpose oilseed seed crop in India next to soybean. There was remarkable increase in the production during last 25 years. This crop requires fewer inputs like seed, fertilizers and irrigation water as compare to other *rabi* crops. The growth, development and yield of *Brassica* depends on the optimum conditions of the weather parameters such as rainfall (conserved soil moisture), temperature, humidity and duration of sun light hours. Out of these, soil moisture is most important factor for mustard cultivation in rainfed area and it depends upon the number of rainy days as well as quantity of total rainfall precipitated during the monsoon. In India, there are large areas in which it is possible to take rainfed mustard on conserved soil moisture. Since, limited efforts have been made for research on development of mustard varieties suitable for rainfed conditions of India; breeding efforts are essential to develop high yielding varieties with improved oil content. In this context, a mustard genotype SKM 518 was developed at Castor-Mustard Research Station, Sardarkrushinagar and evaluated in IVT and AVT trials (rainfed) along with national check Kranti and zonal checks viz., Geeta, RB 50 and RGN 48 at five different locations *i.e.*, Bhatinda, Hisar, Navgaon, Sriganganagar and Bawal of zone II under AICRP during 2011-14. The results revealed that the genotype SKM 518 exhibited wider adaptability and consistent superiority for seed and oil yields in rainfed condition in zone II as compared to the check varieties during the three years of testing. On the basis of weighted mean performance it yielded 2213 kg/ha, which was 25.88%, 78.76%, 22.40% and 9.94% higher than Kranti (NC), Geeta (ZC), RB 50 (ZC) and RGN 48 (ZC), respectively. The same genotype also contain 40.50% oil in its seed and gave on an average 897 kg/ha oil yield, which was 24.6%, 81.2%, 23.7% and 6.8% higher than Kranti (NC), Geeta (ZC), RB 50 (ZC) and RGN 48 (ZC), respectively. Being medium in height it has inbuilt capacity for tolerance to lodging and shattering. It is also tolerant to the biotic stresses *i.e.*, it showed lower incidence of mustard aphid under natural conditions and low incidences of *Sclerotinia* stem rot, white rust and alternaria blight. This genotype is identified as GDM 5 (Gujarat Dantiwada Mustard 5) by Varietal Identification Committee during 2015 and released for mustard growing farmers of Zone II (Punjab, Haryana, Delhi, North Rajasthan and Jammu) under rainfed conditions. Therefore, it will be helpful in enhancing and stabilize the income of mustard growing farmers in that area.

Registration for protection of Public and Private sector plant varieties/ hybrids in India

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The Protection of Plant Varieties and Farmers' Right Act, 2001 (PPV&FR Act) is an act of the parliament of India enacted to provide for the establishment of an effective system for protection of plants, the rights of farmers and plant breeders, and to encourage the development and cultivation of new varieties of plants. This act received assent of the president of India on October 30, 2001. The PPV&FR Act, 2001 was enacted to grant Intellectual Property Rights (IPR) to plant breeders, researchers and farmers who have developed any new or extant plant varieties. The Intellectual Property Rights granted under PPV&FR Act, 2001 is a dual right- one is for the variety and the other is for the denomination assigned to it by the breeder. The rights granted under this Act are heritable and assignable and only registration of a plant variety confers the right. Essentially Derived Varieties (EDV) can also be registered under this Act and it may be new or extant. Farmers are entitled to save, use, sow, re-sow, exchange or sell their farm produce including seed of a registered variety in an unbranded manner. Farmers' varieties are eligible for registration and farmers are totally exempted from payment of any fee in any proceedings under this Act. The period of protection for field crops is 15 years and for trees and vines is 18 years and for notified varieties it is 15 years from the date of notification under section 5 of Seeds Act, 1966. The Protection of Plant Varieties Farmers' Rights Authority has so far received 1758 application of Public sector, 3404 of private sector, 7527 of farmer and 02 applications received of individual breeders for registration of plant varieties out of which 2193 have been granted certificates of registration. Crop wise analysis of issue of certificates of registration revealed that cereals, (such as maize, bread wheat, rice, pearl millet, sorghum) and cotton along with few pulses formed more than 90 percent of the varieties and rapeseed and mustard more than 94 certificates of registration have been granted till November.30, 2016. So far only 37 rapeseed and mustard varieties have been registered through ICAR- Directorate of Rapeseed- Mustard Research, Sewar, Bharatpur (Rajasthan) and 57 rapeseed and mustard varieties have been registered through the other centers under PPV&FR for protection of plant varieties. Those 37 varieties are registered through the ICAR- DRMR under PPV&FR, which had only 5 varieties and 1 hybrid of ICAR- DRMR, Bharatpur and 31 varieties of Pantnagar, Hisar, Kanpur, Navgaon, S.K. Nagar, Bawal, Sriganganagar, Ludhiana, Bhathinda and Kangra.

Studies on genetic diversity among various genotypes of *Brassisa napus* L. using morphological and molecular markers

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Rapeseed and mustard are the major *rabi* oil seed crops of India. Globally India continues to be at rank 3rd after Canada and China in acreage (19.3%) and after China and Canada in production (11.1%). Genetic diversity of 22 Brassica genotypes viz.18 *Brassica napus,* 2 *Brassica juncea* and 2 *Brassica rapa* were assessed using RAPD primers & morpho-phenological traits. The characters days to maturity, plant height, number of primary branches/plant, number of seeds/siliqua, number of siliqua/plant and seed yield /plant showed higher influence of environment whereas, siliqua length and 1000-seed weight showed the least. Days to maturity and days to 50% flowering exhibited the highest heritability. The significant positive correlation with seed yield/plant was found in plant height, number of primary branches/plant, number of siliqua on main raceme, 1000-seed weight, oil content, days to 50% flowering and days to maturity. Path coefficient analysis showed that the plant height had maximum positive direct effect on seed yield followed by 1000-seed weight and siliqua length. Plant height, number of primary branches/plant and number of siliqua on main raceme were the most important contributors to seed yield/plant and should be considered for future selection program. We obtained a dendrogram for the morphological traits and a dendrogram for RAPD analysis; we compared them and concluded that AKGS-3, EC552608 & CNH-11-7 are most diverse genotypes. Results indicate primer OPD-18 as the best primer for genetic diversity analysis. Molecular similarity matrix showed that CNH-11-2, CNH-11-13, HNS1001 & NUDB-26 had the highest similarity.

Genetic diversity analysis in Indian mustard (*Brassica juncea* L. Czern and Coss) genotypes using agro-morphological parameters

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An experiment was conducted using 45 genotypes including local cultivars, advanced lines and notified varieties of Indian mustard for genetic diversity analysis through Mahalanobis's D^2 method. The study was conducted in RBD design with 3 replications having plot size of 1.5 x 5 m^2 and row spacing of 30 x 10 cm. Data were recorded on 14 different agro-morphological characters *viz.* days to 50% flowering, days to maturity, plant height (cm), number of primary and secondary branches per plant, main shoot length (cm), leaf area index, root width and length ratio, number of siliqua per plant, siliqua length (cm), number of seeds per siliqua, seed yield per plant (g), 1000 seed weight (g) and oil content (%). The analysis of variance revealed significant differences among the genotypes for all characters under study. The genotypes were grouped into 7 clusters using Tocher's method, with cluster I containing maximum genotypes (18 genotypes) followed by cluster III (9 genotypes), cluster IV (8 genotypes), cluster II (6 genotypes), cluster VI (2 genotypes) while cluster V and VII had only single genotype each. Root width and length ratio, siliqua per plant, main shoot length (cm) and 1000 seed weight, were the major contributors for genetic diversity among the genotypes with 23%, 21.80%, 21.32% and 20.51% respectively. The cluster IV exhibited maximum intra-cluster D^2 distance followed by cluster VI (844.272) while maximum inter-cluster D^2 distance were found between cluster V and VII (7273.532). Selection of diverse genotype containing desirable characters from the cluster and utilizing in hybridization programme will likely produce more transgressive segregants and heterotic F1's.

Genetic divergence for yield and physio-morphological-quality traits in early sown Indian mustard (*Brassica juncea* (L.) Czern&Coss.)

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Genetic diversity analysis is one of the potent techniques for measuring force of differentiation at inter and intra-cluster levels and determines the relative contribution of each component trait to total divergence. In the present experiment an attempt was made, under early sown conditions to assess the genetic divergence among thirty-five genotypes from different AICRP-RM research centres located across India. Tocher's method was used where in generalized distance employed for twenty-one physio-mophological and quality traits was studied, based on statistic related to coefficient of racial likeliness developed by Mahalanobis (1936) and Rao (1952). Subsequently 35 genotypes were grouped into seven clusters reflecting diversity of which V and VII were mono-genotypic, cluster II had the highest number of nine genotypes while cluster I,III,IV,VI accommodated eight, seven, seven and two genotypes. Mono-genotypic clusters V (DRMR150-35) and VII (TPM-1) followed by VI (KMR10-2 & Pusa Mahak) and VII (TPM-1) were strikingly divergent based on highest inter-cluster distance, indicating greater diversity. This was subsequently utilized in inter-mating i.e.TPM-1/DRMR-150-35; TPM-1/KMR-10-2 & TPM1/Pusa Mahak for generation of wider variability and utilization in transgressive breeding for development of early –sown mustard. Minimum inter-cluster distance was observed between cluster I and cluster IV. Intra-cluster values varied from 0.00 (mono-genotype) to maximum 281.34 in cluster IV (comprised of the most heterogeneous genotypes) followed by cluster III. Harvest Index (45.01%) exhibited maximum contribution towards divergence followed by seeds/siliqua (22.86%), days to physiological maturity (15.80%) and length of primary mother axis (14.45%). Conclusively, based on contribution towards total divergence, inter-cluster distance and cluster mean performance, clusters VII, V and VI genotypes viz. TPM-1;DRMR-150-35 and KMR10-2, Pusa Mahak were most promising divergent genotypes of Indian mustard and could be effectively utilized in hybridization – selection breeding programme to develop early –sown Indian mustard.

Marker-trait association studies for morpho-biochemical traits and yield attributes under water stress conditions using diversity fixed foundation set of *B. juncea*

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Drought induced changes in morpho-biochemical traits and yield attributes were investigated for a set of 96 diversity fixed set of *B. juncea* genotypes under irrigated and rainfed conditions at three different plant growth stages (vegetative, flowering and podding). Water stress significantly increased the activity of anti-oxidative enzymes (peroxidase, superoxide dismutase, catalase) and content of non-enzymatic metabolites (MDA, proline, reducing sugar, chlorophyll, carotenoid), as compared to irrigated conditions. Reduced trait performances were indicated for yield and component traits under water stress conditions. However, defensive responses varied. Maximum activities for defense enzymes and non-enzymatic metabolites were recorded during flowering. A significant positive correlation among the enzymatic antioxidants was observed as these act synergistically to defend against negative effects of reactive oxygen species (ROS). All the non-enzymatic metabolites except malondialdehyde (MDA) showed a positive correlation with the anti-oxidative enzymatic traits. Apparently, these enzymes must be acting to protect the plants from oxidative injury by reducing MDA content and consequently membrane damage. A positive correlation was also observed among morphological and yield attributes. Correlation studies indicated that drought tolerance was associated with the more efficient antioxidant system. Drought tolerant cultivars showed superior morphological, physiological and biochemical adaptations to reduced water availability. Ten genotypes; PBR-357, CSR-7, PLM-2, PRG901, MCN-12-42, NRCQR-376-1, DJ-124-1-76, LES-38, PRG-901 and JJ-210-5-4 were identified for higher stress tolerance and yield potential. Marker-trait association studies helped to identify 22 QTLs for POD, SOD, CAT, reducing sugars, proline, chlorophyll, silique length and yield. As limited information is available for tagging of various biochemical components under water stress conditions, our study could help in unravelling genetics of these biochemical traits in response to water stress. Several of the major QTLs identified in this study may be good sources of favorable alleles for marker-assisted selection and targeted trait introgression.

BLUP based breeding values of advanced lines of Indian mustard for seed yield and biotic stresses

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In plant breeding, specialized mating designs such as diallel and line x tester are generally used to estimate General Combining Ability (GCA) for assessing breeding value of parents. Though, these mating designs partition genetic effects of a genotype into additive effects vis-à-vis non-additive effects (Specific Combining Ability; SCA), but these have some limitations such as a few lines can be examined for GCA coupled with that of SCA effects which comprise of both dominance as well as epistatic effects at a few locations. Hence, the role of

additive × additive epistasis becomes less ideal in self-pollinating crops or inbred lines as inbreeding will eliminate dominance effect alongwith dominance × dominance interactions. This limitation of mating design can be overcome with BLUP (Best Linear Unbiased Predictions) of breeding values for selecting superior genotypes because BLUP allows using information from relatives through coefficients of parentage (COP). Thus, in the present study, breeding values and epistatic effects were estimated for 41 genotypes of Indian mustard, *Brassica juncea* (L.), having unbalanced data from five experiments over two years i.e. 2011-12 and 2012-13 at PAU Regional Research Station, Bathinda for seed yield and reaction to biotic stresses (white rust and mustard aphid). The present set of germplasm comprised of half sibs, full sibs and unrelated strains. For seed yield, genotypes such as PBR 418, PBR 417, PBR 357 and PBR 422 showed high GCA effects, while, PBR 418, PBR 392, PBR 417 and PBR 357 exhibited high score for SCA contribution. Strains PBR 418, PBR 417, PBR 422 and NRCDR 2 had high additive effects for resistance to whit rust (*Albugo candida*), while epistatic effects in genotype(s) PBR 418, PBR 417, PBR 422 and PBR 378 indicated that gene interaction is important for late sown condition for this biotic stress. Similarly for mustrd aphid (*Lipaphis erysimi*) infestation, the contribution of additive vis-à-vis non-additive effects had differential response among the present set of genotypes. Genotypes viz., PBR 417, PBR 391, PBR375 and PBR 385 showed additive while PBR 417, PBR 385, PBR 418 and PBR 375 non-additive effects for mustard aphid tolerance. Thus, from the present investigation it can be concluded that strains such as PBR417, PBR 418 and PBR 422 are good candidates for further genetic improvement for seed yield coupled with tolerance to biotic stresses in south-western Punjab’s agro-climatic conditions.

Mitigating effects of climate change and development of thermo-tolerance in Indian mustard

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Rapeseed-mustard (*Brassica* spp.) is a major group of oilseed crops of the world with India being the second largest cultivator after China. It is the major *Rabi* oilseed crops of India next to groundnut, both in area and production and accounts for about 25% of total oilseed production. Heat stress due to high ambient temperatures is a serious threat to crop production worldwide and negatively affects plant growth, development and crop yield. Mustard is much sensitive to climatic variables which could significantly affacts its production. High temperature adversely affects rapeseed-mustard at germination, seedling and pod filling stage. Heat stress at seedling stage is a problem unique to India where it is sown in the post-monsoon season, when average day time temperatures exceeds the recommended maxima. A rise of 3^0C in maximum daily temperature (21-24^0C) during flowering and grain filling causes a decline of 430 kg/ha in canola seed yield. Thus, it is crucial to develop seedling thermo-tolerant Indian mustard varieties to mitigate the losses occurring due to stress which will also help in early sowing of the crop. Suitable screening methods need to be developed and tested so that more heat tolerant lines can be included in *Brassica* breeding programs. Plants possess a number of adaptive, avoidance or acclimation mechanisms to cope with heat stress. The physiological and biochemical responses to heat stress are active research areas and the molecular approaches are being adopted for developing thermo tolerance in plants. Development of new crop cultivars tolerant to high temperature is a major challenge for plant scientists. Molecular approaches have included omics techniques and the development of transgenic plants through manipulation of target genes. Investigation of underlying molecular processes may provide ways to develop stress tolerant varieties and to grow agriculturally important crop plants under high temperature. Thus, it has become a major concern for crop production worldwide; keeping in view the elevated temperatures it has become the need of hour to study the plant responses and adaptation mechanisms underlying it to develop heat-tolerant varieties to mitigate the climate change.

Evaluation of genotypes for physiological traits responsible for terminal heat stress in *Brassica juncea*

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Heat stress is a major problem for the agricultural crops. Late sowning of the *rabi* crop of *Brassica juncea* because of late harvesting of earlier *kharif* crop is the major cause which results in terminal heat stress for mature crop. The research on the genetics of the terminal heat stress tolerance responsive traits in *B. juncea* is scanty. The present study proposes to study the genetics of the terminal heat stress responsive traits using the physiological traits *viz*., relative water content, excised leaf water loss, membrane susceptibility index and chlorophyll stability index. A field experiment with half diallel analysis using 6 parents (PM 26, Bio 902, EJ 20, PM 21, EC 597325 and NPJ 119) and their 15 F_1s is being carried out. These physiological traits along other yield and yield contributing traits like seed index, oil content and number of pods on the main branch will be studied to evaluate superior genotypes for terminal heat stress.

Identification of Heat Tolerant Donors in Indian mustard (*Brassica juncea* L.)

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Low yield and impact of climate change on Indian mustard production highlights the need to improve productivity in north western India. Climate projections suggest concurrence of high temperatures within drought-prone areas. Research in model species suggests that tolerance to drought and heat stress together is genetically distinct from tolerance to either stress alone. In this study, 30 Indian mustard genotypes (tolerant and susceptible to heat) were evaluated in a complete randomized block design with three replications during *rabi* 2015-16 under heat stress (early sown) and normal (optimum time) environmental conditions. The genotypes were selected from the reports of All India Coordinated research Project on Rapeseed-Mustard. The analysis of variance for 17 physio-morphogical traits, showed highly significant difference among the tested genotypes except for oil content in normal conditions, indicating towards presence of sufficient amount of genetic variability in the experimental material. Results indicated that most of the genotypes responded differently under normal and heat stress conditions. The population survival at 10 and 25 days after sowing (DAS) decreased with incresed heat stress in all the

genotypes. However, the decrease was lesser in DRMRHT-13-7, Urvashi, DRMR-541-44, DRMR-1165-40 and RH-555. Membranes are the main loci affected under heat stress conditions. In this investigation, membrane stability index (MSI) increased under heat stress in most of the genotypes. Among the genotypes MSI was high in DRMR-541-44, Urvashi, DRMRHT-13-7, RH-555 and DRMR-1165-40 under normal and stress conditions. High heritability estimates coupled with high to moderate genetic advance as per cent of mean was recorded for siliqua per plant (SPP), population survival at 25DAS, excised leaf water loss (ELWL) and seed yield per plant (SYPP) under normal and heat stress conditions indicating the role of additive gene action for its inheritance and could be improved through selection. Based on heat stability index, yield stability ratio, siliqua per plant, higher RWC and MSI values; genotypes DRMRHT-13-7, DRMR-541-44, DRMR-1165-40, RH-555 and Urvashi were identified as heat tolerant at seedling stage.

Screening of mustard genotype for high temperature tolerance at terminal stage

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Twenty six genotypes of mustard were sown under two environments created by staggering the date of sowing. First sowing was done on October 31 (normal) and second on November 30 (late) when the crop encounters high temperature stress at oilseed Research Farm, Kalyanpur, Kanpur. The first sowing escapes high temperature stress and the late sown crop encounter stress at seed filling stage. Study revealed that seed yield, number of seeds per siliqua, number of siliquae on main shoot, 1000 seed weight and siliquae density were reduced under late sown conditions when compared with timely sown conditions. Out of twenty six genotypes RMWR 209-5-1 , NPJ 191, RK (E) 8-1, RHO 923, DRMR 1566-1, LES 49, PRO 5222 and DRMR 1153-12 showed minimum per cent reduction in seed yield (<20%) under late sown and were rated as tolerant to high temperature at terminal stage.

Influence of cytoplasms and nuclear backgrounds of parental lines on fertility restoration in *Brassica juncea* [(L.) Czern and Coss] hybrids

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Heterosis in oilseed *Brassica* can be exploited commercially using efficient hybrid seed production options such as Cytoplasmic Male Sterility- Fertility Restoration (CMS-FR) system. Diversification of cytosterility sources is one of the major objectives in most of the crops. Information on stability of fertility restoration in hybrids developed from parental lines having different cytoplasmic and nuclear backgrounds is necessary for diversification of CMS-FR systems. Fertility in new cytoplasm donors viz., *Diplotaxis erucoides (eru)* and *Diplotaxis berthautii (bar)* can be restored by a common restorer derived from *Moricandia arvensis (mori)* in *B. juncea*. Therefore, it was important to check if some variation exists for fertility restoration in isonuclear lines, possessing different cyto-sterility sources (*mori*, *eru* & *bar*), by a common restorer gene in different nuclear backgrounds. Isonuclear alloplasmic cytoplasmic male sterile (CMS) lines with *mori, eru and bar* cytoplasms were developed in the six diverse *B. juncea* genetic backgrounds (NPJ 112, NPJ 139, LES 1-27, SEJ 8, EC 308575 and Pusa Agrani). Each of these eighteen CMS lines were crossed with six locally developed restorers possessing fertility restorer gene from *mori* to observe the effect of sterile cytoplasms and nuclear backgrounds of parental lines (A & R) on fertility restoration. Comparison of the mean percent pollen fertility in 108 single cross hybrids, 36 hybrids in each cytoplasms, revealed that the hybrids based on *mori* cytoplasm was significantly different from the ones possessing *bar* & *eru* cytoplasms. Paired comparisons of the mean per cent pollen fertility of hybrids revealed that the per cent pollen fertility in hybrids was influenced by the genetic backgrounds of parents. Although, this effect was not consistent for any cytoplasm or nuclear background of parent. The linear regression analysis between per cent pollen fertility and number of seeds per siliqua in hybrid plants, both under open and self pollinated conditions, indicated that there is no significant relationship between them. This study demonstrates that there was no consistent effects of nuclear background and cytoplasm on fertility restoration and no significant association between the variation in pollen fertility and the seed set in hybrids. Therefore, the use of new cyto-sterility sources *viz., eru* & *bar* along with *mori* is advocated for diversification of parental lines and sustainable exploitation of heterosis in Indian mustard.

Electron microscopic appraisal to reveal the pollen morphology in *fruticulosa* cytoplasmic male sterile line of *B. juncea* and its fertile maintainer

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Electron microscopy is an excellent approach to study the ultra architecture of cells. We carried out scanning and transmission electron microscope imaging to study the surface properties and ultra-structures respectively of the sterile and fertile pollen grains of newly developed *fruit* CMS system in *B juncea*. Such studies are useful as wall architecture is critical for pollen viability. It is also known that some meiosis pathway genes are the key regulators for the sexine and nexine formation. For the present studies,anthers were extractedfrom both the sterile and fertile plants and fixed for scanning electron microscopy as per standard protocol. The samples were sputter coated and viewed under Scanning Electron Microscope (Hitachi S3400N). SEM imaging was carried out by secondary electrons at 15.0 KV under high vacuum conditions at various magnification levels. Scanning electron micrographs revealed that in fertile anthers the pollens were densely packed with average length of polar axis (P) at 19.300 µm (with the whole range 16.00-22.00 µm) and equatorial axis (E) 22 µm (with the whole range 21-24.6 µm). P/E value oscillated from 0.76 to 0.89, with the mean value 0.85. The grains were mostly sub spheroidal in shape, with equatorial outline circular or lobate. Three-four zonocolpate pollen grains were observed. Colpi were comparatively narrow and deeply sunken in exine, with acute endswith the colpus almost running the full length of the grain and terminating at the poles. Exine thickness was around 4-5µm. All grains were with tectum perforatum and with cross reticulate type of ornamentation with perforations. Lumina of different sizes were visible which were polygonal in shape. Muri as visible had the rounded edges with single rows of columellae (Fig2). On the contrary no or very few distorted and flattened pollens were seen in sterile anthers

(Fig 1b). Transmission micrographs of sterile anthers revealed that the outermost wall of the anther is intact showing innermost intine and outermost exine with intact baculae and periplasmic space in between. Feeble tectum, baculae and nexine are visible in the micrographs. In the cytoplasmic space various vacuole like structures, deeply stained vacuoles double layered structures that could possibly be mitochondria were visible in micrographs.

Evaluation of hybrid seed purity in Indian mustard hybrid NRCHB-506

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Hybrid technology has been recognized in the field and vegetable crops worldwide. In Indian mustard, the first public bred hybrid NRCHB-506 has been developed at Directorate of Rapessed-Mustard Research, Bharatpur in 2009. The yield superiority of the hybrid is fully realized once the hybrid shows very high level of genetic purity. Studies have been conducted for two years to evaluate the hybridity of hybrid seed produced under open field conditions vis-à-vis the female line seed purity. The hybrid and female plants were selfed and pollen fertility/sterility of the flowers of each plant was observed under a compound microscope. The results showed that about 18-21% plants in the hybrid had sterile pollen and no seed set upon selfing while the female parent plants had sterile pollens that resulted no seed setting upon selfing of the inflorescences. An evaluation of fertile and sterile plants for seed yield indicated that the sterile plants had lower seed yield and yield attributing traits under open pollination. The study concluded that the CMS line breeds pure but due to impurity in the restorer line in terms of fertility restorer gene(s) the hybrid purity of the resultant hybrid was lower than the expectation. However, some more studies are required to be undertaken to reach to a minimum level of genetic purity of hybrid in Indian mustard without a significant loss in *per se* yield potential.

Genetic basis of heterosis for seed yield in Indian mustard (*Brassica juncea* L.)

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Mustard is predominantly a self pollinated crop and the exploitation of hybrid vigour will depend upon the direction and magnitude of heterosis, biological feasibility and the gene action involved. Since, heterosis has an important role in all the plant breeding programmes; it would be very helpful to know the relationship between heterosis for seed yield and its components. To understand the role of epistasis in the genetic control of heterosis for yield and component traits four families viz; PR-2009-6×Albeli (Family A), PR-2009-6×RGN-73 (Family B), PR-2009-6×NDYR-8 (Family C) and KMR-13-3×PR-20 (Family D) comprising six generations were subjected to joint scaling test for obtaining estimates of gene effects. On the basis of estimated gene effects, expected heterosis was calculated and compared with the observed heterosis. The results showed that the heterosis manifested in different crosses was in general low, being significant in all crosses for seed yield. The relative magnitude of observed heterosis for seed yield was highest in Family D (15.67%) followed by in Family B (13.87%), C (13.47%) and A (11.97%). The estimated heterosis based on gene effects was positive in all the four families. Manifestation of observed heterosis for number of primary branches/plant was positive and significant in families A and C. The estimates of relative heterosis in different crosses ranged from 13.48% in Family A to 2.42% in Family B. The observed heterosis for number of secondary branches/plant was significantly positive and of high magnitude in Family B (18.95%) and D (35.68%). In epistatic crosses high heterosis resulted from larger estimate of either [h] or [l] or both and a lower magnitude of [d] and [i]. In Family B heterosis for seed yield was solely due to larger magnitude of [l]. Similarly for secondary branches per plant [l] was responsible for high heterosis in Families B and D. It is, therefore, apparent that most of the characters in all the four families were observed under the control of both fixable (additive, additive x additive) and non fixable (dominance and epistatic) gene effects coupled with duplicate type of epistasis. Presence of fixable component of variation in several characters indicated that selection will be effective even in early segregating generations. The magnitude of dominance and epistatic effects present in the material examined may be exploited through appropriate recurrent selection procedure.

Combining ability and heterosis for seed yield and its component traits in Indian mustard (*Brassica juncea*)

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Indian mustard (*Brassica juncea*) is the second most important oilseed crop in India after soybean in terms of production, however due to more oil content (ranging from 35-45%) it ranks firts in terms of oil yield among oilseeds crops. It is cultivated in the area of 6.5 million ha with 8.02 million tons of production and 1262 kg/ha productivity, respectively. However, productivity of rapeseed-mustard in minor mustard producing state like Jharkhand (690 kg/ha) is far below the national average. To address these facts, study was planned to carry out pooled analysis of combing ability and heterosis on 40 hybrids developed by crossing 8 lines (including 4 locally adapted genotypes) with 5 testers in line x tester design, under three dates of sowing i.e. 21st October, 6th November and 21st November. The pooled analysis of variance revealed sufficient differences among environments, parents, hybrids and parent vs. hybrids for most of the traits studies. Both additive and non-additive types of gene actions were observed for seed yield and its component traits. Estimates of GCA effects indicated that NRCHB-101, Pusa Bold, RGN-73 were good general combiners for seed yield per plant and yield contributing traits like 1000-seed weight, siliqua length, number of primary and secondary branches. Pusa Mustard-25, on the other hand, showed good combining ability for dwarfness and early maturity. Four hybrids for number of primary branches, 10 for number of secondary branches, 9 for 1000-seed weight, 2 for number of siliqua on main shoot and number of seeds per siliqua showed significant positive SCA effects. Hybrids viz., NRCHB-101 x EC552577, NRCHB-101 x BPR 543-2, Pusa Mustard-25 x EC552577, BAUM-2007 x EC552577 and BAUSM 92-1-1 x RGN-73 had significantly high sca effects, >15% heterobeltiosis and high *per se* performance for seed yield per plant. The hybrids like Pusa Mustard-25 x RGN-73, BAUSM 92-1-1 x EC552577, BAUM-2007 x Pusa Mustard-21, BAUM-2007 x RGN-73, BAUSM 92-1-1 x Heera observed high sca effects for earliness. The parents having good combining ability, high sca effects and high heterobeltiosis in pooled analysis would be identified as promising genotypes for converting into parental lines for development of hybrids for improved seed yield under different dates of sowing. This shall help in overcoming the yield barrier imposed by delayed sowing of Indian mustard.

Heterosis and combining ability in F_1 and F_2 generations of Indian mustard for seed yield and its attributes

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Studies on heterosis and combining ability are useful in formulating effective breeding strategies and choice of suitable parents for crosses in different breeding programmes. Combining ability analysis on F_1 generated in Line x Tester fashion in Indian mustard revealed that general combining ability effects of the parents had a positive association with their per se performance. EC401574, Pusa Bold and Rajendra Sufalam for seed yield and number of siliqua on main raceme, RAURD 153, RAURD 34 and RAURD 32 for days to flowering and main shoot length, EC 399788 for number of siliquae per plant and number of secondary branches per plant were observed as good general combiners. In most of the crosses, the specific combining ability estimates for most of the traits were higher in the F_1 than in the F_2. Hybrid generated from the cross EC 401574/Rajendra Sufalam recorded better parent heterosis and specific combining ability for number of siliqua per plant followed by seed yield per plant and number of secondary braches per plant. It was evident from the two analyses that additive and non-additive gene effects were important for the inheritance of different characters studied. However, the relative magnitude of non-additive component was higher than additive component for all the characters in both the populations. Hybrid from cross RAURD 153 x Pusa Bold for number of primary branches per plant, EC 399788 x Pusa Bold for secondary branches per plant, EC 401574/ Rajendra Sufalam for seed yield per plant, number of siliqua per plant and siliqua on main raceme, RAURD 214/ Rajendra Sufalam for siliqua length and RAURD 32/Vardan for seeds per siliqua manifested high SCA as well as heterotic effects. Such crosses are expected to deliver better segregants for yield and its components in the subsequent generations which can be exploited effectively for mustard improvement. Repeated crossing and modified recurrent selection in the segregating generations may prove useful in improving seed yield, other contributing traits in Indian mustard.

Heterosis for seed yield and other agronomically important traits in *Brassica* species

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Heterosis has extensively been explored and utilized for improving various yield and quality traits in brassica and other crops. Rapeseed (Brassica napus L.) oil ranks third behind soybean and oil palm showing the importance of this product. Rapeseed breeding strategies are mostly dealing with developing cultivars characterized by high and stable seed and oil yield, as well as by low content of glucosinolates and erucic acids for human consumption. Seed yield and oil contant are quantitative traits, which are highly influenced by environmental and genotype-environment interaction. Therefore, identifying potential parental material for producing high yielding varieties and to isolate better parental line for hybrids is a common practice. Understanding the underlying gene action in a set of diverse material shall help in defining breeding strategy for improving selection efficiency and identifying heterotic combination. Keeping this in mind crosses were attempted in diallel fashion among diverse parents. Observations were recorded in F_1 generation on oil yield, oil percent, number of primary branches per plant, number of pods per plant, number of seeds per pod, oil percent, seed yield per plant and oil yield. The crosses namely C-93 x C-90, C-93 x C-16, GM 1 x GM 3, GM 3 x SKM 139 and GM 1 x RK 9501 had shown high heterotic response for seed yield/plant. Similarly, hybrid from the crosses C-88 x C-97 and C-13 x C-16 recorded high heterosis for number of primary branches per plant, whereas, hybrid from cross C-88 x C-93 observed maximum heterosis for oil content. Hybrids GM 3 x SKM 139 and GM 3 x C-16 observed high heterosis for number of pod per plant. Based on the findings of this study improvement in yield and oil quality traits can be achieved through developing high yielding *Brassica* hybrid cultivars.

Heterobeltiosis and economic heterosis for yield and its attributes in taramira (*Eruca sativa* Mill.)

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Eight genetically diverse open pollinated populations of Taramira were crossed in diallel fashion (excluding reciprocals) during *Rabi* 2013-2014 season. The resultant 28 F_1 progenies along with eight parents were evaluated in RBD, by keeping 3 replications, under four environments during *Rabi* 2014-15 at Agricultural Research Farm of S.K.N. College of Agriculture, Jobner. Specific heterosis (S_{ii}) was also significant for all characters in all the environments except days to flowering in the environment-I and days to flowering and days to maturity in environment-III. Among the parents RTM-1359 and RTM-1375 in all the environments, RTM-314 in the environment-II and III were found to be superior based on *vi* effects and *per se* performance not only for seed yield per plant but for some of the other yield traits studied. Crosses T-27 x RTM-2002 and RTM-1415 x RTM-2002 observed significantly high positive heterobeltiosis in all the four environments, whereas, crosses RTM-314 x RTM-1359 and RTM-1415 x RTM-2002 showed significantly high positive economic heterosis in all the four environments. Interestingly, these crosses also had desirable $s_{ii'}$ effects in all the environments. These crosses were also consistently superior for several other characters in each environment. On the basis of *hi* values RTM-1375 in environment-I, RTM-314 in environment-II, RTM-1415 and RTM-1359 in the environment-III and RTM-314 and RTM-1359 in environment-IV were identified as superior. It was therefore recommended to include these parents in hybridization programme to improve seed yield and seed quality. Highly heterotic crosses identified in this study viz., RTM-1351 x RTM-314, RTM-314 x RTM-1359, RTM-1415

X RTM-2002 and T-27 x RTM-2002 were desirable as they had observed high seed yield per plant, high S_{ii} values, with high heterobeltiosis and economic heterosis for yield and yield contributing traits. Development of inbreds is not feasible because of sporophytic self-incompatibility although parents RTM-1375, RTM-1415, RTM-314, T-27 and RTM-1359 can be used in development of high yielding synthetic varieties having high seed yield and oil content.

Studies on combining ability parameters for seed yield and its related attributes in Indian mustard [*Brassica juncea* (L) Czern and Coss.]

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An experiment was carried out at Oil Seed Research Farm, Kalyanpur, of C.S. Azad University of Agriculture and Technology, Kanpur, during *rabi* 2014-15. Seven strains/varieties viz. Varuna, Maya, RL 198, NDR 8501, RK 2012, Pusa Bold and Bio 902 were crossed in diallel mating design excluding their reciprocals. Twenty eight treatments (7 parents and 21 crosses) were evaluated for 10 characters, viz., days to flowering, days to maturity, plant height (cm), length of main receme (cm), number of siliquae/plant, number of primary branches/plant, number of secondary branches/plant, oil content (%), seed size and seed yield/plant (g). The results indicated that additive type of gene action was more prominent than non-additive type for most of the characters. The estimates on average degree of dominance indicated presence of partial to over dominance for most of the characters. Combining ability analysis revealed that good general combiners were found. Bio 902, Varuna and Maya for high oil content and Varuna, Maya, RK 2012 and Bio 902 for high seed yield/plant. Out of 21 crosses, 12 crosses viz., Maya x Pusa Bold, Varuna x Maya, Varuna x Bio 902, Maya x Bio 902, NDR 8501 x Bio 902, Pusa Bold x Bio 902, Varuna x RK 2012, Maya x RK 2012, RLM 198 x Bio 902, RK 2012 x Bio 902, Maya x NDR 8501 and RK 2012 x Pusa Bold showed good specific combining ability for high seed yield/plant. Heterosis over economic parent was found in only one cross Maya X Pusa Bold for seed yield/plant. Seed yield/plant was significantly co-related with number of siliquae per plant, number of primary branches per plant and seed size. High heritability coupled with high genetic advance was found for seed yield/plant, number of primary branches/plant, seed size, length of main raceme and number of secondary branches/plant. These characters may be utilized in effective breeding programmes in *Brassica*.

Multivariate analysis for evaluation of Indian mustard genotypes for different traits

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Multivariate analysis was carried out with 20 morphological (including quantitative as well as qualitative) and five oil quality traits in 43 genotypes of Indian mustard [*Brassica juncea* (L.) Czern & Coss.]. Principal factor analysis led to the identification of nine principal components (PCs) which explained about 77% variability. The first principal component (PC1) explained 16.65% of the total variation. The remaining PC's explained progressively lesser and lesser of the total variation. Varimax Rotation enabled loading of similar type of variables on a common principal factor (PF) permitting to designate them as seed yield and component traits leaf, oil and its quality factors. Based on PF scores, the genotypes viz., RH(OE)0801, EC597320, EC597341, EC597344, EC592579, EC592584 and JM6014(YS) have been identified superior for seed yield/plant, while the genotypes JM6009, JM6011, EC697334 and ZEM-1were found superior for oil content. Similarly, the genotypes JM6009, NUDBYJ-10, Pusa Mustard-21, RLC-2 and ZEM-2 showed superiority for erucic acid, whereas genotypes JM6004(YS), JM6026 and EC552583 exhibited superiority for glucosinolate content. These genotypes may further be utilized in breeding programmes for evolving mustard varieties having high seed yield and oil content; and with superior oil quality. Hierarchical cluster analysis resulted into eight clusters containing one to 16 genotypes. The results of cluster and principal factor analyses confirmed each other.

Phenotypic stability for seed yield and related traits in Trombay mustard genotypes under North western Himalayas

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Rapeseed-mustard group of crops are grown over an area of 11.37 thousand ha with total production of 6.37 thousand tonnes and productivity of 590 kg/ha which is much lower than the national average. The major constraint for realization of full yield potential is the limited availability of high yielding varieties suitable for cultivation under varied agro-climatic conditions. Genotype × environment interaction is of major importance to a plant breeder to develop high yielding and stable mustard genotypes which can withstand fluctuating environmental conditions and produces commercially satisfactory harvest. Keeping this in view, the present study was conducted to evaluate different Trombay mustard genotypes for their stability in yield performance under varied agro-climatic conditions. Five promising Trombay mustard genotypes viz., TM-136, TM-172, TM-204, TM-215 and TM-224 were evaluated along with three checks viz. Kranti, RL-1359 and RCC-4 in eleven environments spread over different agro-climatic zones of Himachal Pradesh during *rabi* 2012-13 to 2015-16, for stability parameters regarding four characters such as plant height (cm), number of siliquae per plant, maturity duration (days) and seed yield (kg/ha). Pooled analysis of variance for stability revealed significant differences among different genotypes for plant height, days to maturity and seed yield indicating that the genotypes selected possessed significant variation for these characters. Significant mean squares due to environments confirmed that the environments selected were variable in nature which influenced the expression of all the characters under study. Significant mean squares for genotype×environment interaction revealed the differential response of Trombay mustard genotypes over environments for plant height, days to maturity and seed yield. The partitioning of environment + (genotype × environment) mean squares into different components revealed that the linear component of environment appeared to be highly significant for all the characters under study which indicated large macro-environmental differences in four years for these characters. All the eight genotypes were tested for three stability parameters viz. mean, bi and S^2di. Out of eight genotypes, only one genotype viz. TM-224 was identified to be stable for dwarf plant height. The genotypes such as TM-172, Kranti (national check) and RL-1359 (zonal check) exhibited higher siliquae per plant than the overall population mean and stability for this character. The two genotypes viz., TM-136 and Kranti exhibited stability for early maturity while none of the genotypes exhibited stability for seed yield across the varied environments. The check Kranti appeared to be average in performance and stability for seed yield though, the values were slightly lower than the population mean. Thus, these genotypes may be involved in breeding programme to develop high yielding and stable genotypes over different environments or could be recommended for cultivation across the environments.

Stability analysis of Indian mustard [*Brassica juncea* (L) Czern & Coss] genotypes

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Mustard is grown in diverse agro-climatic conditions in India; however, the crop is affected by several environmental factors at different growth stages due to climate change. Development of the variety which give desirable and stable yield under changing environmental conditions play a vital role to enhance the mustard productivity. In this context the stability parameters along with per plant performance of 14 promising genotypes of Indian mustard were worked out for eight quantitative traits under five different environments viz., Sardarkrushinagar, Junagadh, Amreli, Vijapur and Derol. Significant differences among the genotypes were observed for all the characters except days to maturity, seeds per siliqua and seed yield per plant. Genotypes×environments interactions were observed significant for all the characters. Environment (linear) interaction component was also significant for all the traits studied whereas; the linear component of environment interaction was significant for length of siliquae and number of siliquae per plant. The variance due to pooled deviation (non linear) was highly significant for all the traits except for number of siliquae per plant which reflected presence of considerable genetic diversity in the tested material. A variety may be said to be stable over different environments if it shows unity or less than unity regression coefficient (bi) with lowest deviation (non significant) from linear regression (S^2di). In the present investigation, genotypes SKM 1219 and SKM 1428 were stable for days to flowering as well as maturity, SKM 1414, NRCHB 506, SKM 1404 and SKM 1219 for length of siliquae, Kranti, SKM 1413, GDM 4 and SKM 1219 for seeds per siliquae; GDM 4 and SKM 1428 for test weight were found to be stable over varying environmental conditions. The genotypes viz., SKM 1424, SKM 1413 and SKM 1219 were stable for seed yield per plant. Further, the genotype SKM 1219 was observed to be desirable and stable for other yield contributing characters like days to flowering, days to maturity, length of siliquae and seeds per siliquae. In addition to that the genotype SKM 1305 was having high seed yield, S^2di = 0 and b > 1 indicating that this genotypes would perform better under favourable environmental conditions. Thus the genotypes, SKM 1219, SKM 1424 and SKM 1413 could be effectively utilized in future breeding programme to increase seed yield in Indian mustard.

Gene X environment interaction in different varieties of Indian mustard [*Brassica juncea* (L.) Czern & Coss]

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Most of the agronomic traits are highly influenced by environmental conditions and genetic gains from such traits are primarily conditioned by effective selection methodology. Thirty varieties of Indian mustard [*Brassica juncea* (L.) Czern & Coss] were evaluated for stability over three different environments created by three different dates of sowing during *Rabi* 2013-14. Environment wise analysis of variance revealed that in all the three environments significant differences were observed for all the characters. The stability analysis following Eberhart and Russell (1966) model revealed that based on stability parameters varieties RGN-48, RGN-73, Maya, PCR-7, CS-52 and RH-749 were stable and desirable because these had high mean, regression coefficient equivalent to unity and S^2d were non- significant and near to zero. Thus, these varieties are desirable over wide range of environmental conditions. Varieties RGN-13, RGN-229, RGN-236 and RGN-303 had superior performance and responded well to optimum sowing conditions as they exhibited greater mean with significantly higher regression coefficient. Thus, these varieties namely- RGN-48, RGN-73, Maya, PCR-7, CS-52, RH-749, RGN-13, RGN-229, RGN-236 and RGN-303 should be used in hybridization programme to produce genetically superior gene pool.

Studies on selection parameters for seed yield and its components in Indian mustard

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Indian mustard [*Brassica juncea* (L) Czern & Coss] is a major oilseed crop accounting for more than 80% of the area under rapeseed-mustard, followed by toria, yellow sarson and brown sarson. Assessment of genetic variability is a logical way to initiate any breeding programme. The variability study ensures identification of traits that offer substantial scope for improvement through selection. The exploitable variability is, therefore, required to be judged through various genetic parameters like heritability, genetic advance and others. The present investigation was carried out in a set of 10 genotypes of Indian mustard of diverse origin involving two genotypes suitable for early sown (PRE-2011-15, PM-2), six for timely sown (Divya-55, Maya, DRMR-675-39, RRN-778, RB-57 and RMM-09-4) and two for late sown (PRL-2012-13, NRC-HB-101) situation. The parents and their 45 F_1's along with one standard variety (Kranti) were evaluated in a randomized block design with three replications during *rabi* 2015-16. Heritability (broad sense) ranged from 0.29 to 0.98 and genetic advance varied from .043 to 26.67. Higher heritability in broad sense (h^2_b) was associated with high genetic advance for glucosinolate content, number of siliquae on main raceme, plant height and days to maturity which suggested that these characters were controlled by considerable proportion of genetic variance in the material studied. Predictability ratio was less than unity (0.098-0.400) and an average degree of

dominance (1.55-3.38) exhibited presence of over dominance for most of the characters. High magnitude of σ^2S and σ^2D coupled with over-dominance for most of the characters indicated preponderance of non-additive gene effects suggesting its exploitation through heterosis breeding. Narrow sense heritability (h^2_n) was moderate (0.30-0.10) for seed yield/plant (0.28), length of main raceme (0.25), glucosinolate content (0.20), test weight (0.15), oil content (0.14), days to maturity (0.14), number of primary branches/plant (0.13), length of siliqua (0.12) and number of siliquae on main raceme (0.11); and low (<0.10) for remaining characters. Moderate to low h^2_n further suggested limited scope of improvement through selection and perceptible advantage of heterozygosity.

Genetic architecture for yield and its related traits in Brown sarson (*Brassica rapa* L.) under temperate conditions

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A study was undertaken in brown sarson through diallel analysis involving ten diverse genotypes. The analysis revealed significant mean squares for general and specific combining ability for all the traits studied. The estimates of variance due to dominance ($\sigma^2{}_D$) were much higher than the corresponding additive genetic variance ($\sigma^2{}_A$) for all the traits. The predictability ratio was less than unity for all the traits which indicated that performance on general combining ability of parents alone would not be advisable to select materials in segregating generations, but a combination involving both general and specific combining ability of the parents and particular crosses along with their *per se* performance would be more useful in selecting materials in the segregating generations. None of the parents revealed significant and desirable gca effects for all the traits. The study of sca effects revealed that none of the cross observed specific combining ability for all the traits under study. However, several cross combinations were observed to have highest desirable significant sca effects for these traits.

Genetical analysis of F_1 and F_2 generations for qualitative and quantitative traits in yellow sarson (*Brassica campestris* (L.) var. yellow sarson)

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Twenty nine parents along with 100 F_1s and F_2s were sown in Randomized Block Design with three replications during *Rabi* 2014-2015 at Oilseed Research Farm, Kalyanpur of C.S. Azad University of Agriculture & Technology, Kanpur-208002. The observations were recorded on 15 characters namely, days to 50% flowering, days to maturity, plant height (cm), length of main raceme (cm), leaf area index (cm/m^2), number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, number of seeds per siliqua, biological yield per plant (g), 1000-seed weight (g), harvest index (%), oil content (%), protein content (%) and seed yield per plant (g). The analysis of variance indicated significant differences among the treatments for all the characters. Parents vs. F_1s, parents vs. F_2s and F_1s

vs. F_2s also revealed highly significant differences for all the characters except number of primary branches, number of secondary branches, days to maturity and oil content. Average degree of dominance $(\hat{\sigma}^2 s/\hat{\sigma}^2 g)^{0.5}$ was over dominant type for days to maturity, in both the generations. The parents namely, YSC-41, B-09, YSC-76, YSKM-11-1, YSKM-10-02, K-88, YSC-15, YSK-03, YSC-92, YSC-30, YSC-46, YSC-84, B-09, YSC-76, YSC-75, YSC-80, K-88, T-42, YSC-92, YSC-95, YSC-84, YSC-71, YSK-9-01, YSC-80, T-42, YSK-03, YSC-45, YSC-40, YSC-84 and NRCYS-05-02 were found to be good general combiners in both F_1 and F_2 generations on the basis of gca effects and *per se* performance for seed yield per plant. The cross combinations namely, YSC-63 x YSH-401, YSC-41 x NRCYS-05-02, YSC-41 x Benoy, B-09 x YSH-401, B-09 x Benoy, YSC-71 x NRCYS-05-02, YSC-71 x Pitambari, YSKM-11-02 x YSH-401, YSC-95 x Pitambari, YSC-71 x Pitambari, YSC-46 x Benoy and YSC-84 x YSH-401 were found common good specific combiners in both F_1 and F_2 generations on the basis of sca effects and *per se* performance for seed yield per plant. The cross combinations namely, B-09 x Benoy, YSKM-10-02 x Benoy, YSC-15 x Benoy, YSC-30 x Benoy and YSC-84 x Benoy were shown desirable and significant heterotic response over best and economic parent for seed yield per plant. The cross combinations namely, YSC-92 x YSH-401, YSC-45 x Pitambari, YSC-95 x NRCYS-05-02, YSC-40 x Benoy and YSC-84 x Pitambari showed negative and desirable inbreeding depression for seed yield per plant. High heritability was observed for 1000-seed weight (89.39g) and oil content (52.67%) in F_1 generation and for harvest index (30.97%) in F_2 generation. Among all the characters, the highest values were recorded for 1000-seed weight (89.39g) and harvest index (30.97%) in F_1 and F_2 generations, respectively. High genetic advance were observed for leaf area index ($F_1$76.45; $F_2$67.64) and 1000-seed weight ($F_1$36.60; 51.59). Among parents and F_1s, seed yield per plant showed positive and significant association with leaf area index (cm/m^2), number of secondary branches per plant, number of seeds per siliqua, harvest index (%), oil content (%) and protein content (%) at both phenotypic and genotypic level. Among parents and F_2s, seed yield per plant showed positive and significant association with number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, number of seeds per siliqua, 1000-seed weight (g), harvest index (%), biological yield per plant (g), oil content (%) and protein content (%) at both phenotypic and genotypic level. Number of siliquae per plant (0.1611), followed by 1000-seed weight (0.1358), oil content (0.1324), number of seeds per siliqua (0.1191), number of secondary branches per plant (0.1182), plant height (0.0947) and number of siliquae per plant (0.0613), followed by plant height (0.0714), number of secondary branches per plant (0.808), oil content (0.1806) and harvest index (0.2305) exerted very high and positive direct effect on seed yield per plant at both phenotypic and genotypic level among parents and F_1s, respectively. Plant height (0.0016), followed by harvest index (0.0660), leaf area index (0.0726), 1000-seed weight (0.0759), number of siliquae per plant (0.0953), length of main raceme (o.1271), number of seeds per siliqua (0.1340), number of secondary branches per plant (0.1787) and protein content (0.2745) and number of seeds per siliqua (2.1773), followed by length of main raceme (1.0040), protein content (0.1964), leaf area index (0.3026) and plant height (0.4316) exerted very high and positive direct effect on seed yield per plant at both phenotypic and genotypic level among parents and F_2s, respectively.

Estimation of different components of genetic variation for important quantitative traits in Indian mustard (*Brassica juncea* L.)

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Indian mustard (*Brassica juncea* L.) is an important oilseed crop of India and plays a vital role in vegetable oil economy of the country. The knowledge about genetic architecture of various yield attributes is vital for efficient selection of genotypes. Therefore, the present study was conducted at ICAR-DRMR, Bharatpur during 2013-14 to 2015-16 to detect epistasis and to estimate the additive and dominance components of genetic variation for seed yield *per se* and yield attributing traits using triple test cross (TTC) analysis. Twenty seven progenies were produced by crossing nine lines with three testers viz., NPJ 112, RRN 727 and their F_1 in triple test cross fashion. TTC set was evaluated in RCBD with 3 replications for 12 quantitative traits. Analysis of variance revealed the existence of epistasis for all the traits except secondary branches/plant and oil content. It's partitioning showed higher magnitude of (i) type for days to flowering, days to maturity and primary branches and (j+l) type for siliqua length, seeds/siliqua, 1000-seed weight and seed yield. Significant MS due to sums (L_{1i} + L_{2i}) and differences (L_{1i}- L_{2i}) for days to flowering, maturity, plant height, seeds/siliqua, 1000-seed weight and seed yield indicated the role of both additive (D) and dominance (H) variance in their inheritance. Estimates of D and H components revealed predominance of D for days to flowering, maturity, plant height, primary & secondary branches and 1000-seed weight; whereas, H was predominant for remaining 6 traits viz., number of siliquae on main shoot, main shoot length, siliqua length, seeds/siliqua, oil content and seed yield. Non-significant correlation coefficient for all the traits except 1000-seed weight indicated the scatter of dominant alleles among testers. Degree of dominance $(H/D)^{1/2}$ indicated over dominance for siliquae on main shoot, main shoot length, siliqua length and seeds/siliqua. Thus, epistasis was an integral component with conspicuous role of both additive and dominance variance for different characters. Therefore, the study will be helpful in deciding the breeding strategy that would enable to utilize maximum proportion of fixable as well as non-fixable genetic variation in Indian mustard.

Genetics of seed yield and its components under late sown conditions in Indian Mustard [*Brassica juncea* (L.) Czern. & Coss.]

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An experiment was carried out at Oil Seed Research Farm, Kalyanpur of Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, during *rabi* 2015-16. 7-parents/strains (Kranti, NRCHB-101, RLM-198, RGN-291, RH-30, Vardan and Ashirwad) were crossed in diallel mating design (excluding reciprocal). 28 genotypes (21 F_{1s} and 7 parents) were evaluated for 12 characters viz., days to 50% flowering, days to maturity, plant height (cm), number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, number of seeds per siliqua, 1000-seed weight (g), biological yield per plant (g), harvest index (%), oil content (%) and seed yield per plant (g). Analysis of variance revealed that the genotypes were significantly different from each other for all the characters. Genetic components analysis exhibited that both additive and dominance components were highly significant for almost all the traits indicating the role of both additive and non-additive gene action in controlling the expression of the concerned trait. In general, dominance component values were higher than that of additive component for all the traits. The estimates of average degree of dominance indicated presence of over-dominance for all the traits. Combining ability analysis revealed that good general combiners were NRCHB-101, Kranti and RH-30 for seed yield per plant. Heterotic combination over the economic parents viz., Kranti x NRCHB-101, Kranti x Ashirwad, NRCHB-101 x RLM-198, NRCHB-101 x RGN-291, RLM-198 x Ashirwad, RGN-291 x Ashirwad, RH-30 x Ashirwad and Vardan x Ashirwad for seed yield per plant were also recorded. The results revealed that heritability estimates were low for all the characters. The genetic advance in percent over mean was estimated for all the 12 characters which ranged from 0.07% for harvest index to 22.16 for number of siliquae per plant. The high values were recorded for number of siliquae per plant (22.16) and biological yield per plant (11.34). Seed yield per plant was positively correlated with number of primary branches per plant, number of secondary branches per plant, days to maturity, plant height, number of siliquae per plant, number of seeds per siliqua, biological yield, harvest index, 1000-seed weight and oil content.

Genetic variability, heritability estimation for yield and yield components in drought tolerant RIL population of Indian mustard (*Brassica juncea* L.) derived from Rohini x RH819

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This investigation was aimed to study the pattern of genetic variation among 215 RILs derived from cultivars Rohini (drought susceptible) and RH819 (drought tolerant). The RILs were characterized and evaluated under stress as well as irrigated conditions along with parents and checks in augmented block design. Observations were recorded on plant height, main shoot length, fruiting zone length, siliqua length, seeds/siliqua, biological yield (BY)/plant, 1000-seed weight, harvest index, seed yield/plant, oil content, glucosinolates, fiber and phenol content. Analysis of variance indicated that significant differences were found among RILs for all traits except oil content under irrigated conditions while under stress conditions they were non-significant for seed/siliquae and BY/plant. The range of seed yield/plant, harvest index, 1000-seed weight was 6.49-20.52g, 11.83-48.86%, 2.34-5.74g and 7.93-32.26g, 10.85-60.34%, 2.36-5.59g under stress and irrigated conditions, respectively. Genetic components such as GCV, PCV and high heritability estimates (>50) were also calculated. Seed yield/plant was significantly and positively correlated with plant height (0.243**), fruiting zone length (0.203*), seeds/siliquae (0.343**), BY/per plant (0.444**) and harvest index (0.790**) and negative with oil content (-0.224**) and fibre (-0.213**). Out of these 215 RILs, 25 were identified as most promising lines which may further be used for multi-location trials and in various *brassica* improvement programs to develop drought tolerant varieties.

Selection of Quantitative Characters for Higher Seed Yield in Indian Mustard [*Brassica juncea* (L) Czern. & Coss.]

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The morphological variability and contribution of morphological parameters viz., days to 50% flowering, days to maturity, plant height, number of primary branches, number of secondary branches, number of siliqua per plant, number of seeds per siliqua, length of siliqua, 1000-seed weight and seed yield per plant towards seed yield was worked out using analysis of variance, genetic parameters of variability and correlation coefficients. Analysis of variance revealed highly significant differences for all the characters except plant height and number of seeds per siliqua. Highest phenotypic coefficient of variation was found for number of secondary branches per plant followed by length of siliqua, seed yield per plant, number of siliqua per plant and 1000 seed weight. Moreover, highest genotypic coefficient of variation (GCV) was recorded for number of secondary branches per plant. Other characters which showed higher genetic variation were length of siliqua, seed yield per plant, number of siliqua per plant and 1000 seed weight. High estimates of heritability in broad sense were recorded for oil content followed by days to 50% flowering, number of siliqua per plant, length of siliqua, seed yield per plant, days to maturity, 1000 seed weight and number of secondary branches per plant and moderate for number of primary branches per plant. Low heritability estimates were observed for plant height and number of seeds per siliqua. Thus, on the basis of number of secondary branches per plant, number of siliqua per plant, length of siliqua, 1000 seed weight, oil content and seed yield per plant possessing high GCV and heritability. High estimates of genetic advance (GA) were observed for number of siliqua per plant, medium for days to 50% flowering, days to maturity, seed yield per plant and number of seeds per siliqua and low for number of primary branches per plant and number of seeds per siliqua. Expected GA expressed as percentage of mean was highest for length of siliqua followed by seed yield per plant, number of secondary branches per plant, number of siliqua per plant and 1000 seed weight. High heritability coupled with high genetic advance reveals that additive gene action was in operation for control of length of siliqua, seed yield per plant, 1000 seed-weight, number of secondary branches per plant and number of siliqua per plant and improvement in these traits can be achieved through simple selection.

Genetics of seed yield and its component traits in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.]

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The materials comprising of 8 parents, their 28 F_1 and F_2s were sown in Randomized Block Design with three replications during *Rabi* 2014-2015 at Oilseed Research Farm, Kalyanpur of C.S. Azad University of Agriculture & Technology, Kanpur. The observations were recorded on 10 characters viz. days to flowering, number of primary branches, number of

secondary branches, days to maturity, plant height (cm), number of siliquae per plant, number of seeds per siliquae, 1000-seed weight (g), oil content (%) and seed yield per plant (g). The analysis of variance indicated significant differences among the treatments for all the characters. Parents vs. F_1s, parents vs. F_2s and F_1s vs. F_2s also revealed highly significant differences for all the characters except for number of primary branches, number of secondary branches, days to maturity and oil content. Combining ability revealed highly significant gca and sca variances in respect of all the traits in both the generations. It indicated the presence of both additive and non-additive genetic effects in the expression of these characters. Average degree of dominance $(\hat{\sigma}^2 s/\hat{\sigma}^2 g)^{0.5}$ was over dominant type in both the generations for days to flowering, number of primary branches, number of secondary branches, number of siliquae per plant and seed yield per plant. Parents NRCDR-2, CS-52 and Urvashi were good combiners each for nine, five and four characters, respectively. The cross NRCDR-2 × Maya, NRCDR-2 × Urvashi, Maya × Urvashi, JM-2 × RGN-73, JM-2 × Geeta and CS-52 × Urvashi were adjudged as good combination in both the generation having desirable sca effects. The maximum heterosis over economic parent was observed in cross CS-52 × Urvashi for seed yield per plant. The maximum desirable inbreeding depression was recorded in the cross NRCDR-2 × JM-2. High heritability estimates were observed for days to maturity, number of siliquae per plant, number of seeds per siliquae, seed yield per plant and oil content in both the generations and number of secondary branches and plant height in F_1 generation. In F_2 generation, high heritability was observed for plant height, number of seeds per siliqua and number of secondary branches. The maximum genetic advance coupled with high heritability was observed for number of siliquae per plant in F_2 generation. Correlation study indicated that seed yield per plant showed a positive and highly significant association with 1000-seed weight.

Studies on genetical parameters in Indian mustard [*Brassica juncea* (L) Czern and Coss.]

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An experiment was carried out at Oil Seed Research Farm Kalyanpur, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur. Seven Strains/Varieties viz. Varuna, Pusa Bold, Jawahar Mustard-1, PR-15, Rohini, NDR-8501 and Ashirwad were crossed in dialled mating design (excluding reciprocals). 28 treatments (7 parents and 21 F_1s) were evaluated during *rabi* 2015-16 for 9 traits viz., days to flowering, plant height (cm), number of primary branches, length of main raceme (cm), number of siliqua on main raceme, number of seeds/siliqua, seed size, oil content and seed yield/plant. Result indicated that additive type of gene action was prevalent than non-additive type of gene action for most of the traits. The estimates of average degree of dominance indicated presence of partial to over dominance for most of the traits. Combining ability analysis revealed that good general combiners were Varuna, PR-15, Pusa Bold for high percent of oil content and PR-15, Varuna, Pusa Bold and NDR - 8501 for high seed yield/plant. Out of 21 crosses, Jawahar Mustard-1 x Ashirwad, Varuna x PR-15, Pusa Bold x NDR-8501 and Varuna x NDR-8501 were good specific combiners for high seed yield/plant. Heterosis over economic parent was found in only one cross Varuna x PR-15 for

seed yield/plant. Seed yield/plant was significantly correlated with number of primary branches, length of main raceme, number of siliqua on main raceme, number of seeds/siliqua, seed size and oil content. High heritability coupled with high genetic advance was found for seed size, seed yield/plant, length of main raceme and number of siliqua on main raceme. These characters may be utilized for improving efficiency of breeding Programme in Indian mustard.

Genetic variability, heritability and genetic advance studies in yellow *sarson* (*Brassica rapa* var. yellow *sarson*)

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An experiment was carried out during *Rabi* 2014-15 season at Research farm of College of Agriculture, Gwalior (M. P.) to assess the genetic variability, heritability and genetic advance in 21 diverse genotypes of yellow sarson (*Brassica rapa* var. yellow *sarson*) for 10 characters. Analysis of variance indicated highly significant differences for all the characters under study. High Phenotypic Coefficient of Variation (PCV) and Genotypic Coefficient of Variation (GCV) were observed for number of secondary branches per plant followed by seed yield per plant, number of primary branches per plant and number of siliqua on main raceme indicating that direct selection of these traits will prove effective. Days to 50% flowering, plant height and length of siliqua showed low PCV and GCV. Higher estimates of broad sense heritability were observed for all the characters. High heritability coupled with high genetic advance was observed for number of primary branches per plant, number of secondary branches per plant, length of main raceme, number of siliqua on main raceme, number of seeds per siliqua and seed yield per plant. High heritability with moderate genetic advance was recorded for length of siliqua and 1000 seed weight, whereas, high heritability and low genetic advance was observed for days to flowering and plant height. This extent of genetic variability, heritability and genetic advance for agronomically important traits, reported in this study, can help in defining selection methods for improvement for yield related traits in *Brassica rapa* var. yellow sarson.

Correlation coefficient and Path coefficient analysis for yield and its components in *Brassica compestris var. toria*

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The present study was carried out at the Research Farm of S.G. College of Agriculture and Research Station, Kumhrawand, Jagdalpur (C.G.), Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) during *Rabi* 2013-14. Experimental material comprised of 30 F_1 from a 6 × 6 diallel crosses was grown under Randomized Complete Block Design in three replications with the objectives to estimate the genotypic and phenotypic correlation coefficient and path correlation. The genotypic and phenotypic correlation coefficient revealed that the seed yield/plant (g) had positive significant correlation with number of branches/plant followed by number of siliquae/plant, number of seeds/siliqua, plant height and siliqua length at phenotypic and genotypic levels. Seed yield/plant had significantly positive correlation with 1000-seed weight at genotypic level which would led to the

development of high yielding genotypes. Path coefficient analysis of different characters contributing towards seed yield/plant revealed that number of siliquae/plant had the highest positive direct effect on seed yield/plant followed by 1000-seed weight, days to maturity, number of seeds/plant, plant stand/plot, harvest index, number of seeds/siliqua, number of branches/plant, erucic acid content, siliqua length and plant height. Therefore, due importance should be given to these traits while selecting high yielding toria genotypes.

Association among yield determining quantitative characters in Indian mustard [*Brassica juncea* (L.) Czern & Coss.]

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Association between ten selected characters with seed yield was studied in Indian mustard. The strong genotypic correlation of seed yield was found with number of primary branches/plant, number of secondary branches/plant, number of siliqua/plant, number of seeds/siliqua and plant height. Importance of these four traits while making selection for seed yield/plant is, thus, evident. Number of primary branches/plant, number of secondary branches/plant and number of siliqua/plant were found singnificant and positive associated with seed yield. Maximum weight-age should be given to higher number of primary and secondary branches/plant and number of siliqua/plant, while making selection for higher seed yield. Days to 50% flowering, an important trait, was negativly correlated with seed yield indicating that it is difficult to assamble high yields with short duration. Path analysis revealed that, number of siliqua/plant and number of seeds/siliqua were the major characters which had highest direct contribution towards yield per plant. Thus, the two traits viz. number of siliqua/plant and number of seeds/siliqua were undisputedly most important components for yield improvement in mustard.

Effect of seed size and osmo-priming on yield and its component characters in Indian mustard (*Brassica nigra L*)

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Rapeseed-mustard is a major oilseed crop of India. Rapid seedling establishment is an important requirement for successful crop production. Seedling establishment and speed of emergence influence the time required for seedling to reach the autotrophic phase. The present investigation showed that, influence of seed size differed significantly for two traits viz. number of secondary branches and days to 50% flowering and it was non-significant for other traits. The effect of priming treatments differed significantly for five traits; viz days to first flowering, days to 50% flowering, number of primary branches, number of secondary branches and seed yield per plant; whereas, it was non-significant for other yield attributing traits. Hydro priming had a prominent effect on most of the characters and is a preferred method for improving seed yield. This was followed by KCl treatment, which showed its positive effect on yield related traits like

number of seeds per pod and 100-seed weight. NaCl treatment had good effect on increasing the primary branches and decreasing the number of days required to flower. Bold seeds showed higher number of secondary branches, 100 seed weight and took more number of days to attain first flowering and 50% flowering. Medium sized seeds gave better mean performance for most of the traits under consideration which was followed by small sized seed. All the traits showed positive correlation to yield, but, were non-significant, indicating that bold/large seed size and seed priming produces more seed weight.

Quality improvement through inter-specific hybridization in *Brassica* spp.

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Brassicas are the major oilseed crops of India and belonges to the family Brassicaceae. Inter-specific hybridization is an important tool to develop synthetic amphidiploids and to transfer characters like yield, quality, adaptation and resistance to biotic and abiotic stresses across the species. Successful inter-specific hybridization can be achieved by attempting reciprocal crosses, involving bridging species, protoplast fusion and embryo resque technique etc. In Brassicas, oil quality is determined by its fatty acid profile. Fatty acid contains myristic, palmitic, palmitoleic, stearic, eicosadienoic, behenic, lignoceric, oleic, linoleic, linolenic, erucic and eicosenoic acids. Erucic acid and eicosenoic acid are undesirable fatty acids; erucic acid increases blood cholesterol, interferes in myocardial conductance and shortens coagulaton time. Large quantity of mustard oil may cause gastric irritation, bleeding from stomach, intestinal mucosa and may also cause skin burn. Therefore, improvement in oil quality is inevitable. Fatty acid variability generated through inter-specific and intra-specific hybridization increased variability in fatty acid profile. Potential of inter-specific crosses in increasing the range of variability for quality traits in rapeseed-mustard is, thus, demonstrated.

Biotic stress amelioration in Indian mustard *B. juncea* through biotechnological interventions

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The changing climatic conditions have serious impact on plants and associated microbial population. The yield losses vary depending upon the type and nature of pathogen association, time and severity of the attack, resistance level of the cultivars grown and prevailing environmental conditions. White rust (WR) and *Alternaria* blight (AB) are the most ravaging fungal diseases of oilseed *Brassica* with worldwide prevalence resulting in yield losses up to 60%. While appropriate location specific strategic interventions can help to a limited extent, biotechnological approaches assume significance to reduce vulnerability of crops to various biotic stresses. High tolerance to white rust and *Alternaria* blight has been incorporated from *B. rapa*/ *B. carinata* into *B. juncea* through ovule/ ovary culture. The advanced BC_3 progenies showed tolerance to white rust with disease severity ranging from 8 to 28% at 90 DAS in lines WR-C21, C22 and C23 under naturally occurring very severe infection conditions. For *Alternaria* blight the disease severity under similar conditions varied from 18 to 30% at 75 DAS and only up to 8% at pod bearing stage in selected lines (WR-C5, C12, C26, C39, C40, C51 and C68).

The most likely effects of climate change are altered geographical distribution of host and pathogens, and changes in crop loss and efficacy of control measures due to altered physiology of host-pathogen interactions and changes in stages and/ or infection rates. Therefore, in order to achieve horizontal resistance, it is imperative to understand the spectrum of diversity in the pathogen population. In view of this, 55 pure isolates of *Alternaria* species (32 isolates of *A. brassicae*, 20 of *A. brassicicola* and 3 of *A. alternata*) were isolated from infected leaf samples collected from eight states of India and were evaluated for their morphological, cultural, biochemical and molecular characteristics. Analysis of RAPD banding profiles showed a high level of genetic diversity varying between 57-78%, 78-92% and 89-100%, among the *A. brassicae*, *A. brassicicola* and *A. alternata* isolates, respectively. Significant variations were observed among the isolates of each species for the parameters studied; sporulation intensity, spore morphology, radial growth, carbohydrate concentration ($P< 0.05$), however, no correlation could be established among various parameters. The study thus indicates that there exists a non-specific relation between the isolates interacting and infecting with different species and varieties of *Brassica* spread over different North West regions of India. The study also reports for the first time, a comparative evaluation of the three *Alternaria* species from different locations, their growth pattern on three different media and the revival of isolates after one year of cryopreservation in glycerol and DMSO. Among different methods of preservation, cultures preserved in 10% glycerol (-20ºC) could be used for storage at least for two years without losing pathogenicity.

Biotechnology for the development of climate resilience in rapeseed-mustard

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Change of climate over time has led to decrease in crop yield and thus the need of agricultural innovation has become even more apparent. The increasing demand for food crops worldwide can be satisfied in two ways: first is to increase the area under cultivation and second is to improve productivity on existing arable land. Research and development of new technologies like biotechnology and other advanced agricultural practices have become important to increase the agricultural production. Various approaches such as biotechnology based bio-fertilizers, use of GM crops which lower down the fertiliser input needs, development of resistant and tolerant plants to various abiotic and biotic stresses using modern genomics approaches may lead to increase in the production and can contribute to climate change adaptation and mitigation initiatives. Genetically modified (GM) canola developed by Arcadia Biosciences can use nitrogen more efficiently, resulting in reduced fertiliser needs. Additionally, they can reduce greenhouse gas emissions through reduced fertilizer application. The use of environment-friendly biotechnology-based fertilizers should be encouraged to reduce the negative effects of artificial fertilizers. Further, tissue culture and breeding are also being used to generate stress-tolerant high-yielding hybrids.

Although the biotechnology community generally focuses on either molecular breeding or genetic engineering approaches, it is evident that there is a need to target complex problems caused by different stresses using integrated biotechnology approaches. As the whole genome sequence of plant, physical maps, genetics and functional genomics tools are becoming increasingly available, integrated approaches using molecular breeding and genetic engineering offer new opportunities for improving stress resistance. *Brassica napus* and oilseed rape have already been developed based on GM technology for abiotic stress herbicide resistance. Transgenic Brassica and Brassica hybrids have been developed based on biotechnology to improve yield and oilseed production. Thus, an integrated approach combining both the conventional and modern agricultural biotechnology approaches will not only contribute to increased yield and food security, but also significantly contribute to climate change adaptation and mitigation initiatives.

Assembly and annotation of *Brassica juncea* transcriptome

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Brassica juncea is a major oilseed crop of India. Major efforts have been made to enhance its genetic base through its resynthesis from basic diploid species or through hybridization between non parental allotetraploids. Efforts are now underway to study the available genetic diversity in the natural and resynthesized germplasm through transcriptome analysis. In the present stydy, we report transcriptome from four *B. juncea* genotypes representing natural (RE 15 and RLM 619), one resynthesized/derived (SJN3-2, DJ-22) genotypes. The comprehensive tissues i.e. reproductive tissues, roots, leaves, flower, and fruit at varied developmental stages were used to develop the RNA libraries. Sequencing was outsourced and paired-end 100 bp sequencing was performed on individual libraries using Illumina HiSeq 2000. Prior to read assembly, fastq files were trimmed for adapter contamination using cutadapt tool. After quality control and trimming, each set of trimmed RNA-seq data were mapped to the combined genome sets of *B. rapa* (AA) and *B. nigra* (BB) using the RNA-Seq Analysis utility of CLC Genomics Workbench. A maximum of two mismatches were allowed for alignments. Numbers of reads aligned to reference genome were 63832261, 56647048, 34550336 and 75653190 with alignment percentage 54.10%, 39.47%, 43.55% and 55.29% for SJN3-2, RE-15, DJ-22 and RLM619 respectively. Unique fragment counts were found to be 51.2%, 37.53%, 41.34% and 52.62% in SJN3-2, RE-15, DJ-22 and RLM619 respectively. For differential gene expression analysis, four genotypes were classified in two groups based on their cytoplasmic background. Group 1 included SJN3-2 and RLM619, while DJ-22 and RE-15 were included in group 2. Empirical analysis of DGE, Gaussian tests and proportions tests were then applied to identify differentially expressed genes (DEGs). For compressed dynamic range of the expression values, filtering was done, with Fold change >3, FDR p-value correction <= 0.05 and difference >20. A total of 812 DEGs were identified out of 8465 genes among group 1 and group 2. Feature clustering helped to identify and genes cluster together with similar expression patterns among genotypes. A heatmap was generated with Euclidean distance for Distances measure and average linkage for Clusters linkage criteria. Heatmap divided test genotypes into two major groups one group of DJ-22 and RE-15; other group of RLM-619 and SJN3-2. Analysis of gene ontologies of DEGs confirmed their involvement in diverse biological processes.

Plasted transcriptome in Brassica juncea and its diploid progenitors

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Chloroplast genomes carry only a small number of genes, encoding a small number of proteins (<200). Most of the other genes were transferred to host genomes during evolution. Little is known in *Brassica juncea* and its two progenitors regarding regulation of chloroplast gene expression responses associated with light, stresses, and developmental cues. Present studies were conducted to carry out comparative plasted transcriptome analysis in *B. juncea* and its progenitor species. Experimental material involved two resynthesized *B. juncea* genotypes namely, SJN3-2 and SJR13 along with their *B. rapa* (Baltoria and EC3390101) and *B. nigra* (UP, FRG 2) parents. Denovo transcriptome assembly was performed by Trinity on short reads generated through Illumina RNA-Seq platform. Paired-end reads were assembled into 1520, 1104, 2078, 267 and 238 trancripts with N50 lengths of 775bp, 2747bp, 549bp, 5614bp and 4817bp in SJR13, SJN3-2, EC3390101, FRG2 and Baltoria respectively. Clustered unigenes were searched against nr database using BLASTx in BLAST2GO. Differentially expressed genes (DEGs) were identified using EdgeR methods among two synthetic *B. juncea* genotypes with respect to their progenitor parents. 100 genes were differentially expressed between SJN3-2 and its parent; 139 genes in SJR13 and its parents. Of these, 14 unigenes in SJN3-2 and 15 in SJR13 could be assigned to GO-term classification related to chloroplast. Hierarchical clustering helped to generate a heatmap of SJR13 with respect to EC3390101 and FRG2 while for SJN3-2 with Baltoria and FRG2. Both SJR13 and SJN3-2 appeared more closely related to their respective *B. rapa* parent (AA). From this collection of unigenes, large number of simple sequence repeats (SSRs) were identified. These included 60 in SJR13, 36 in SJN3-2, 37 in EC3390101, 65 in FRG-2 and 72 in Baltoria. This new dataset will be a useful resource for future genetic and genomic studies in these species.

Transcriptome sequencing of two inbred lines of *Brassica rapa* L.

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Transcriptome (RNA-seq) has the potential to provide better insights into the genes of interest, development of functional markers, quantitation of gene expression, and comparative genomic studies. In this study, we used two very diverse genotypes of *B. rapa* namely, Sunbean and Baltoria for reference based assembly. Sunbean is a Canadian *B. rapa* genotype, while Baltoria is a very early flowering landrace from Pakistan. In the present study, transcriptome from these two genotypes analyzed. For this comprehensive tissue sampling was carried out by pooling reproductive tissues as well as roots, leaves, flower, and fruit at varied developmental stages for development of RNA libraries. Sequencing was outsourced and paired-end 100 bp sequencing was performed on individual libraries using Illumina HiSeq 2000. Prior to read assembly, fastq files were trimmed for adapter contamination using cutadapt tool. After quality control and trimming, each set of trimmed RNA-seq data were mapped to the combined genome sets of *B. rapa* (AA) and *B. nigra* (BB) using the RNA-Seq Analysis utility of CLC Genomics Workbench for reference based assembly. A total of 75,836,430 and 85,490,686 reads of Sunbean and Baltoria were investigated for assembly with *Brassica rapa* reference genome. Out of these 51,932,974 (68.48%) reads of Sunbean and 61,723,420 (72.20%) of Baltoria, were mapped on reference *B. rapa* genome. Differentially expressed genes (DEGS) were identified by CLC Genomic Workbench using Kal's statistical analysis test in term of Fold change >20, FDR p-value correction <0.005 and difference > 30. A total of 2391 differentially expressed gene were identified. Of these, 236 genes were annotated as homologous as well as differentially expressed genes between the two. These genes (236) were located on chromosomes A2. A3, A5, A6, A7 and A9 of *B. rapa*. These DEGs were used for gene ontology analysis on *Arabidopsis thaliana* database and confirmed for biological, molecular and cellular functions. Of special interest was GA2OX7, a gene that appear to influence plant growth by inactivating endogenous bioactive gibberellins. Another important gene was BEH1, which is associated with brassinosteroid mediated signaling and also helped to regulate plant growth and development.

Identification and molecular characterization of an elaborate heterotrimeric G-protein signalling complex from Indian oilseed mustard (*Brassica juncea*)

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Heterotrimeric G-proteins, consisting of Gα, Gβ and Gγ subunits, are important signalling molecules that involved in diverse cellular processes in eukaryotes. In recent years, growing evidences suggest that components of G-protein signalling complex are not simpler in plant lineage, as earlier thought off. In present study, we identified a total of 18 genes encoding two Gα, six Gβ and ten Gγ subunits from the allopolyploid *Brassica juncea* (AABB genome). Sequence and phylogenetic analysis revealed that the *B. juncea* G-protein subunits are evolutionary conserved and have evolved via whole genome triplication followed by hybridization of two *Brassica* genomes namely, *B. rapa* (AA) and *B. nigra* (BB); and retained high level of sequence conservation following allo-polyploidization. In general, the BjuGα were found to be highly conserved proteins whereas BjuGγ subunits were highly unique and showed sequence divergence. Gene expression studies demonstrated that the G-protein genes were ubiquitously expressed across different tissue types tested, with each member showing developmentally regulated spatio-temporal expression patterns. Besides, a high degree of interaction specificity was also observed between the members of G-protein subunits. Interestingly, the ‘A’ and ‘B’ sub-genome counterparts of *B. juncea* G-protein subunits showed almost comparable expression pattern and interactions specificity, thereby suggesting sub-functionalization of G-protein orthologs during allo-polyplodization of *Brassica* genomes. To investigate the roles of multiple members of G-protein genes towards regulating various developmental, agronomical and environmental responses in polyploidy *Brassica* crops, characterization of key G-protein genes using targeted silencing and over-expression approaches is currently being performed.

Isolation and functional characterization of heterotrimeric *Gα* subunit and *RGS* genes from *Brassica* species

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Heterotrimeric G-proteins (hereafter G-proteins) are important signaling transducers of the cell, comprising of α, β and γ subunits which along with Regulator of G-Protein Signaling (RGS) protein regulate wide range of biological processes across phyla. Among these G-protein components, the Gα subunit and RGS are the two important regulatory elements of G-protein signaling. RGS protein has the ability to accelerate the GTP-hydrolysis of GTP-bound Gα subunit thereby controlling the signal onset and decay. Genetic evidences from model plant Arabidopsis and rice clearly established the significant role of G-protein components towards controlling the wide array of cellular and biological functions. For many decades, the cultivable *Brassica* species have been investigated for several agronomical traits like yield, oil quality, phyto-remediation, resistance against pest and pathogen etc. However, comprehensive data from any *Brassica* species on the important roles played by G-proteins in regulating fundamental growth and development processes are not available at present.

In this study, we identified one Gα subunit and two duplicated RGS proteins each from three divergent diploid genomes of *Brassica* “U” triangle. The two RGS proteins interacted with Gα subunit but display varying level of interaction strength across different *Brassica* genomes when tested using membrane based split ubiquitin system. *In-vitro* enzymatic G-protein activity shows the similar rates of GTP-binding and GTP–hydrolysis of the recombinant *Gα* proteins for *Brassica* species. Moreover, the two divergent RGS proteins exhibited similar rate of GTP-hydrolysis on its cognate Gα protein, as evident by fluorescent based GAP activity studies suggesting that the RGS-mediated G-protein cycle regulated in *Brassica* crops is biochemically conserved. Transcript profiling of these G-protein candidate genes in various tissue types revealed differential temporal and spatial expression pattern, where *B. rapa RGS* genes showed high degree of transcriptional bias across various developmental stages. In response to various environmental factors and phyto-hormones, these candidate G-protein genes were differentially regulated. Taken together, our data suggests that different modes of regulation of G-protein regulation exist in *Brassica* species wherein the transcriptional and interaction network appear to be predominantly controlled the G-protein signaling. This study is a first step towards our understanding on the roles played by G-protein regulatory components in controlling various growth and development processes in polyploid *Brassica* species.

Understanding the molecular basis and identification of responsive genes imparting thermo-tolerance at early seedling stage in *Brassica juncea*

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Heat stress is becoming major abiotic stress restricting crop productivity, photosynthesis, seed germination etc. Losses due to high temperature are ever increasing due to global warming. *Brassica juncea* possesses better tolerance to most of abiotic stresses; however, growing environments still demands a better level of tolerance. Therefore, it is imperative to understand and employ genetic and molecular mechanism(s) underlying the heat stress responses for development of temperature tolerant cultivars. High temperature induces expression of several heat responsive genes; therefore, to compare their expression level between tolerant and susceptible genotypes, gene expression profiling using qRT-PCR is one of the most preferred method. Orthologues of several heat stress responsive (HSR) genes from *Arabidopsis thaliana* were identified in *B. rapa*. Primer sets targeting 'A' genome of *B. juncea* based upon *B. rapa* sequences for above mentioned orthologues were designed using IDT primer quest tool. A set of four genotypes differing in their response to juvenile stage heat stress, including two tolerant (Pusa Bahar and Pusa Mustard 28) and two susceptible (BEC144 and Pusa Karishma) genoitypes were exposed to heat stress under controlled conditions in National Phytotron Facility (NPF). RNA was extracted from both the control and stressed plants and several heat responsive genes were quantified usinging Real time PCR. 18S rRNA was used as housekeeping gene for normalization of qPCR. Out of these orthologues five candidate genes including three HSFs, one HSP20 responsive gene and a Brassinosteriod biosynthetic gene (*DWF4*) were confirmed as Heat Stress Resistance (HSR) genes through qPCR. This study elucidated the molecular bases of heat responses at juvenile stage and provides valuable information on responsive genes for improvement of heat stress tolerance in *B. juncea*.

Development of genomic resources for predicting heat stress responses in *Brassica juncea*

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Heat stress is one of the major abiotic stresses challenging crop productivity worldwide. Plants differentially respond to heat stress with rapid change in gene expression. Plant stress responses are generally controlled by a network of stress responsive genes through a complex regulation by specific transcription factors. Comparative genomic approaches can be exploited to understand molecular mechanisms involved in crop responses during stress conditions and identify some of the underlying candidate genes. Trigger of several heat shock factors (hsfs), heat shock proteins (hsps) and transcription factors (tfs) is a common protective response to heat

stress in plants. Various genes underlying important heat stress responses (HSR) in *Arabidopsis* have been identified and it is possible to elucidate orthologs of these genes within *Brassica rapa* using various genomic tools. CDS sequences for different HSR genes were taken from available databases (Phytozome, BRAD) and their orthologs sequences in *B.rapa* were identified through sequence alignment tools (BLAST). Sequences with above 90 per cent similarity and 0.0 e-values were considered as orthologs. Several Primer pairs spanning intronic regions were designed to exploit Intron polymorphism (IP) for marker development from two contrasting varieties for HSR. These primers when used with cDNA can be used for expression profiling of the contrasting genotypes for heat stress through (qRT)-PCR. However, these primers when used with gDNA results in the development of IP markers. Fourteen such primer pairs targeting 'A' genome of *B. juncea* including hsp-70, SCARE-CROW LIKE PROTEIN, myb 14, DREB 2A, XPO1A, bZIP etc. were designed. Differential expression of these genes between contrasting varieties was validated using several molecular biology techniques ((qRT)-PCR, PCR). This study facilitates quick discovery of stress responsive genes and their variable expression levels between susceptible and tolerant varieties for heat response. This shall help in speeding breeding efforts aiming at mitigating the ill effects of high temperature in Indian mustard resulting in enhanced crop productivity.

Molecular and Genetic characterisation of flower colour variegation in Indian mustard (*Brassica juncea* L. Czern&Coss)

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Molecular genetic basis of flower and seed coat colour variegation was investigated in *B. juncea.* We show that this variegation was caused by unstable mutant allele encoding pigment pathway genes. To analyze the role of an active transposon in flower colour variegation, we cloned and sequenced 4 genes each associated with carotenoid [Carotene hydroxylase21 (CHX21), Carotene hydroxylase23 (CHX23), Lycopene cyclase (LYC) and Zeta-carotene desaturase (ZDS)] and anthocyanin biosynthesis [transparent testa 2 (TT2), transparent testa glabrous 1 (TTG1), leucoanthocyanidin dioxygenase (LDOX) and UDP-3-*O*-glucosyltransferases (UF3GT)] pathways. Sequences have been deposited with NCBI (Accession numbers KY001619-KY001634). The sequences were analysed for transposon display using CENSOR software. The gene encoding TTG1 revealed signs of a transposon belonging to the CACTA super-family. As the gene TTG1 is associated with seed colour, it is likely that transposon insertion conferred yellow seed coat colour. Transposon excision in dividing epidermal cells may produce clonal patches of brown tissue on the yellow background and in cells giving rise to gametes to generate reversion alleles conferring a brown seeded phenotype. Similarly, the carotenoid gene ZDS revealed signs of transposon belonging to DNA/hAT super-family which may be causing instability for flower colour. The transposons show independent transmission and systemic activity in the higher plant genome. So theoretically, these can move around the genome and their insertion can cause instability in any locus.

Allelic variation for meiosis related genes in *Brassica juncea* and its diploid progenitors

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Patterns of allelic differentiation were investigated for 34 meiosis related genes in natural and resynthesized *B. juncea* allotetraploids as well as their progenitors. Pollen fertility varied in a narrow range, with *B. juncea* showing the maximum variation. A representative set of 96 lines were then genotyped with 70 STS markers derived from the sequence information of meiotic genes. Out of these markers analysed, 55 were polymorphic and these amplified 137 alleles. Within population differences (76%) accounted for maximum variation, followed by variation among species (19%). Population structure analysis largely reflected the ploidy boundaries. Diploids were grouped together, but *B. juncea* formed two major subgroups. Linkage disequilibrium (LD) deviated significantly between species and subpopulations as well. Large LD block with *MMD1* was observed for *B. juncea*. For diploids, major LD blocks spanned *MRE11* and *TES*. Markers based on two candidate genes, *SCC3* and *BRCA2b* showed significant association with pooled pollen fertility, explaining 11-14 % of trait variation. For *B. juncea,* only *MS5b* provided evidence of directional selection using softwares Arlequin and LOSITAN. Tajima's D values were negatively significant for *RAD51C, ZYP1a* and *ZYP1b* for A homolog, indicating balancing selection. B homolog of *SWI1* showed evidence of positive selection. Hierarchical clustering analysis based on gene expression indicated diverse meiotic machinery in *B. juncea* as compared to progenitor species. One or both the homologs of several meiotic genes (*SMC3, SWI1, ZYP1a, ZYP1b*) were over expressed in natural and resynthesized *B. juncea*. In contrast; *CAP-E2, SCC3, SPO11-1* were distinctly down regulated in allotetraploid. Though, expression level variations were higher in *B. juncea* in comparison to the diploid progenitors, a comparative balance of up- or –down regulation of meiotic genes in both natural and freshly resynthesized allopolyploids was apparent. This suggested that changes in gene expression regulation may occur in the early aftermath of genome merger.

Molecular cloning and characterization of flowering genes and their correlation with photo-sensitivity

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The studies were aimed at isolation and cloning of four flowering genes associated with photo-sensitivity viz. CONSTANS (CO), FRIGIDA (FRI), CRYPTOCHROME2 (CRY2) and SUPPRESSOR OF OVEREXPRESSION OF CONSTANS1 (SOC1) from three photo-sensitive and four photo-insensitive genotypes of *B. juncea*. The primers for the amplification of the genes were designed from respective sequences from GenBank (CO: AF016011; FRI: AC240938; CRY: GQ891988 SOC1: NC_024797). The amplified gene fragments were subjected to cloning and sequencing, which resulted in sequence lengths of ~1400bp for CO, ~2050bp for FRI,

~2750bp for CRY2 and ~3400bp for SOC1. The sequences were analysed and consensus sequences were prepared using Geneious program. The sequences of CO and FRI have been submitted in GenBank with Accession numbers KY218733-36. The CO and SOC gene sequences were found to be conserved within the photo-insensitive and photo-sensitive genotypes. The consensus sequences of FRI were AA homeologues positioned on chromosome A03. However, two consensus sequences were generated for photo-insensitive genotypes, but one was generated for photo-sensitive genotypes. The annotation of the sequences was done using FGENESH program, which revealed that FRI sequences are partial from both ends with 3 exons and 2 introns. The differences were observed in the protein sequences of two FRI sequences of photo-insensitive genotypes, where A is replaced by V, N by K, GE by K, D by A at positions 35, 154, 182, 252, respectively. Three consensus sequences were obtained from CRY gene sequences, two of which were AA homeologues positioned at chromosome A08. The differences were observed in the gene sequences of photo-insensitive and photo-sensitive genotypes corresponding to AA homeologue. The annotation of the sequences revealed that CRY gene has 5 exons and 4 introns. The protein sequence alignment of AA homeologue sequences showed that E was replaced by G, N by K and N by S at positions 18, 441 and 563 in photo-insensitive genotypes. In addition to this, there were insertions in the photo-insensitive CRY protein sequence at the position 288 (H), 571 (A;E) and a deletion of E at position 596. Identified SNPs for FRI and CRY are being validated to differentiate between photo-sensitive and photo-insensitive genotypes of *B. juncea*.

Genetic diversity at subgenome level in *Brassica juncea* (L.) Czern & Coss

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Indian mustard (*B. juncea*) is a crop of great economic significance for India. It is an allotetraploid that arguably arose several times through multiple hybridization events. Understanding the patterns of genetic diversity is critical for its effective management and utilization. To facilitate that we carried out a genome wide analysis of a panel of 100 samples highly representative of the existing population structure of a *B. juncea* diversity panel. These studies allowed us to characterize the distribution of genetic variation across two subgenomes. To facilitate that 65 A-genome and 78 B-genome specific markers were used for genotyping. This diversity set comprised 60 accessions of natural *B. juncea*, 28 of derived resynthesized *B. juncea* and 12 introgression lines. The genotypic data were investigated for observed (Ho) and expected heterozygosity (He) by GenAlEx software. Observed heterozygosity was 0.184 and expected heterozygosity was 0.143 of A-subgemone and Ho was 0.234 and He 0.192 for B-subgenome, whereas polymorphic information content (PIC) 0.1145 observed in A-subgenome and 0.1551 in B-subgenome. Average Shannon's information indices (I) were 0.204 and 0.274 for A- and B-subgenomes, respectively. Analysis of molecular variance (AMOVA) also showed higher genetic variance among population for B-genome rather than A-genome. The Fst values represented low differentiation. DARwin generated dendrogram divided the all accessions into three groups for both genomic data generated. Dendrogram based on A-genome polymorphism revealed highest MCP-12-3, DJ-126, CN-12-33 and Kranti to be the most diverse. In contrast, DJ-127-DT-36, A8-4-2, MCP-12-401 and EC-564647 revealed maximum genetic diversity for B-genome.

Karyotype analysis and estimated DNA content per chromosome of *Brassica juncea* and its progenitor species

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The cytogenetic characterization of *Brassica's* chromosomes is challenging. The chromosomes of mitotic metaphase of A, B and C genomes are small and generally uniform. Analysis of *B. rapa* L. (syn. *B. campestris* L. AA) and *B. oleracea* L. (CC) have revealed that mitotic prometaphase and meiotic diakinesis stages provide better possibilities for morphological characterization of *Brassica* chromosomes due to partially contracted chromosomes, differential chromatin condensation and staining. To our knowledge, the diakinesis chromosomes of the B genomes have not been characterized in detail till now and only a little information is available on the morphology of the chromosomes of the B genome. Therefore, the present study was planned to gain insights regarding comprehensive karyotype analysis of the AA, BB and AABB genomes in *B.rapa, B. nigra and B. juncea*. For karyotype construction of the *Brassica* genomes, the diakinesis bivalents were classified according to their patterns of chromatin, condensation and staining. Karyotype was made with the help of IKARYOS karyotyping software (5.5.8) version, using Carl Zeiss Axioscope microscope equipped with DAPI one way filter set. The chromosomes of test species displayed different appearance and significant variability among karyological features. The main attributes studied were: Total Chromosome Length (TCL), Relative Chromosome Length (RCL), Mean Arm Ratio (MAR), Total Form (TF%), Satellite chromosome, chromosme type and Estimated DNA Content (EDC). Maximum TCL was found in *B. nigra* followed by *B. rapa* and the lowest was in *B. juncea*. TF%, the main parameter for the measurement of asymmetry indices provided strong evidence that juncea has been derived from *B. rapa* and *B. nigra*. Expected DNA content (EDC) in *B. nigra* (99.16) and *B. juncea* (90.18) was higher as compared to *B. rapa* (73.95). In *B. rapa* and *B. nigra* the presence of more number of m/sm chromosome indicated their symmetrical nature while in *B. juncea* presence of one st chromosome revealed its asymmetrical nature. Karyotypic formula varied among the species. Thus karyotype analysis of the brassica species revealed that subtle structural diversity chromosomes, which might have contributed their evolution and differentiation. Significant correlation between some karyological attributes including TCL, RCL, MAR &EDC indicate that change in chromosome structure might be due to change in DNA content.

Development of robust markers associated associated with erucic acid content in Indian mustard (*Brassica juncea* l. czern & coss)

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The quality of mustard oil is determined by relative amounts of saturated, monosaturated and polyunsaturated fatty acids. Erucic acid is one of the major fatty acids in the mustard oil

(>50%). Higher amount of erucic acid in edible oils has been associated with several cardiac conditions. Therefore, a major objective for breeding is to develop genotypes with low erucic acid (<2%) in seeds oil. The trait is under digenic recessive inheritance. Low erucic acid mustard genotypes are normally developed by the introgression of recessive alleles for the trait from donor through backcross breeding. However, this is a lengthy process and necessitates selfing after every backcross generation and identifying zero erucic plants in the segregating population through analysis of the fatty acid profile of single cotyledons of individual seeds (half seed technique) by gas chromatography (GC). Development of molecular markers within the candidate genes will allow selection of lines with low erucic alleles in the heterozygous state during backcross, thereby obviating the need of selfing after every backcross generation and extensive GC analyses. Furthermore, the population size for screening will be reduced by a quarter for two-gene materials or to half by one gene material. Two genes *FAE1.1* and *FAE1.2* are involved in erucic acid synthesis pathway in mustard, representing two genomes. We undertook cloning and sequencing of erucic acid genes representing both A and B genomes. For this, corresponding gene fragments high vs low erucic acid lines were cloned and sequenced from *Brassica rapa*, *B. nigra* and *B. juncea*. Respective sequence information were used to detect the presence of SNPs and restriction sites. Restriction sites differentiating high and low erucic acid were identified separately for A and B genomes. Identified restriction sites were used to develop CAPS / SNP markers and are being validated on set of germplasm lines.

Molecular tagging of total seed glucosinolates content in Indian mustard

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Keeping the complex nature of total glucosinolates and advancement of science in terms of development of various molecular marker systems, it would be worthwhile investigating these loci using molecular markers. Hence, an effort was made to screen SSR markers for low glucosinolates in Indian mustard using Recombinant Inbred Line (RIL) mapping population. An initial screening of the two parental lines having contrasting phenotypes for total glucosinolates was done. Out of 594, 413 primers got amplified in the parental genotypes. Out of 119 SSR primers used from *B. rapa*, 72 (60.5%) got amplified and 21 (17.6%) were polymorphic. Among 158 primers of *B. nigra* used, 109 (69.0%) amplified, of which only 19 (12.0%) turned out to be informative. Similarly, 82.3% amplification was recorded with *B. napus* derived SSR primers, where 135 primers could amplify out of total 164 primers selected for this study. Only 12 primers (7.3%) were found to be polymorphic. Likewise, among the *B. oleracea* derived SSR primers 19 (39.6%) out of total 48 could amplify, of which only 2 (4.2%) primers were informative. Of total 56 *Arabidopsis* derived primers, 38 (67.9%) could amplify and eight (14.3%) were recorded as informative showing polymorphism between the parents. In addition 49 more SSR primers derived from other species were also used for parental polymorphism of which 40 (81.6%) could be amplified but none was found to be informative as no polymorphism could be observed between parents. Out of 413 amplified SSR markers, 62 (10.4%) markers showed polymorphism between parents. The Bulk Segregant Analysis revealed four microsatellite markers differentiating both the parental lines and the high and low glucosinolates bulks, hence putatively linked to the genomic regions controlling total glucosinolates. The single marker analysis using the general linear analysis showed that the marker (Ni4H03) was contributing 21.9% of total phenotypic variation and the marker At3g63420 was explaining 12.4% total phenotypic variation for this trait. The recombination frequency between the 'B' genome marker (Ni4H03) and gene of interest was 23.8 cM, while for the 'A' genome marker (At3g63420), distance was as high as 37.3 cM. Though the regression analysis revealed that there is a significant contribution of both markers towards low glucosinolate content, but the genetic distance was high. Since total glucosinolates is a polygenic trait, it can't be classified exactly as 'High' and 'Low' phenotype. It will include another class *i.e.* medium, ranging from more than 30 μ moles per gram defatted seedto less than 70 μ moles per gram defatted seed. However, for the sake of estimating distance, glucosinolates phenotype less than 30 μ moles per gram defatted seed was considered as low and above 30 μ moles per gram defatted seed was considered as high phenotype. This may be one of the reasons that why the distance estimated was high.

Marker assisted selection for development of low seed glucosinolates in Indian mustard

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The reason for poor success of breeding programme for development of low glucosinolate varieties has been its complex nature of inheritance. Genetics of seed glucosinolate content in the amphidiploid *Brassica* species appears to be controlled by large number of genes.There are major limitations to success in the development of low glucosinolate cultivars in *B. juncea* through conventional breeding methods, and to overcome them we used earlier reported SSR markers that were found to be linked to the candidate genes for glucosinolates. MABB was carried out to introgress low glucosinolate trait from exotic genotype 'EC597325' into the popular and widely cultivated Indian mustard variety 'Pusa Mustard 21'. The low glucosinolates donor, 'EC 597325' is a canola type genotype which is not adapted to Indian conditions and is agronomically poor due to very low yield, small seed size, tall plant height with very few branches and late maturity. Pusa Mustard 21 is a popular Indian mustard variety with low erucic acid but it has high total glucosinolates (more than 90 μ moles per gram seed). The F_1 plants obtained from cross between 'Pusa Mustard 21' (recipient parent) and 'EC597325' (donor for low glucosinolates), were genotyped with earlier reported (Bisht *et al*. 2009) four molecular markers *viz*., GER1, GER5, At5gAJ67 and Myb 28 associated with low glucosinolates and were validated in the present study. Plants showing heterozygosity with all four markers were picked up for attempting backcross (BC_1) with the recipient parent 'Pusa Mustard 21'. 140 BC_1F_1 seeds could germinate, and 121 plants survived to maturity in the field. Foreground selection with same four markers was applied to select heterozygotes for glucosinolate trait. Genotyping of all these 121 BC_1F_1 plants revealed that only four plants have shown heterozygosity for all the four markers and five plants showed heterozygosity for three markers. Plants carrying candidate gene markers were very few in number, hence, background selection was not applied in BC_1F_1 generation. Plants heterozygous for four markers were again backcrossed with Pusa Mustard 21 to obtain BC_2F_1 population which were grown in next crop season. Total of 486 BC_2F_1 plants could be established to maturity. Genotyping of these plants was again done with the same molecular markers tightly linked with low glucosinolate *viz*., GER1, GER5, At5gAJ67 and Myb 28. Gel electrophoresis revealed that only seven plants were showing heterozygosity for all four markers where as 22 plants showed heterozygous bands with three markers. Hence, identification of hetrozygotes with maximum recovery of recurrent parent genotype and back crossing them again with Pusa Mustard 21 would result in improved Pusa Mustard 21 with low glucosinolate genes in addition to all its original traits.

Genetic analysis of total seed glucosinolate content in Indian mustard

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Glucosinolates are major sulphur rich secondary metabolites found in *Brassicaceae* family. Glucosinolates themselves appear to have very little antinutritional effects. However, when present in seed meal, they have harmful effects on animal health. It is, therefore, important to manipulate glucosinolate profiles and contents in seeds of *Brassica* species. To design proper breeding method for the development of low glucosinolate lines, information concerning the genetic nature of the total glucosinolates of plant materials should be studied. Hence current study was carried out to study inheritance of total glucosinolate content using high and low glucosinolate parents (Pusa Mustard 30 and EC597325 respectively) and their F_1, F_2, B_1 (F_1 backcrossed to high-parent P_1) and B_2 (F_1 backcrossed to low-parent P_2). Direct and reciprocal crosses were also generated. Glucosinolates were analysed using earlier published method. Mean value of F_1 plants from the cross Pusa Mustard 30 × EC597325 was 67.279 ± 0.676 μmoles per gram defatted seed, whereas, the meanvalue of F_1 plants of the cross EC597325 × Pusa Mustard 30 was found to be 46.051 ± 0.477 μmoles per gram defatted seed. This difference was statistically significant (t=2.29, df=40) indicating that seed glucosinolate accumulation is under the control of maternal genotype. Moreover, observing non-significant difference in F_2 generation further established that trait is under maternal influence.Out of the 171 F_2 plants only four fall into this group following a trigenic 1:31 segregation($\chi2 = 0.206$, $p = 0.6499$). B_1 population distribution is in accordance with a 1:2 segregation ($\chi2 = 0.434$, $p = 0.51$). On the other hand, a 1:5 segregation ($\chi2 = 0.001$, $p = 1$) was evident in case of the B_2 population, Recovery of transgressive types in both the crosses confirms that trait of interest is under the polygenic control. Cavalli's joint scaling test was applied to obtain the estimates of three parameters *viz*. m, [d] and [h]. Values for the adequacy of 3-parameter model were highly significant indicating involvement of digenic or multigenic interactions in the genetic control of glucosinolate content in these crosses. Additive gene effect was more pronounced in the cross Pusa Mustard 30 × EC597325, however, both additive and dominant gene effects as well as all interaction effects were present in the cross EC597325 × Pusa Mustard 30. Results of the current study concluded additive nature of gene action; hence trait will have high heritability and will show more response to selection. Quantitative nature of genes with additive gene action will lead to more probability of recovering of transgressive segregants. These transgressive segregants will serve as material for diversification of low glucosinolate trait.

Marker assisted backcross breeding for reducing total glucosinolates in Indian mustard (*Brassica juncea*) cultivars with low erucic acid content

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Improved oil quality coupled with high yield is essential in any oilseed crop. Aliphatic glucosinolates are the predominant sulfur-rich plant secondary metabolites in economically important *Brassica* crops. It is, therefore, important to manipulate glucosinolate profiles and contents in *Brassica* species. Low glucosinolates (<30ppm) is a major breeding target to improve the edible oil quality in *Brassica juncea*. In this study, aliphatic glucosinolates were genetically manipulated through homoeologous recombination in backcross lines followed by marker assisted selection in *B. juncea*. In mustard, molecular markers linked were used for introgression of low glucosinolate trait. For development of low mustard genotypes, two backcross populations were generated i.e., PM30/PDZ1//PM30 and PM24/PDZ1/PDZ1//PM24. These populations are being analyzed for low glucosinolate trait linked markers viz GER 1, GER 5 and At5g67. These molecular markers having linkage with total glucosinolates content in *Brassica*. In first population out of 107 plants three plants were found heterozygous and in second population fourteen plants were found heterozygous out of 40 plants for glucosinolate trait. These heterozygous plants will be use for further marker assisted backcross breeding programme. This study will be helpful for the improvement of oil quality of mustard and improved oil quality will make variety beneficial for farmers, traders and consumers.

Introgression of White rust resistant and low Glucosinolate traits in Single Zero Indian mustard

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Improvements in Brassica oilseeds for both canola quality and disease resistance traits are essential to keep canola oil in high demand on international markets. So, the objective of this research was to introgress white rust resistance and low glucosinolate trait into zero erucic acid mustard variety by exploiting Marker Assisted Backcross Breeding (MABB). Several molecular

markers linked to white rust resistance and total glucosinolate content in *Brassica* have already been reported. In the present study, the earlier reported At2g36360 marker, linked to white rust in Donskaja was found polymorphic between Donskaja and PM30. Likewise, GER1 & GER5 earlier reported markers linked to low glucosinolate in EC 597325 genotype were found to be polymorphic between EC597325 and PM30. A progeny population generated through breeding scheme PM30/Donskaja//EC597325///PM30 has been screened by At2g36360, GER1 and GER5 markers. Only 10 were found to be carrying the alleles for white rust as well as low glucosinolate trait and were used for further backcrossing with elite genotype (recurrent parent). MABB helps to develop resistant and high-yielding mustard varieties with inbuilt quality traits.

Transfer of white rust resistance in Indian mustard using transgenic approaches

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Indian mustard (*Brassica juncea* L.), a member of *Brassicaceae* family, is an economically important oilseed crop cultivated globally. It is a major oilseed crop of Indian subcontinent and the second most important source of edible oil, contributing about 30% to the total edible oilseeds production. White rust, caused by *Albugo candida* (Pers.) Kuntze, is one of the major fungal diseases of Indian mustard and may result in up to 60% of yield losses under favorable environmental conditions. Thirteen races of this obligate pathogen have been reported from different *Brassica* species. The presently cultivated varieties of *B*. *juncea* in India are highly susceptible to white rust. The conventional strategies have their limitations for incorporation of durable resistance; use of fungicides poses serious hazards for the environment and human health. There is no known source for white rust resistance in *B. juncea* that may be transferred in popularly grown varieties. The advent of plant genetic engineering techniques has helped in the transfer of resistance in *B. juncea* against pathogenic fungi like *Alternaria* and *Sclerotinia*. In a recent study, transfer of WRR4 (a member of TIR-NB-LRR gene family identified in *Arabidopsis thaliana)* in *B. juncea* conferred white rust resistance. Genes conferring rust resistance identified from secondary (*B. nigra*, *B. napus* and *B. rapa*) and tertiary (*A. thaliana*) gene pools may be an effective approach, and is being investigated in our laboratory, to incorporate white rust resistance in Indian mustard genotypes.

Comparative investigation of mitochondrial genomes between the *Cor* cytoplasmic male sterile line and its maintainer lines in *Brassica rapa* and *Brassica juncea*

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Cytoplasmic male sterile (CMS) lines are important for exploiting heterosis in *Brassica* oilseeds. These can also be used for understanding nuclear-cytoplasmic interactions. CMS is caused by mutations, rearrangement or recombination in the mitochondrial genome. Many CMS systems are available in *Brassica*. Here we report the development of yet another CMS system in

Brassica rapa. This CMS (Cor CMS) was developed by backcross substitution of *B. rapa* genome in the cytoplasmic background of *Brassica fruticulosa* subsp. *cossoniana* (Boiss. &Reut.) Maire. All the tested genotypes of *B .rapa*, *B. juncea* and *B. napus* acted as sterility maintainers. Attempts are currently underway to introgress fertility restorer gene(s) from the cytoplasm donor species. We also conducted comparative analysis of the mitochondrial genome of the Cor CMS line and its maintainer lines in *B. rapa* and *B. juneca*. The sequencing of the mitochondrial genomes was outsourced. Subsequent bioinformatics analysis helped to assemble the *B .rapa* Cor CMS mitochondrial genome into a single, circular-mapping molecule that was 5516935 bp in size. The mitochondrial genome sizes of the maintainer *B. rapa* and *B. juncea* lines were 6183470 and 6547515, respectively. Total number of annotated genes varied from 77-81.These included rRNAs, tRNA genes and unidentified ORFs. The Cor CMS mitochondrial genome was highly rearranged when compared with its maintainer lines in *B. rapa* and *B. juncea*. Male sterility appeared to be associated with a known CMS-associated gene *orf288*. Comparative analysis the mitochondrial genomes of the Cor CMS line, its maintainer line and ogura CMS lines allowed us to develop specific markers to differentiate these sterile cytoplasms. This study is expected to be useful for understanding the structural and evolutionary differences between different CMS lines currently available in crop Brassicas.

Optimizing fertility restoration for *ogura* CMS system in *Brassica juncea* through reduced size of introgressed chromosome fragment carrying *Rfo* gene for fertility restoration

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The *Ogura* CMS is globally used for producing hybrids in *B. napus* and *B. juncea*. Fertility of the *Ogura* CMS is restored by altering the post translational expression of *orf138*, a mitochondrial gene by a nuclear fertility restorer (*Rf_o*) gene, which had to be transferred from radish as none of the available genotypes in crop *Brassica* species could restore fertility of this CMS. Fertility restorer was initially transferred to *B. napus* and subsequently to a number of genotypes of Indian mustard (*B. juncea*). A number of hybrids have since been bred and commercialized in India, primarily by private seed companies. Level of hybridity, primarily in form of male sterile contaminants, in commercially bred F_1 combinations still remain a challenge. Presence of male sterile plants in F_1 combinations can be attributed to chance contamination by air borne pollen, use of male parent that is heterozygous for fertility restoring gene or due to poor transmission frequency of introgressed segment carrying fertility restorer gene in *B. juncea*. We estimated the frequency of *Rfo* gene in a small set of hand bred hybrids .On the basis of percent fertile plants in the F_1 hybrids, maximum percent transmission frequency was recorded for TCN (89.7) followed by RRM (58.5), AJR102A(47.3) and RRF 1359 (41.6).We extended the studies further through molecular characterization of fair set of fertility restorers bred under ICAR National Professor project. Purpose was to obtain an approximation for the size of alien introgression harbouring *Rfo*.To facilitate that around 500 plants belonging to ten established *B. juncea* fertility restorers (AJR-102A, AJR-102B, AJ-7, AJR-7A, AJR-7BCR, TCN, RRM, RL-1359, MH-13 and ORH-41C) were used as experimental material. Molecular markers used for the studies included: gene based marker for *Rfo*, C9 markers of *B. napus* (sN3553F, sS2285, sN3841, sN12905 and At5g58730) and four radish markers

(At3g27100, At5g25080, At4g13720 and At5g06240) along with a set of six radish markers (ScH03, ScA14, OPF3, Bo1Jon, CAB and PGIint).These studies helped to identify four restorers positive for only *Rfo.* Many of the restorers continued to harbour large segments of C genome(from *B.napus*) and *Raphanus sativus*. Based on these studies, it may be possible to develop fertility restorers with least possible linkage drag. Cloning of *Rfo* gene is underway.

Seed quality traits prediction with accuracy in *Brassica* using genomics

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The breeding goal for *Brassica* is high oil yield coupled with excellent oil quality. The latter is driven by the composition of the fatty acid components of erucic acid, stearic acid, oleic acid, linoleic acid, and linolenic acid. Moreover, protein and glucosinolate content determine to a large extent the quality of the *Brassica*. However, such traits in many cases can only be assessed in an advanced developmental stage or in maturity stage. Therefore, the use of marker-assisted selection (MAS) has the potential to reduce time in the breeding program and increase the gain of selection. To achieve this, the identification of quantitative trait loci (QTL) controlling such traits is required. However, the identification of QTL which explain an adequate amount of the phenotypic variance is challenging. Linkage mapping or association mapping approaches are suitable for the discovery of QTL. Various studies in *Brassica* have identified various QTL for yield and yield contributing traits using such approaches. Due to only two parental alleles and large confidence intervals of QTL, however, the results of mapping studies had so far little impact on the breeding process. However, the results of Linkage disequilibrium (LD) analyses suggested that the number of such SSR-markers is at the lower end of what is required to have a high power to detect marker-phenotype associations for seed quality traits in *Brassica*. The genome-wide association analyses of the yield and excellent oil quality will perform as a multiple forward regression analysis to take into account the LD between SNPs to identify those SNP marker combinations which explain best the genotypic variation.

In vitro haploid plantlet regeneration through anther culture in locally adapted cultivar of Indian mustard (*Brassica juncea* L. Czern and Coss)

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A study was carried out to observe androgenic responses in local genotypes of Indian mustard *i.e* Local Yella (CAULC-1) along with JD-6, Kranti, and NDRE-22. B_5 and MS media were used for anther culture with different concentrations of phytohormones (2, 4-D, BAP and NAA). The floral buds were given cold pre-treatment at 4°C for 24 hours and they were surface sterilised with $HgCl_2$ for 1 minute. After culturing, the inoculated anthers were incubated at 25°±1°C temperature in complete dark condition for callus induction and 25˚±1˚C with 16 hours photoperiod for root and shoot initiation. The Genotype CAULC-1 (Local Yella) showed the best performance for days to callus initiation and per cent of callus induction while NDRE-22 was the poorest. The maximum rate of callus induction in terms of percentage (%) was observed in MS + 3 ml/l of 2, 4-D + 1ml/l of BAP (66.39) followed by B_5 + 3 ml/l of 2, 4-D +1 ml/l of BAP (63.06) at 30 days after inoculation (DAI). Significant variations were also observed among the genotypes and treatments for shoot regeneration. Local Yella (CAULC-1) recorded the best shoot regeneration followed by Kranti. B_5 + 4 ml/l of BAP + 1 ml/l of NAA medium showed minimum days (24.47) for shoot initiation and recorded maximum length of regenerated shoot (2.58 cm). Maximum per cent of shoot initiation at 30 and 45 DAI (55.55% and 59.44% respectively) was observed in MS + 4 ml/l of BAP + 1 ml/l of NAA. For root initiation, Local Yella was found to be the best genotype which took minimum time (12.44 days). The media composition MS + 1 ml/l of NAA + 0.5 ml/l of BAP showed the minimum days and highest per cent of root initiation (45.83%) and also maximum length of regenerated root (3.42 cm) respectively. Regeneration of haploid plants was confirmed by cytological examinations of the root tips of the plantlets from the callus of anther culture. The present study concluded that Local Yella (CAULC-1) showed better androgenic response than others genotypes under study. Among the treatments, the media containing B_5 + 3 ml/l of 2, 4-D + 1 ml/l of BAP and MS + 3 ml/l of 2, 4-D + 1 ml/l of BAP enhanced callus induction. MS + 4 ml/l of BAP + 1 ml/l of NAA responded best for shoot regeneration and MS + 1 ml/l of NAA + 0.5 ml/l of BAP and B_5 + 1 ml/l of NAA + 0.5 ml/l of BAP responded best for root initiation.

Response of different genotypes and their cross combinations to anther culture in Ethiopian mustard (*Brassica carinata* A. Braun)

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Conventional methods for breeding crop plants require more than six to seven years of continuous efforts to get true breeding lines after following hybridization approach. Biotechnological tools including anther culture hold a great promise in accelerating the pace of breeding programme thereby saving time and resources for their further use directly as commercial cultivars and/or in structural and functional genomics. The present study was conducted to investigate the androgenesis-mediated response of different genotypes & their cross combinations in Ethiopian mustard (*Brassica carinata* A. Braun). The anthers of four elite genotypes *viz.,* Jayanti, P-18, P-51 and $P_{(2)2}$ and their hybrids *viz.,* Jayanti x P-18, Jayanti x P-51 and Jayanti x $P_{(2)2}$ were cultured on B_5 and MS media. Each of these medium was supplemented with two different sucrose concentrations *i.e.* 3 per cent and 4 per cent sucrose and each of these sucrose concentrated media was also supplemented with three combinations of hormones *viz.*, HM_1 (NAA (1.0 mg/l)), HM_2 (BAP (2.0 mg/l) + NAA (2.0 mg/l)) and HM_3 (2, 4-D (0.5 mg/l) + NAA (1.0 mg/l)). All the media were supplemented with 0.8 per cent agar to know their effects on androgenic callus induction frequency. Mean sum of squares due to all factors were significant, revealing thereby significant effects of genotypes, media, hormones, sucrose and their interactions on callus induction frequency (%). The Effects of media and genotypes on callus induction frequency indicated that B5 medium gave highest callus induction frequency (77.50 %) and was found significantly superior than MS medium. Out of the seven genotypes, P-51 gave highest mean callusing (75.80 %). The Effects of hormones and genotypes indicated that

out of three hormonal combinations tested, HM_2 gave the highest mean callusing (81.80 %) and was found significantly superior to HM_1 and HM_3. The Effects of sucrose and genotypes indicated that 3 per cent sucrose gave highest callus induction frequency (74.27 %) and was found significantly superior than 4 per cent sucrose. The interaction between two factors *i.e.* sucrose x hormones, hormones x media and media x sucrose had significant effects on the callus induction frequency. Considering interaction, the highest callus induction frequency was observed in 3 per cent sucrose supplemented with HM_2 followed by 4 per cent sucrose supplemented with $HM_{3.}$ Overall, out of all factors and their interactions, the genotype P-51 performed better in B5 medium supplemented with HM_2 and 3 per cent sucrose concentration for high callus induction frequency.

Near-infrared reflectance spectroscopy (NIRS) a non-destructive technique for analysis of quality traits in Rapeseed-mustard

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Near-infrared reflectance spectroscopy (NIRS) is a non-destructive spectroscopic technique that uses near infrared region (780-2500nm) of electromagnetic spectrum for simultaneous analysis of multiple traits. It quantifies organic compounds by measuring the absorption of near infrared light by chemical bonds in the organic materials in less than a minute. The present study was conducted to test utilization of NIRS as a fast substitute for measuring quality traits estimated by organic and chemical methods which are often hazardous, time consuming and laborious. The plant material containing 240 seed samples of *B. juncea* and 193 of *B. napus* were analyzed for oil, phenol, glucosinolate and fatty acids profiling by traditional wet chemistry methods. Spectra of same samples were generated by scanning on NIR System model 6500, Foss. Reference analysis data was correlated with NIRS spectra by using modified partial least-square method (MPLS) to develop the calibration models for quality traits. Calibration results obtained were checked on the bases of high value of coefficient of calibration (RSQ). The calibration equation showed good RSQ values for oil (0.991, 0.992), phenol (0.979, 0.908), glucosinolate (0.939, 0.865), palmitic acid (0.769, 0.849), oleic acid (0.953, 0.929), linoleic acid (0.912, 0.875) and erucic acid (0.954, 0.924) in case of *B. juncea* and *B. napus* respectively, however, model was not good for stearic, linolenic and eicosenoic acids. The calibration model was validated internally and externally to check the accuracy, trueness, precision and range. The internal validation showed good correlation between laboratory and the predicted data with high RSQ for oil (0.879, 0.743), phenol (0.740, 0.757), GSL (0.865, 0.866), oleic (0.604, 0.932), linoleic (0.672, 0.900) and erucic acid (0.692, 0.925) for *B. juncea* and *B. napus* respectively. Similarly, external validation results also showed higher RSQ values for oil (0.766, 0.865), phenol (0.821, 0.915), glucosinolate (0.951, 0.986), oleic (0.814. 0.810), linoleic (0.974, 0.781) and erucic acid (0.963, 0.943) for *B. juncea* and *B. napus* respectively. Results obtained demonstrated the efficacy of newly developed model for rapid screening of breeding material for oil, phenol, glucosinolate and core fatty acids.

Assessing seed quality traits from smaller seed lots using near-infrared reflectance spectroscopy

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Rapid and non-destructive methods of seed quality detection can significantly improve the scope and pace of quality improvement programmes. Near infrared-reflectance spectroscopy (NIRS) is an excellent tool for non-destructive analysis of seed quality in oilseed crops. However, most of available calibration equations require 3-4g of mustard seed for seed quality determination. Such NIRS assays cannot be utilized during early segregating generation due to availability of smaller seed lots. We now report a new calibration equation that works efficiently with smaller lots of mustard seeds (0.6 to 0.8 g) for estimating seed quality traits. This calibration equation is based on a data base developed from wet chemistry analysis of 177 *B. juncea* genotypes for oil, phenol, glucosinolate and fatty acids (palmitic, stearic, oleic, linoleic, linolenic, eicosenoic, and erucic acid). Spectra of same sample(s) were generated by scanning 0.6-0.8 g of seed sample instead of 3-4g of mustard seeds. This calibration equation has been developed for Foss NIR Systems model 6500, using special adapters for standard ring cup. Validity of equation was indicated by high coefficient of calibration (RSQ >0.8) for oil (0.905), GSL (0.804), palmitic (0.805), oleic (0.905), linoleic (0.900) and erucic acid (0.919). In contrast, RSQ values were lower for phenol (0.581), stearic acid (0.616), linolenic acid (0.470) and eicosenoic acid (0.128).This equation was further tested to check the accuracy, trueness, precision and range. The internal and external validation results showed high RSQ values (> 0.8) for oil (0.857, 0.0.916), glucosinolate (0.700, 0.764), oleic (0.806, 0.740), linoleic (0.817, 0.918) and erucic acid (0.920, 0.932). However, lower RSQ values (<0.6) were recorded for phenols, stearic, linolenic and eicosenoic acid suggesting lower reliability of the calibration equation for these traits. Newly developed calibration equation can be effectively utilized for rapid seed quality estimation from smaller seed lots. We expect to further improve predictive value of the equation by broadening the calibration database to fill the gaps in trait values.

Genetic variability studies for Fatty Acid Composition In Oilseed Brassicas

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Brassica oil is the world's third most important sources of edible vegetable oil. It provides energy, improves taste and palatability of the food. The fatty acid composition of oil is extremely important as the presence or absence of different fatty acids and their relative amounts determine the nutritional quality of the oil. The present study was carried out in the biochemistry laboratory of DRMR, Bharartpur during 2014- 15 for fatty acid profiling with the wield of Gas Chromatography using twenty five germplasm lines of *B. napus* and three genotypes of *B. rapa var. brown sarson* (two released varieties, *Guchin & Shalimar Sarson-1* & one pre-release genotype *KBS-49*), genetically maintained at MRCFC, Khudwani, SKUAST-Kashmir. The

results have revealed that the oleic acid in the 28 genotypes ranged from 22.58 to 56.67%. Similarly, the linoleic & linolenic acid ranged from 16.63 to 29.05 % and 4.58 to 26.76 respectively. The erucic acid, an ant-inutritional fatty acidr also showed wide range, however the study has identified genotypes KBSG-3, KBSG-5, KBSG-6, KBSG-8, KBSG-13 & KBSG-15 where the erucic acid was less than 2 percent. Also KBSG-17 was identified as a canola type, as the genotype contained the 1.99% erucic acid & glucosinalate content of 26.3 μmole per gram in the defatted meal (double zero). The identified lines having low erucic acid/ high oleic acid/ high linoleic acid are being utilized in the quality improvement programme at the Khudwani centre for the development of *B. napus* with desired fatty acid profiles for edible purposes.

Study of oil quality characteristics and fatty acid in some genotypes of Indian mustard (*Brassica juncea* (L).Czern & Coss)

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Seed and oil quality analysis is an important parameter to be studied for varietal improvement of mustard genotype. Seven genotypes of Indian mustard were evaluated during *rabi* 2013-14 for fatty acid profile and also for oil quality characteristics using FT-NIR (Bruker MPA). The genotypes reflected the range of 1000 seed weight 4.3 to 6.0 g with a mean value of 5.0 g. The highest 1000 seed weight was recorded in NRCHB 101 and Bio 902. Seed oil content varied from 40.2 to 42.2 % with mean value 41.2, the highest oil % was found in RGN 303. The variation may be due to genotypic differences. The variation in specific gravity was from 0.9561-0.9652 with mean value of 0.9607; refractive indexes 1.4679-1.4697 with mean value of 1.4685. Very less variation was observed among different genotypes for specific gravity and refractive index. Acid value varied from 3.25-3.62 with mean value of 3.42, genotype SKM 815 had highest acid value 3.62. Free fatty acid as Oleic acid from 1.6-1.8 with mean value of 1.7 highest value of FFA was recorded in SKM 815 and Bio 902. Low value of FFA indicated that the oil from genotypes is suitable for *kachhi Ghani.* When studied for fatty acids, the genotypes reflected the range of Myristic acid 2.5 to 3.3 % with a mean value of 2.8%; Palmitic acid 1.6-1.9 % with mean value 1.7%; Stearic acid 7.0-11.0% with mean value of 9.1%; Oleic acid 24.3-27.8% with mean value of 26.7%; Linoleic acid 3.4-7.9% with mean value of 5.4% and Linolenic acid 5.4-7.6% with mean value of 6.5%; erucic acid 49.2-52.8% with mean value of 50.6%. The present study indicated a great potential for selecting better oil quality for edible and industrial purposes.

Introgression of low erucic acid trait into high yielding Indian mustard genotypes

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Indian mustard (*Brassica juncea*) is occupying more than 80% of total area of Rapeseed and mustard in India and it plays a significant role in oil economy. In *Brassica juncea* presence of high concentration (35-50%) of erucic acid (C22:1) is a major disadvantage to the Indian mustard. The major breeding target is to improve oil quality by reducing the erucic acid content in the oil, coupled with high seed yield. Crosses were attempted to introgress genes for low erucic acid into high yielding superior *Brassica* genotypes. Segregating material from F_2 to F_7 generation were studied for erucic acid content in *Brassica juncea* , through analysis of fatty acid profile of seed oil by gas chromatography using method developed in our own lab. Our biochemical studies were carried out on the progeny generations of the cross Pusa Vijay with PM30. Pusa Vijay though high yielding, is high in erucic acid content while PM 30 is a superior single zero low erucic acid released variety. F_1·s were all intermediate. The F_2 segregation patterns confirmed that inheritance of erucic acid content in *B. juncea* was governed by two genes with additive effects. As the selections were done only for low erucic acid trait, as the generation proceeded from F_3 to F_7, the trait got fixed with both loci having recessive alleles and erucic acid content of less than 2%. The biochemical analysis in each generation confirmed the erucic acid content of the individual progenies.

Fatty acids and glucosinolate evaluation of some promising mustard genotypes

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Indian mustard is an important source of edible oil and meal in India. The suitability of seed oils for human consumption is determined largely by its fatty acid composition. Seed oils low in saturated fats, high in monounsaturated fat (MUFA) and polyunsaturated fat (PUFA) are suitable for use as edible oil. Traditional Indian mustard varieties accumulate high amount of erucic acid and glucosinolate in their seeds. These quantitatively inherited anti-nutritional factors drastically reduce the utility of mustard derived seed oil and meal for consumption purposes. Thirty one genotypes from important breeding material procured from ICAR-DRMR were evaluated during Rabi 2015-16 for oil, glucosinolate and fatty acid profile. Variations in oil content were observed to range from 37.65 to 41.10 *%* with a mean value of 39.57 *%*. The range of variations in oleic, linoleic and linolenic acids were found from 9.57 to 60.30 *%*, 14.86 to 41.00 *%* and 7.26 to 22.68 *%*, respectively. The palmitic and stearic acids varied from 2.34 to 4.50 *%* and 1.06 to 3.60 *%*, accordingly. Oil stability index ranged from 0.47 to 3.75. Variations in glucosinolate content and erucic acid were observed from 11.15 to 97.09 µmole/g defatted meal and 0.19 to 45.40 *%*. The study indicated PDZ-4, EJ8-118, NUDB-26-11, PDZ-2, RLC-3, PDZ-5, EJ8-379, RLC-4, EJ8-369, Q2-1-5 (DRMR1-5), PDZ-1, Q-2-2-11 (DRMR 2-11) and RLC-5 were identified as nutritionally superior '00' genotypes of mustard, based on <2% erucic acid and low glucosinolate content (<30µmole/g defatted). MUFA: PUFA and nutritional quality index (NQI) varied from 0.32 (RH-749) to 2.55 (NUDB-26-11) and 5.15 (RH-749) to 21.37 (DRMRIJQ15-1) whereas ω6: ω3 ratio varied from 1.08 (LES-51) to 4.36 (Pusa Mustard 21) in mustard genotypes. The study thus indicated wide variation in individual biochemical parameter(s) of nutritional significance. Plant breeders engaged in mustard improvement can exploit the genetic potential of this crop for individual quality parameter of the dietary significance. Besides based on

varietal rating taking into consideration performance of genotypes with regards to desirable quality attributes viz., oil, oil stability index, NQI, ω6 to ω3 ratio (in descending order) and anti-nutritional factors glucosinolate and erucic acid (in ascending order) taken together, genotypes RLC-3, EJ8-118, PDZ-5, PDZ-2, PDZ-6, Q-2-2-11 (DRMR 2-11), EJ8-379 and PDZ-4 were identified to be multipurpose genotypes might be useful for food enrichment and value addition purposes.

Use of biochemical indices as selection criteria for quality traits improvement in Indian mustard (*Brassica juncea* L.)

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Development of genotypes with better oil quality and defatted meal is of paramount importance. With this objective, contribution of eight quality parameters towards quality of end products of thirty genotypes of *B. juncea* was investigated. Study based on nature and extent of variability for various quality components as well as direction and magnitude of their relationship revealed that high proportion of Oleic and Linoleic acid coupled with higher oil content were found to be the strong biochemical indices which could be used as selection criteria for improvement in quality of consumable products of Indian mustard.

A comparative study of free and bound phenolics in mustard seeds involved in the control of degenerative diseases

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Cruciferous plants contain various free & bound phenolics to provide wide range of protection against diseases. Major phenolics e.g. sinapic acid (SA), gallic acid (GA), p-hydroxy benzoic acid (BA) in mustard seeds are the potent antioxidants in various lipid biosynthesizing systems. The study investigated these phenolic antioxidants using fractions of mustard seeds. Phenolic compounds were extracted from whole seeds of 50 genotypes and their fractions using 85% methanol by the centrifugation method and quantified using HPLC. The major free phenolics from extracts were gallic acid, ferulic acid, sinapic acid, p-coumaric acid, p-hydroxy benzoic acid, and caffeic acids with a significant difference of phenolic contents. Sinapic acid was predominant compound among all the samples ranged from 11.59 to 16.77 mg/g DW in both bound as well as in free fractions. Seeds showed relatively high content of SA, GA, BA and total phenolics ($p < 0.05$). The concentration of SA in different fractions ranged from 14.01 ± 1.06 mg/g to 15.98 ± 0.79 mg/g. Few genotypes showed all the six phenolic compounds with good amount of sinapic acid & gallic acid. Further, a high degree of correlation ($r = 0.95$) was also noted between DPPH scavenging activity and total phenolic content. Phenolics usually significantly minimize the formation of the specific cancer-promoting nitrosamines from the dietary nitrites and nitrates. Therefore the results achieved in this study will be helpful to assess the therapeutic & neutraceutical potential of brassica seeds as well as of seed meal.

Conventional and quality Indian mustard *vis a vis* seed biochemical composition, quality traits, and storage behaviour

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An investigation was undertaken to seed quality traits in conventional and quality Indian mustard genotypes and understand its association with biochemical composition, seed vigour, and storage behaviour. Observations were recorded on seed quality, membrane integrity and biochemical activities related to seed vigour. It was found that imbibitional rate were significantly associated with the seed colour as well as quality of the genotypes. Double zero genotypes imbibed more water followed by single zero genotypes and than by conventional which influenced their storage behaviour. The fresh and controlled deteriorated seeds with yellow seed coat had the highest water uptake, while black seed had the lowest water uptake ratio. Imbibitional damage during aging could be one of the factors which contribute to seed quality differences among Indian mustard genotypes with varying seed coat colour. Significant differences were found in superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), ascorbate and total tocopherol contents among different genotypes of Indian mustard seeds. Studies on incidence of storage fungi during storage showed incidence of storage fungi i.e. *Aspergillus* sp., while insect species involved in mustard seed damage were found to be *Corcyra cephalonica* and *Tribolium* spp. especially in double zero genotypes. Our results uphold the hypothesis that loss of free radical scavenging enzymes (*i.e.*, SOD and CAT) and molecules during ageing and showed a direct relationship with the germination potential and vigour of ageing mustard seeds. High quality/vigour seed has efficient antioxidant system either in terms of antioxidant enzymes or antioxidant molecules.

Relationship between Indian mustard seed germination and ROS

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Germination *sensu stricto* is an important developmental switch when quiescent seed cells initiate oxidative phosphorylation for further development and differentiation. It is associated with many metabolic events, rendering the radicle able to emerge from the seed. The reactivation of metabolism following seed imbibition may be an important source of ROS (reactive oxygen species). ROS were initially recognized as toxic molecules that causes damage at different levels of cell organization and thus losses in cell viability. However, recent evidence shows that hydrogen peroxide is a signaling molecules which cross talk with plant phytohormones and has a role in seed germination. Thus, study was undertaken to study the role

of superoxide radical and hydrogen peroxide during germination in different genotypes of Indian quality mustard (*Brassica juncea).* Among the conventional genotypes, Pusa Mustard-28 shows maximum germination percentage and its protrusion of radical is much faster than other two genotypes. At the same time the content of hydrogen peroxide is also much higher in seeds at 24hours of germination in comparison to others. Among single zero type, Pusa Karishma shows highest germination percentage and fastest radicle protrusion. The hydrogen peroxide content is highest at 36 hours of germination (44.68μM/g) of this genotype and superoxide accumulation too. Superoxide anion showed positive correlation with axis length. This indicates a ratio of hydrogen peroxide to superoxide which is important for elongation and the change in axis length of the particular genotypes revels the maximum elongation in axis length is during this time only. Genotypes under double zero type of quality mustard shows minimum germination percentage in comparison to all other types. These genotypes show maximum accumulation of hydrogen peroxide at 42 hours of germination. It was concluded that superoxide anion is negatively correlated germination and positively correlated with MGT. The hydrogen peroxide showed positive correlation with seed germination and vigour index II

Quality improvement of edible oil by blending

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India is the third largest oilseed producing country in the world. The growing demand for edible oils with the increase in population is creating a stage of crunch in production of oils, thereby necessitating the need to search for the alternate sources of cheaper and nutritional oils. It was observed that no single conventional oil obeys the ideal fatty acids ratio (1:1-3:1 :: SFA: MUFA: PUFA). Some edible oils are rich in antioxidants; some are rich in saturated fatty acids while others are rich in unsaturated fatty acids. The saturated fatty acid > 7 % is unsafe for consumption. At the same time higher unsaturated fatty acids in oil are not fit for frying purposes as oxidation may occur upon storage. The ratio of SFA: MUFA: PUFA, ratio of essential fatty acids (ω-6: ω-3) and the presence of natural antioxidants are the parameters to judge an oil as "Healthy oil". Therefore, edible oil is often marketed as a blend of two or three oils. Blended oils are popular due to improved nutritional benefits, thermal stability and oxidative stability to acclimatize the desired properties. Oxidative stability of blended oils is measured by peroxide value and thiobarbituric acid (TBA) test. Nutritional status of blended oils is determined by fatty acid profile which includes palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid and erucic acid. Mustard oil in most of the popular varities has > 50% erucic acid which is not desirable but simulatenously it contains < 7 % saturated fatty acid (palmitic and stearic acid), which is preferred for edible purposes. Mustard oil also contains essential fatty acids *i.e.*ω-6 and ω-3. So quality of mustard oil can be improved by blending it with other edible oils (palm oil, rice bran oil, sesame oil and olive oil). Blending helps in achieving desired fatty acid composition. These designed oil blends are nutritionally superior over individual oils.

Effect of pollination modes on yield components in Indian mustard (*Brassica juncea* L.)

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The present study was carried out on Indian mustard variety RH-749 at research area of oilseeds section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar during 2015-2016. The effect of different modes of pollination quantitative and qualitative yield was investigated using following three modes i.e. open pollination, bee pollination and pollinators' exclusion. The mean number of pods per plant of *B. juncea* was significantly the highest (508.72 pods/plant) in open pollination followed by that in bee pollination (404.56 pods/plant) and pollinators' exclusion (287.56 pods/plant). The mean pod length of *B. juncea* was significantly the highest (5.69 cm) in open pollinated plots followed by that in plots caged with *A. mellifera* colony (4.92 cm) and pollinators' exclusion (3.89 cm). The mean per cent pod setting of *B. juncea* was significantly the highest (86.32%) in open pollinated plots followed by that in plots caged with *A. mellifera* colony (78.33%) and pollinators' exclusion (65.87%). The mean number of seeds per pod of *B. juncea* was significantly the maximum (15.66 seeds/pod) in open pollinated plots followed by that in plots caged with *A. mellifera* colony (14.26 seeds/pod) and pollinators' exclusion (12.24 seeds/pod). The mean thousand seed weight of *B. juncea* was significantly the highest (6.87 g) in open pollinated plots followed by that in plots caged with *A. mellifera* colony (6.39 g). The lowest mean thousand seed weight (5.30 g) was recorded in plots caged to exclude all pollinators. The mean seed yield per plot of *B. juncea* was significantly the highest (1763.0 kg/ha) in open pollination followed by that in bee pollination (1557.0 kg/ha) and pollinators' exclusion (1301.0 kg/ha). Significant increase in seed yield by 35.5 per cent was observed in open pollinated plots of *B. juncea* and by 19.66 per cent in *A. mellifera* pollinated plots over pollinators' exclusion. The mean per cent seed germination was highest (89.20%) in open pollinated plots followed by plots caged with *A. mellifera* colony (85.2%) and pollinators' exclusion (78.40%). The mean seed vigour of *B. juncea* was significantly the highest (628.1) in open pollination followed by that in bee pollination (542.5) and pollinators' exclusion (385.5). The data recorded on mean oil content of *B. juncea* revealed that significantly the highest oil content (39.42%) was observed in open pollinated plots followed by that in plots caged with *A. mellifera* colony (38.36%). Significantly the lowest mean oil content (37.04%) was recorded in pollinators' exclusion. Thus augmentation of hive bees and wild bees as part of crop management should be adopted by farmers for increasing the yield of Indian mustard.

THEME 2

RESOURCE USE-EFFICIENT PRODUCTION TECHNOLOGIES

Climate smart strategies for sustainable production of rapeseed and mustard

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Globally, India accounts for 21.7% and 10.7% of the total acreage and production of rapseed-mustard. India is the largest oilseed economy of the world. The contribution of oilseeds to the agricultural economy of India ranks second only to food grains. Among all sectors of Indian agriculture, the oilseed is one, which still largely depend on import from other country to meet the requirement of edible oils and these are the crops mainly grown under various biotic and abiotic stresses. The oilseed production in the country needs a substantial boost to meet the rising edible oil demand in the country. The production constraints and strategies to increase the productivity of the oilseeds, listed out can serve as a guideline for future research in these crops. To meet the ever growing demand of oil in the country, the gap is to be bridged through improved agronomic management. The vertical growth in mustard production can be brought by exploiting the available genetic resources with breeding and biotechnological tools which will break the yield barriers. Horizontal growth in rapeseed-mustard can be brought in those rapeseed-mustard growing areas/ districts of the country, wherever, the yield is lower than the national average. Production technologies for different agro-ecological cropping systems, crop growing situations like inter- cropping, salinity, rainfall, etc., under unutilized farm situations like rice - fallows, mustard to be followed after cotton, sugarcane, soyabean, etc., and mustard as a paira crop in rice with lathyrus, lentil or any other competing rabi crop in traditional and non traditional areas, need to be worked out. It is estimated that at least 1 million hectares can be brought under cultivation, through adoption of such cropping systems. Development of new crop production and protection techniques which are eco regional in scope and simultaneously incorporating the constraints imposed by the natural resource availability of the region is the need of the hour. The scope of productivity enhancement in oilseed crops is probably highest among any group of crop. The attainment of self sufficiency in edible oils through enhanced rapeseed-mustard productivity is possible, if we realise the production potential of our annual edible oilseed crops.

Problems of mustard productivity in Rajasthan

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Indian mustard (*Brassica juncea (L.) Czernj. & Cosson*) is predominantly cultivated in Rajasthan, UP, Haryana, Madhya Pradesh, and Gujarat. The crop can be raised well under both irrigated and rainfed conditions. Rapeseed-mustard is the major source of income especially even to the marginal and small farmers in rainfed areas. Due to its low water requirement (80-240 mm), rapeseed-mustard fit well in the rainfed cropping system. Despite the high quality of oil and meal and also its wide adaptability for varied agro-climatic conditions, the area, production and yield of rapeseed-mustard in Rajasthan is fluctuating due to various biotic and abiotic stresses. Weather abnormalities are a potential limiting factor in realizing optimum yield. In such a scenario, emerging fields of agronomic research like contingency crop planning techniques can be used. Major challenges in mustard productivity are; shrinking land holding, shortage of water availability, increased drought and high temperature during crop establishment and terminal stage of crop. Generally farmers are adopting mono cropping in the major areas is also main problem of low mustard productivity. Other problems also associated with mustard productivity are; cold spells leading to frost damage, uncertain rains during crop period, insect and diseases like: *Orobanche* and weeds, S*clerotinia* stem rot disease, white rust and downy mildew, aphid etc. In Rajasthan crop also damaged by wild animals particularly blue bull has been a major issue according to farmer's consultation. The mitigation of these constraints/problems requires innovative research strategies. Fallow mustard is the most common cropping system in Rajasthan, which can be rotated with sorghum/pearlmillet/maize/sesame depending on the availability of water and climatic conditions. In the other hand, so many ways of improving productivity of mustard through enhancing input (soil, water and nutrients) use efficiency, improving irrigation potential, farm mechanization (through improved agricultural tools, implements and machines), post harvest and value addition and use of resource conservation technologies viz. conventional tillage, reduced tillage, zero tillage, and furrow irrigated raised bed system.

Relative efficacy of natural resource use in rapeseed-mustard in Himachal Pradesh

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Rapeseed-mustard group of crop (s) are grown as sole crop or as an intercrop with wheat in Himachal Pradesh. These crops are grown over an area of 11.37 thousand ha with a total production of 6.37 thousand tonnes and productivity of 590 kg/ha which is much lower than national average. The lower productivity is thus, a major cause of concern. Deficit precipitation further aggregates the situation as was the case during last two monsoon seasons. The climate and soils of the state are largely suitable for the cultivation of rapeseed-mustard. This crop is grown in all the districts mostly under rain fed conditions. Adequate residual moisture availability during sowing (particularly *toria*) ensures germination but inadequate and erratically distributed rains cause moisture stress at later stages which reduce the productivity. Shallow coarse textured soils with undulating topography have poor soil moisture holding capacity leading to poor moisture availability. Mid and high hills encounter low air and soil temperature conditions resulting in stunted growth during initial phases of crop growth. Keeping this in view, an experiment was conducted with five varieties *viz.,* HPN-1, HPN-3 Hyola-401, ONK-1 and GSL-1 sown on 20th October, 30th October and 10th November during each year from *rabi* 2011-12 to 2014-15 at Palampur ((lat. 30.10 N and long. 76.54 E). The natural resource use by different gobhi sarson varieties was quantified in terms of Heat Use Efficiency (HUE), Radiation Use Efficiency (RUE) and Water Use Efficiency (WUE) facilitating identification of varieties suitable for different sowing environments. It can be inferred from the analysis that differential response exists for HUE, RUE and WUE. In all the varieties and sowing dates, WUE was observed to be higher as compared to other two efficiencies. Barring few exceptions, the efficiency to use these resources generally decreased with delay in sowing. The variety ONK-1 was found to be more efficient in respect of heat use and water use than the other varieties studied. The comparison of radiation utilization efficiency of wheat and rapeseed-mustard indicates that the radiation utilization efficiency is much lower than wheat. Photosynthetic efficiency of irrigated rapeseed-mustard is nearly half that of irrigated wheat and two-third of rain fed wheat. Vigorous efforts are required by Plant Breeders/Crop Physiologists to develop an ideal plant type which can efficiently utilize radiation for source-sink conversion in rapeseed-mustard. Earlier workers have described a model plant type in *brassica sp.* in which the plant height must be 1-1.25 m with 5-6 primary branches emerging at 30-45^o angle from main stem. There should be approximately 40 siliquae on main stem, 20 siliquae in top two branches and 15 siliquae each on lower three branches. The plant should have deep root system and bear 7-10 leaves.

Quality improvement of rapeseed (*Brassica napus*) through micronutrient fortification in conservation agriculture system

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Rapeseed (*Brassica napus*) is one of the major edible oilseed crop in the world and in India. It is considered to be healthy edible oil due to its low content of saturated fatty acids and its moderate content of polyunsaturated fatty acid among vegetable oils. Today's agriculture is shifting from conventional agriculture to conservation agriculture and rapeseed is now taken mostly after rice at zero tilled condition in residual soil moisture. Because of the sensitivity of *Brassica napus* to boron (B) and Zinc (Zn) deficiency and the wide distribution of low available-B and Zn soils in India more and more attention is being paid to the effect of B and Zn nutrition on yield and quality of rapeseed and its regulation mechanism. *Brassica napus* requires high soil B for sufficient growth and is sensitive to low-B stress which may hampers the growth and development of rapeseed and even results in a typical symptom named 'flowering without seed setting' when under severe B deficiency. Studies have reported that B could increase seed yield and improve seed quality, e.g., it could increase oil content and oleic acid content and reduce glucosinolate and erucic acid content. The response of various ideotype to the applied micronutrients varies considerably. The concentration of Zn at flowering, pod formation stage, concentration and uptake of Zn in straw and grain at maturity and uptake of Zn in grain and straw at maturity of rapeseed increased significantly with increase in Zn levels. Differential micronutrient fortification methods and stage of application have significance enhancing effects on rapeseed growth, yield and quality oil contents.

Site-specific nutrient management is a key for enhancing productivity of mustard in India

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In India, rapeseed- mustard alone contributes in total oil production to the extent of about 24% with its average productivity of about 1.00 t ha^{-1}. Analysis of 1601 soil samples from major mustard growing areas representing 14 agro-ecological sub-regions (AESRs) indicated widespread multi-nutrient deficiency involving 2 to 6 nutrients including NK, NKS, NKB, NPKS, NKSZn and NPKSZnB. Incidence and expansion of such multi-nutrient deficiencies in Indian soils owing to inadequate and unbalanced nutrient input through fertilizers is considered one of the major constraints in enhancing productivity of oilseed crops. In this context, different nutrient supply options namely T_1: SSNM; T_2: State *ad-hoc* recommendation plus potassium (SR) + K; T_3: SR; T_4: Farmer's fertilizer practice (FFP) + K; and T_5: FFP were evaluated in Lohtaki village district Gurgaon representing AESR 4.1 with pearl millet-mustard cropping system. On an average mustard grain yield responses over FFP across the experiments were the highest in SSNM (85%), followed by SR+K (40%) and SR (24%). Average, net return over FFP in pearlmillet-mustard cropping system, was higher (Rs. 43963 ha^{-1}) under SSNM, followed by SR+K (Rs. 26092 ha^{-1}) and SR (Rs. 15693 ha^{-1}). In all these experiments, SSNM proved superior to state recommendation and farmers' fertilizer practice in terms of annual crop yields, nutrient recovery, soil fertility restoration and net economic returns. Site-specific nutrient management (SSNM) seems to be one of effective ways to improve nutrient supplying capacity of soil and enhance the productivity of mustard which in turn will help in achieving much needed self sufficiency in oilseeds production in India.

Effect of fertility levels on yield attributes and yield of Indian mustard in South –Eastern Rajasthan

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A field experiment was conducted at Agricultural Research Station, Ummedganj farm, Kota during *rabi* 2014-15 for evaluating the effect of fertility levels on yield attributes and yield of Indian mustard. The experiment consisting three levels of nitrogen (60, 80 & 100 kg N/ha), two levels of phosphorus (20 & 40 kg P_2O_5/ha) and two levels of potassium (0 & 30 kg K_2O/ha) was carried out in factorial randomized block design with replications thrice. The **s**oil of the experimental field was clay loam, alkaline in reaction (pH 7.56), medium in organic carbon (0.55 %), nitrogen (305.0 kg/ha) and phosphorus (23.0 kg/ha) and high in potassium (284.0 kg/ha). The nitrogen and phosphorus were given through di-ammonium phosphate and remaining quantity of nitrogen was given through urea applied as basal as well as top dressing at 40 DAS. The potassium was applied through murate of potash. The variety of mustard (RGN 73) was used in this experiment with plot size was 5.0 m X 4.2 m. Application of 80 kg N/ha registered significantly higher branches/plant (4.90), siliquae / plant (211.08), seeds /siliqua (15.62), test weight (4.72 g) and seed yield of mustard (2019 kg/ha) over 60 kg N/ha but it was found on par with 100 kg N/ha. Similarly, amongst the P and K levels, the maximum branches/plant, siliquae/plant, seeds/siliqua, seed weight/plant and test weight were noted with the application of 40 kg P_2O_5 and 30 kg K_2O/ha. Consequently, application of 40 kg P_2O_5/ha significantly enhanced seed yield of mustard by 206 kg, over 20 kg P_2O_5, whereas application of potassium levels were found non-significant in respect of seed yield of mustard. It is concluded that in vertisol of south eastern Rajasthan, mustard variety RGN 73 should be fertilized with 80 kg N, 40 kg P_2O_5 and 30 kg K_2O / ha for higher seed yields.

Growth and productivity potential of Indian mustard as influenced by nutrient management practices

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Identification and quantification of the critical agricultural inputs for enhancement of productivity of the mustard is the need of the hour. The balanced nutrition along with improved cultivar, weed, water management, is one of the most critical factor for realising genetic yield potential of mustard crop. Indian soils are becoming deficient in sulphur, zinc, boron and other secondary as well micro-nutrients due to intensification of cropping system and use of high analysis fertilizers. Indian mustard (*Brassica juncea* L.) requires relatively higher amount of the nutrients for realization of better yield but imbalance supply of nutrient led to lower yield. Therefore, the present study was conducted to study the integrated nutrient management on growth and yield of Indian mustard in north Gujarat agro-climatic condition. The experiment was conducted during *rabi* season of 2013-14 at Castor and Mustard Research Station, SDAU, Sardarkrushinagar, Gujarat, India. The soil of the experimental plot was sandy loam in texture. The experiment was comprised ten treatments *viz*. Control, 50% NPK, 100% NPK, 150% NPK, 100% NPK + S @ 40 kg S/ha, 100% NPK + Zn @ 25 kg $ZnSO_4$/ha, 100% NPK + B @ 1 kg B/ha, 100% NPK + FYM @ 2.5 t/ha (dry weight basis), 100% NP and 100% N with replicated thrice in RBD. The recommended dose of fertilizer for Indian mustard (GM 3) was N_{50}, P_{50}, and K_{20} kg/ha and it was sown in fourth week of October with spacing of 45 cm x 15 cm by using 3.5 kg/ha seed rate. The full dose of P, K, S, micronutrient and half dose of nitrogen were drilled just before the sowing as a basal application in the form of urea, DAP, MOP and sulphur as per treatments and remaining 1/2 dose of nitrogen was top dressed at 25-30 DAS as per treatments plot. Results revealed that the various growth and yield characters *viz*., plant height, no of branches/plant, no. of siliquae/plant, length of siliqua and grain yield were recorded higher with the application 150% NPK. This treatment was tended to increase grain yield to the tune of 92.63% and 96.04% as compared to control/no fertilizer and 50% NPK. However, the application 100% NPK along with sulphur @ 40 kg/ha recorded higher number of seeds/siliqua, test weight and oil content, respectively.

Integrated nutrient management for Indian mustard (*Brassica juncea*) in maize-Indian mustard cropping system for sustainable production

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Indian mustard is the most important oilseed crop of semi-arid north-west and north-east India and makes the highest contribution in terms of edible oil in the country. Effect of different nutrients on growth and productivity of Indian mustard in the Indian mustard-maize cropping system was studied for five years from 2011-12 to 2015-16 to study their long term effect in sustaining the productivity of the cropping system. The study comprised 14 treatments which were replicated thrice as per RCBD. Maize hybrid was grown during preceding *kharif* seasons (second fortnight of June to first week of October in different years) with application of nutrients as per treatments (excluding organic sources). Indian mustard was grown from October/November to end March in different years. Soil analysis prior to Indian mustard sowing in 2011-12 revealed that the soil of the experimental field (0-15 and 15-30 cm depths) was loamy sand, free from salts (0.152, 0.141 dS/m), neutral (pH 7.3, 7.4), low in organic carbon (0.35, 0.25 %), low in available nitrogen (107.5 , 94.8 kg/ha), low in available phosphorus (11.8, 7.2 kg/ha) and low in available potassium (121, 114.2 kg/ha). Differences among treatments were significant for plant height, branching, main shoot length, number of siliquae, oil content, seed and oil yields but non significant for number of seeds per siliqua and 1000 seed weight. Application of 150% NPK (150 kg N, 45 kg P_2O5, 22.5 kg K_2O/ha) resulted in 11.4%, 16.8%, 36.1% and 171.9% more mean seed yield over application of 100% NPK, 50% NPK, 100% N and without nutrient application. Similarly, application of 100% NPK resulted in 4.9%, 22.2% and 144.0% more seed yield than 50% NPK, 100% N and without application of nutrients. Similar trend was discerned for oil yield. The highest mean seed yield (1938 kg/ha), and oil yield (739 kg/ha) obtained with application of 150% NPK were statistically at par with application of 100% NPK + S @ 40 kg/ha + ZnSO4 @ 25 kg/ha + B @ 1.0 kg/ha (1914 kg/ha, 738 kg/ha), application of 100% NPK + rice residue @ 2t/ha on dry weight basis (1807 kg/ha. 696 kg/ha) and 100% NPK + S @ 40 kg /ha (1801 kg/ha and 694 kg/ha). The oil yield obtained with application of 150% NPK (739 kg/ha) was also statistically similar to that obtained with application of 100% NPK + FYM @ 2.5 t/ha on dry weight basis (691 kg/ha).

Effect of fertility levels on yield attributes and yield of Indian mustard in South –Eastern Rajasthan

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A field experiment was conducted at Agricultural Research Station, Ummedganj farm, Kota during *rabi* 2014-15 for evaluating the effect of fertility levels on yield attributes and yield of Indian mustard. The experiment consisting three levels of nitrogen (60, 80 & 100 kg N/ha), two levels of phosphorus (20 & 40 kg P_2O_5/ha) and two levels of potassium (0 & 30 kg K_2O/ha) was carried out in factorial randomized block design with replications thrice. The soil of the experimental field was clay loam, alkaline in reaction (pH 7.56), medium in organic carbon (0.55 %), nitrogen (305.0 kg/ha) and phosphorus (23.0 kg/ha) and high in potassium (284.0 kg/ha).

The nitrogen and phosphorus were given through di-ammonium phosphate and remaining quantity of nitrogen was given through urea applied as basal as well as top dressing at 40 DAS. The potassium was applied through murate of potash. The variety of mustard (RGN 73) was used in this experiment with plot size was 5.0 m X 4.2 m. Application of 80 kg N/ha registered significantly higher branches/plant (4.90), siliquae / plant (211.08), seeds /siliqua (15.62), test weight (4.72 g) and seed yield of mustard (2019 kg/ha) over 60 kg N/ha but it was found on par with 100 kg N/ha. Similarly, amongst the P and K levels, the maximum branches/plant, siliquae/plant, seeds/siliqua, seed weight/plant and test weight were noted with the application of 40 kg P_2O_5 and 30 kg K_2O/ha. Consequently, application of 40 kg P_2O_5/ha significantly enhanced seed yield of mustard by 206 kg, over 20 kg P_2O_5, whereas application of potassium levels were found non-significant in respect of seed yield of mustard. It is concluded that in vertisol of south eastern Rajasthan, mustard variety RGN 73 should be fertilized with 80 kg N, 40 kg P_2O_5 and 30 kg K_2O / ha for higher seed yields.

Effect of nutrient levels on yield, oil content and economics of Indian mustard (*Brassica juncea* L.)

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A field experiment was conducted during *rabi* seasons of 2014-15 and 2015-16 at Agricultural Research Farm of Tirhut College of Agricultue, Dholi (Muzaffarpur) to study the effect of nutrient levels on yield, oil content and economics of Indian mustard. There were three levels of nitrogen (60, 80 and 100 kg/ha), two levels each of phosphorus (20, 40 kg/ha) and potassium (0,30 kg/ha). The experiment was carried out in factorial randomized block design on sandy loam soil. Response of increasing levels of nutrients on mustard seed yield, straw yield, harvest index, oil content, oil yield, net return and B : C ratio was found significant. It was found that nitrogen had more pronounced effect on yield than phosphorus and potassium. The yield increase was 28.43 per cent when dose of nitrogen was enhanced from 60 to 100 kg/ha and it was 12.87 per cent increase in the yield of mustard seed when the dose of nitrogen was enhanced from 60 to 80 kg/ha. When the level of phosphorus was increased from 20 to 40 kg/ha and to that of potassium was from zero to 30 kg/ha, the increase in yield due to phosphorus and potassium was to the tune of 9.49 and 2.04 per cent, respectively. Similar pattern was observed with straw yield, oil yield and net return but the effect of nitrogen on oil content was just reverse and it was decreasing with the increase in nitrogen levels. Decrease in oil content was 0.47 and 0.62 per cent when the level of nitrogen was increased from 60 to 100 kg/ha, respectively. Effect of phosphorus and potassium on oil content was found positive and it was to the tune of 0.38 and 0.67 per cent when the level of phosphorus was increased from 20 to 40 kg/ha and to that of potassium was from zero to 30 kg/ha. Increase in net return was to the tune of 18.24, 40.63 and 18.94 per cent when the level of nitrogen was enhanced from 60 to 80, 60 to 100 and 80 to 100 kg/ha, respectively. Net return due to increase in phosphorus level (20 to 40 kg/ha) was increased by 12.49 per cent but the increase was almost negligible (0.98%) when the level of potassium was enhanced from zero to 30 kg/ha.

Growth and productivity behaviour of Indian mustard (*Brassica juncea*) under different nutrient management practices

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Indian mustard is an important *rabi* season oilseed crop of north Gujarat. Mustard is grown in, an area of 0.28 million hectares with the production of 0.45 million tonnes and productivity of about 1582 kg/ha in Gujarat. The differential trends in yield of the Indian mustard under a specific agro-climatic condition have been noticed due to varying nutrient status of soil. Mustard is highly responsive to plant nutrients especially major nutrients. However, the use of total organic or inorganic nutrient sources has some limitations, in these circumstances suitable combination of FYM with inorganic fertilizers and micronutrient facilitate profitable and sustainable production. Hence, the present study was carried out to study the effect of integrated nutrient management on productivity Indian of mustard in north Gujarat agro-climatic condition. The field experiment was conducted during *rabi* season of 2015-16 at Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India. The soil of the experimental field was sandy loam with pH 7.2, low in available nitrogen, phosphorus and potassium. The experiment was laid out in randomized block design consisting of ten treatments *viz*. Control, 100% PK, 100% NPK, 150% NPK, 100% NPK + S @ 40 kg S /ha, 100% NPK + Zn @ 25 kg ZnSo4/ha, 100% NPK + B @ 1 kg B/ha, 100% NPK + FYM @ 2.5 t/ha (dry weight basis), 100% NP and 100% NK with replicated thrice. The recommended dose of fertilizer for mustard (GM 3) was N_{50}, P_{50}, and K_{20} kg/ha. Full dose of P, K, S, micronutrient and half dose of nitrogen fertilizers were drilled just before the sowing as a basal application in the form of urea, DAP, MOP and elemental sulphur as per treatments and remaining half dose of nitrogen was applied at 25-30 DAS in the earmarked plots. Over all growing season was normal for crop. Various growth parameters, yield attributes and yield were recorded at harvest. Results revealed that the fertility treatments were failed to showed significant variation on plant height, number of primary branches/plant and no. of siliquae/plant. The nutrient management treatments had significant influence on number of seeds/siliqua, length of siliqua, oil content and seed yield. The application of 100% NP/ha recorded significantly higher number of seeds/siliqua, while length of siliqua was higher under application of 100% NK/ha, respectively. The application of 150% NPK was significantly out yielded and performed comparatively at par with 100% NPK alone and its conjunction with 2.5 t/ha FYM (dry weight basis) but significantly superior over rest of the treatments. However, the oil content was recorded significantly higher with 100% NPK + 40 kg S/ha and it was remained statistically at par to all the nutrient management treatments except control.

Indian mustard (*Brassica juncea*) productivity as influenced by integrated nutrient management under semi-arid region of Rajasthan

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Indian mustard (*Brassica juncea* L.) belongs to the family cruciferae is one of the most important winter oilseed crop. Oil seed crops generally cultivated under energy starvation condition, moisture stress condition particularly rainfed areas under deficient nutrient supply these are the main cause of low productivity in oil seeds. The fertilizers have played a prominent role in increasing the oil seed production, balanced fertilizer is the key to achieve higher production and increase nutrient use-efficiency. The use of chemical fertilizers would remain the mainstay of agricultural production in future. Generally farmers are using unbalanced fertilizer which deteriorates soil health day by day so; this experiment was aimed to improve the balanced use of fertilizers to farmer's field through integrated nutrient management. The field experiment was conducted at agronomy research farm, Directorate of Rapeseed and Mustard Research, Bharatpur during the *rabi* seasons of 2012-13 and 2013-14 to assess the various nutrient combinations aimed to sustainable brassica production system. Eight treatment combinations consisting of six organic manures alongwith recommended dose of nitrogen (40 kg N/ha) and phosphorus (40 kg P_2O_5/ha) viz. sesbania green manure (SGM), mustard straw incorporation @2.5 t/ha (MSI), SGM + MSI, mustard straw mulch @2.5 t/ha, FYM @ 5t/ha, vermicompost 2.5 t/ha, control (without manure & fertilizer) and recommended dose of fertilizers were tested under randomized block resign with three replications. Sesbania green manure + mustard straw incorporation @2.5 t/ha gave 29.5 and 121% higher seed yield of mustard over recommended dose of fertility and absolute control, respectively. So, it can be concluded that mustard productivity can be increased with sesbania green manure + mustard straw incorporation @2.5 t/ha under semi-arid region of Rajasthan

Studies on the effect of nitrogen levels and bio-fertilizers on yield of brown sarson

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A field experiment was conducted at Mountain Research Center for Field Crops, Khudwani of Sher-Kashmir University of Agricultural Sciences and Technology of Kashmir during *rabi* 2013-14 and 2014-15. The soil of the experimental site was silty clay loam in texture and neutral in reaction with medium phosphorous and potassium and low in nitrogen. The rainfall during *rabi* season was 129.8 mm, maximum and minimum temperature during *rabi* season was 22.2^{o}C and 12.1 ^{o}C, average humidity was 60.9 %. Three nitrogen levels (0; 60; 80 kg ha^{-1}) and four biofertilizer inoculations (no inoculation; Azotobacter; Phosphorous solubilizing bacteria (PSB); and Azotobacter + PSB) were tested in randomized block design with three replications. Uniform dose of recommended phosphorous and potassium @ 45 kg and 20 kg and FYM @ 10 t ha^{-1} was applied to each treatment. The data revealed that various nitrogen levels provided significant increase in plant height, number of primary branches, number of secondary branches, siliqua per plant, number of seed per siliqua, 1000 seed weight (g), seed yield (kg ha^{-1}) and stover yield (kg ha^{-1}) of brown sarson as compared to control.

Among the different bio-fertilizer inoculation did not marked any significant variation in enhancing the plant height, number of primary branches, number of secondary branches, siliqua per plant, number of seed per siliqua, 1000 seed weight (g), seed yield (kg ha^{-1}) and Stover yield (kg ha^{-1}) over no inoculation of bio-fertilizers. However, inoculation of bio-fertilizers alone or in combination marked superiority in increasing plant height, number of primary branches, number of secondary branches, siliqua per plant, number of seed per siliqua, 1000 seed weight (g), seed yield (kg ha^{-1}) and stover yield (kg ha^{-1}) over no inoculation. Among the different bio-fertilizers inoculated combined inoculation provided superior results than their lone application. Treatment combinations involving application of recommended dose of nitrogen and combined inoculation of Azotobacter + PSB acquired highest net returns and benefit cost ratio**.** The study also indicated that application of recommended nitrogen is beneficial in improving the yield of Brown sarson. The inoculation of biofertilizers is not that beneficial in increasing the yield of brown sarson under Kashmir Valley condition because of sub zero temperatures during winters. However, environmental safety is there with the application of bio-fertilizers, moreover, reducing almost 10-25 per cent of fertilizer cost.

Moisture stress mitigation in rapeseed-mustard (taramira) through agro chemicals

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A field experiment was conducted during 2013-14 at SKN College of Agriculture Farm, Jobner to investigating the efficacy of agrochemicals (urea, thiourea and potassium permegnate) for mitigating the effect of moisture stress in taramira. Results indicated that all the treatments except water spray proved significantly superior in enhancing the yield attributes and yield of taramira crop. Two sprays of 0.05% thiourea each at 50% flowering and 50% pod filling stages recorded the significantly highest seed yield of taramira (1335.0, 1323.0 and 1337.0 kg/ha) among all the treatments. However, it was found at par with two sprays of 1% urea at 50% flowering and 50% pod filling stages, two sprays of 1% KMnO4 at both stages, thiourea spray at 50% flowering stage and at 50% pod filling stage treatments. These five treatments improved the average of seed yield to the extent of 53.1, 47.5, 37.5, 47.5 and 35.05 per cent over control, respectively. Spray of 1% urea at 50% flowering and 50% pod filling stage, thiourea spray (0.05%) at 50% flowering stage and 1% KMnO4 spray at 50% flowering and 50% pod filling stage were found the next superior treatments in enhancing seed yield of crop. The maximum net returns of Rs. 30413/ ha were obtained with two sprays of 0.05% thiourea each at 50% flowering and 50% pod filling stages. It was closely accompanied by two sprays of 1% urea each at 50% flowering and 50% pod filling stages (Rs. 29023/ ha) and one spray of 0.05% thiourea at 50% flowering stage (Rs. 27500/ha). These three treatments increased the net returns by margin of Rs. 11494, 10104 and 8581 /ha over water spray and Rs.12854, 11464 and 9941 /ha over control, respectively. These treatments also represented significantly higher B : C ratio than most of the treatments. One or two sprays of 1% KMnO4 although, found significantly better than control and water spray, yet proved lesser remunerative than above mentioned treatments due to higher cost of application.

Biochemical role of sulphur on oilseed Brassica

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Sulphur play a vital role in plant and number of biomolecules contains sulphur. Sulphur plays a chief role on oil biosynthesis, protein synthesis, vitamin, enzyme activation, translocation of nutrients, chlorophyll synthesis and plant protection etc. Sulphur increases source to sink relationship in plant and overall increase metabolic activities which seem to have promotedmeristematic activities causing higher apical growth and expansion of photosynthetic surface.Sulphur increases fatty acid composition of the oil changed substantially during seed development. Application of sulphur increasesthe oleic acid (18:1) synthesis, and decreased the erucic acid (22:1) synthesis. Sulphur decreases the antinutritional factors (glucosinolate, erucic acid, and secondary metabolites) which is present in cruciferous plants. There was increase in water use efficiency with increasing sulphur level up to 45 kg S/ha. Application of 60 kg S/ha gave significantly higher seed yield (2647.0 kg/ha) than 20 and 40 kg/ha by 15.5 and 7.2% respectively.The aim of the study was to determinebiochemical role of sulphur on oilseed brassica**.**

Role of Organics in enhancing the production of Rapseed-Mustard

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The nutrient management in agricultural production is an essential factor to increase food production but continuous use of chemical fertilizer has deleterious effects on soil which in turn cause decline in productivity, low nutrient recovery efficiency and increase in cost of production and environmental pollution. Soil degradation is occurring due to inadequate and imbalanced fertilization. Rapeseed- Mustard is the second most important oilseed crop in India after soybean and accounts for nearly 20-22 percent of total oilseeds produced in the country. The imperfect integration of essential plant nutrients and their poor supply are among the major causes of low grain and oil yield in rapeseed-mustard. Organic farming is not new term for Indian community and it has been successfully used by the Indian farmers from hundreds of the years. Even today, the farmers do not have enough funds to purchase costly chemical fertilizers and other agricultural chemicals and use lesser amount of organic fertilizers. Farmers apply chemical fertilizers to both the crops with poor application of organic sources of fertilizers. It has been observed that farmers can reduce the dosage of costly chemical fertilizers by adopting organic sources in combination with inorganic fertilizers. Use of efficient strains of bio-fertilizers are environment friendly, low cost agricultural inputs that have an important role in improving nutrient supply to crops but also reducing the cost of production in *Brassica.* Green manuring, legumes and organic manures can produce the same amount of food with less fossil fuel based inorganic fertilizers and are also beneficial to sustain the problem of multi-micronutrient in *brassica* and also helps in improving the physical health of the soil. Farm yard manure (FYM) and bio-fertilizers are used for eco-friendly organic farming, however they are unable to completely replace chemical fertilizers in terms of crop productivity. The slow release organic fertilizers are slow acting and facilitate long term availability of the nutrients often synchronized with the physiological need of plants and are considered as one of the most viable alternative for the sustainable plant productivity. Organic materials hold great promise due to their local availability, as a source of multiple nutrients and ability to improve soil characteristics.

Role of organic farming in Brassica

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Organic farming has become the most highly valued method for sustainable production in the agriculture and food trade. The time when organic farming was a viable option only for people with alternative views on environmental preservation, wildlife protection, and health food production is long gone. Today farmer is looking for long term faming solutions and production of safe, high quality food, organic farming is the best option. Organic farming has truly developed into one of the most dynamic agricultural sectors. Increased consumer awareness for food safety issues and environmental concerns has contributed to growth in organic farming over last few years. Oilseeds are among the major crops that are grown in the country apart from cereals. India is the fourth largest edible oil economy after the U.S., China and Brazil in world and its vegetable oil production is 6 percent. Rapeseed- Mustard is the second most important oilseed crop in India after soybean and accounts for nearly 20-22 percent of total oilseeds produced in the country. To meet the minimal nutritional requirement of fat and oils (12 kg capita^{-1} yr^{-1}) and for other uses, it has been estimated that nearly 24 million tonnes of rapeseed and mustard are required by 2020 A.D). Nitrogen, sulfur and boron fertilization has significantly enhanced growth and yield of B. *juncea* in the Indian soil. However, a major portion of the applied chemical nitrogen fertilizers is lost through the leaching, run off, emissions and volatilizations which cause economic losses and serious environmental problems. Farm yard manure (FYM) and bio-fertilizers are used for eco-friendly organic farming, however they are unable to replace chemical fertilizers in terms of crop productivity. The slow release fertilizers are slow acting and facilitate long term availability of the nutrients often synchronized with the physiological need of plants and are considered as one of the most viable alternative for the sustainable plant productivity. Certain reports are available regarding use of slow release fertilizers for oilseed crops. Thus, organics along with minimal proportion of chemical fertilizers can be used to enhance the production of brassica and to sustain soil health and other soil properties.

Assessment of Vermicompost + PSB + Sulphur on growth and yield of mustard *(Brassica juncia)* in Rewa district of Madhya Pradesh

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An on farm trial was conducted in farmer's field during 2015-16 of Raipur Karchuliyan block of Rewa district. Rewa district is situated at longitude N 24^{0}36.163' and latitude E 81^{0}48.148' with MSL 359 meter. Five farmers were selected in the village Reethi. Soil fertility status of farmer's field had an average pH 6.7-7.4, organic Carbon (%) 0.52-0.64, EC (dSm-1) 0.41-0.54, available

N (119.8) kgha-1, available P (16.2) kgha-1 and available K (239.8) kgha-1. The micronutrients status of Sulphur and Zinc was low while Fe, CU, Mn and B were normal to Sufficient. In on farm trials, three treatments namely T_1 : Sulphur , T_2 : Vermicompost + Sulphur and T_3 : Vermicompost + PSB + Sulphur were studied. The maximum yield gain was found in T_3 (16.38 qha^{-1}) with Siliquae per plant (109.2), Where as in trials T_1 and T_2 yield gain was 12.82 and 14.13 qha^{-1} and Siliquae per plant 98.3 and 87.4 respectively. The biological yield and economical yield ratio in trial T_1, T_2 and T_3 were 0.89, 0.97 and 1.02 respectively.

Enhancing soil resilience and productivity of Indian mustard through green manuring and residue management in semi-arid tropics

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Oilseed brassica (OSB) is an important edible oil crop of Indian subcontinent and shares one-third of domestic edible oil production. However, yield stagnation has been experienced in last decades. Multiple soil health and climate change issues are major physical reasons for the yield stagnation which needs to be addressed immediately. And building soil organic carbon (SOC) content is most reliable but challenging option to make OSB production system sustainable in semi-arid tropics. Mustard residue due to poor fodder value is usually brunt to clear the field but its incorporation into the soil system could pave ways to improve the soil organic pool. Additionally, green manuring during rainy season is advocated for improvement of fallow-mustard sequence. Therefore the purpose of the study was to evaluate the effects of mustard residue and green manure on soil health and mustard productivity. The long term replicated experiment keeping conventional practices (CS), *Sesbania* Green Manuring (SGM) and 2.5 t/ha mustard straw recycle + SGM (MSGM) in main plot and eight combinations of NPK fertilizers in subplot was started in 2004-05 at Bharatpur. The crop and soil health attributes on each treatment were recorded at regular intervals over the study period. The actual yield was transformed to relative yield to minimise the temporal effect on the data. The standard ANOVA was performed to compare the treatments in a year and pooled information to draw logical conclusions. SGM significantly improved the SOC, soil organic microbial biomass, infiltration rate, available NPK status, but decreased bulk density over CP. MSGM further augmented the soil health attributes. The increase in fertilizer levels from $N_{40}P_{8.7}K_0$ to $N_{80}P_{17.4}K_{33.3}$ also improved the soil attributes gradually. This gradual improvement in soil health was clearly visible in yield attributes and seed yield from 4th year of experimentation. Overall, mustard seed yield was increased by 40.6% due to SGM and by 61.1% due to MSGM over CP in 9 years. Increase in fertilizer levels from N_{40} to N_{80} and $P_{8.7}$ to $P_{17.4}$ also improved the seed yield significantly while results of K application were inconsistent. The combined application of $N_{80}P_{17.4}K_{33.3}$ synergistically increased the seed yield by 53.6% over $N_{40}P_{8.7}K_0$. The growth in relative yield of mustard over years followed logarithmic function and predicted the achievement of plateau yield in 11 years under MSGM and 18 years under SGM in comparison to 33 years under CP. OSB is important source of edible oil and has great potential to make India self reliant in edible oil. But the yields are presently stagnating with negative growth in area and production. The trend could be revered through application of these findings and double the seed yield and profit margin to bring back the crop to the path of sustainable production and thereby the country to reduce the import bills.

Pressmud compost for sustainable productivity of Indian mustard (*Brassica juncea* L.)

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Agricultural sustainability can be defined as the ability of an agric - system to maintain stable levels or increase production and quality in the long term without losing economic profitability or the environmental quality. Rapeseed and mustard are the major *rabi* oilseed crop of India. They occupy a prominent place, both in area and production in the country. In the changing climatic conditions, lowering down irrigation facilities and degradation of soil quality day by day, there is a huge scope for increasing the sustainable production of mustard by bringing more area under cultivation or increasing its productivity by organic manures (e.g.; pressmud compost) with balanced fertilization and maintaining soil fertility status. Pressmud compost (byproduct of sugar industries) produces in huge amount in our country. The pressmud biocompost contains appreciable amount of plant nutrients *viz.,* organic carbon, nitrogen, phosphorus, potassium, sulphur, calcium and magnesium along with traces of micronutrients *viz.,* Zn, Fe, Cu and Mn. If this not being properly utilizes, it creates environmental pollution problems by releasing green house gases eg. CO_2, CO etc., therefore proper composting of pressmud, makes a better quality organic source of plant nutrients. Integrated nutrient management system through efficient use of pressmud compost improves soil physical, chemical and biological condition and conservation of moisture can substantially enhance crop production. With applying the pressmud compost in soil, it increases the soil microbial population and ultimately increase the nutrient cycles, therefore, it makes better nutrient availability for crop plants.

Performance of Indian mustard in relation to irrigation scheduling and hydrogel applications

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Among the various oilseeds of the world, rapeseed-mustard hold a prime position catering the edible oil requirement of a large population in the countries like China, India, Canada, the European Union etc. Contributing to 32% of the total oilseed production in the country, it is the main source of edible oils in India, particularly to the northern. Generally, it is grown on marginal lands with poor fertility under rainfed conditions. Irrigation and fertilizer management are two of the most important agronomic practices for realization of higher yields. Irrigation influences the growth and yield attributes of Indian mustard by supplementing the water requirement of the crop. It also enhances availability of different nutrients to the crop plants. Sowing the crop under rainfed conditions on residual soil moisture in marginal and sub-marginal lands with limited nutrient use are largely responsible for its low productivity. Retaining moisture in the soil through supply of some water absorbing materials like hydrogel, a starch polymer could prove to be a better prospect in this aspect. To explore the use of water absorbing materias an experiment was conducted during the *rabi* season of 2013-15 at N. E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar to study the effect of irrigation scheduling and hydrogel levels on the yield attributes, yield, and WUE of Indian mustard (*Brassica juncea*).The experiment was laid out in split plot design (SPD) with three replications consisting of 12 treatments, having four levels of irrigation scheduling (No irrigation, and irrigation at 0.2, 0.4 and 0.6 IW/CPE ratios) in main plots at 6 cm of depth, and three levels of hydrogel (No hydrogel, 2.5 kg and 5.0 kg hydrogel/ha) in sub plots. Yield attributes, seed yield and WUE were influenced with the application of irrigation and hydrogel.

Effect of irrigation scheduling and polymer application on growth and productivity of Indian mustard (*Brassica juncea*)

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Increasing need of water for different sectors and concomitant decrease in its availability for agriculture makes it imperative to develop water use efficient management practices. Indian mustard is an important oilseed crop grown mainly under semi-arid conditions during winter season under scarce water availability. Hydrogel is a polymer substance capable of absorbing moisture and release it gradually over a period of time. The effect of irrigation scheduling and hydrogel application and the productivity of Indian mustard (*Brassica juncea*) was studied at the Punjab Agricultural University, Ludhiana growth for two consecutive years. The study comprised four treatments of irrigation scheduling (no post sowing irrigation, irrigations at 0.4, 0.6 and 0.8 IW/CPE ratio) in main plots and three doses of hydrogel (0, 2.5 and 5.0 kg/ha) in sub plots as per split plot design of experimentation. Treatments were replicated thrice. Indian mustard variety PBR 357 was sown on 28 October in 2014-15 and 19 October in 2015-16. Soil of the experimental field was loamy sand in texture. Rainfall of 196.2 mm in 17 effective rainy days was received in 2014-15, whereas in 2015-16, rainfall of 61.9 mm in 7 effective rainy days was received during crop growth period. Irrigation treatments of IW/CPE 0.8 and 0.6 received two irrigations each whereas IW/CPE of 0.4 received only one post sowing irrigation in both years. Irrigation treatments of IW/CPE 0.8 and 0.6 received two irrigations each whereas IW/CPE of 0.4 received only one post sowing irrigation. One irrigation applied at 0.4 IW/CPE coupled with well distributed rainfall resulted in highest seed and oil yield in 2014-15 whereas in 2014-15, irrigation scheduling at IW/CPE of 0.4, 0.6 or 0.8 resulted in statistically similar seed and oil yields. Mean seed yields (2538, 2516 and 2482 kg/ha) and oil yields (945, 935 and 923 kg/ha) obtained with one irrigation applied at IW/CPE 0.4 or two irrigations applied at 0.6 and 0.8 resulted in 12.1, 11.1 and 9.6 %, respectively higher mean seed yield and 11.2, 10.0 and 8.6%, respectively higher mean oil yield than that obtained without irrigation (2264 kg/ha seed yield and 850 kg/ha oil yield). Differences in seed and oil yields and plant height due to hygrogel application were significant in 2014-15 and in mean analysis. Application of hydrogel @ 2.5 and 5.0 kg/ha resulted in significantly higher mean seed yield (6.3% and 8.6%, respectively) and oil yield (6.8%, 8.4%, respectively) than without its application and such an increase in mean seed and oil yields with 5.0 kg/ha of hydrogel over without application was significant. However, such an increase in main shoot length, primary branches, siliquae on siliquae per plant with hydrogel application without its application was inconspicuous. Interaction between irrigation levels and hydrogel doses for all the studied traits were non significant in both years and in mean analysis.

Improving productivity and profitability of Indian mustard through hydrogel and thiourea under protective irrigation

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The present experiment was conducted during the winter seasons of 2013-2014 at the Research Farm, Andro of CAU, Imphal- Manipur. The experimental soil was clay loam with pH 5.6. It was highly fertile-being high in available organic carbon (0.93%) and medium in available nitrogen (292.18 kg/ha) as well as available potassium (304 kg/ha) and low in available phosphorus (18.0 kg/ha). The said experiment was laid out in randomized block design consisted 13 treatments and 3 replications. The 100% recommended NPK (60-40-30 kg/ha) was applied with hydrogel @ 2.5 kg/ha as basal followed by thiourea @ 0.05% as foliar spray at 50% flowering and 50% pod formation (as alone or in combination) to Indian mustard except control. However, Lucid improvement in growth parameters (plant height 125.72 cm, dry matter accumulation 17.26 g/plant and leaf area index 3.40, 5.38 at 45 and 75 DAS respectively) phenological events (days to attain 50 % flowering and 80 % maturity) and productivity efficiency (45.5 Kg/ha/day) of mustard were recorded due to application of 2.5 kg/ha of hydrogel + 0.05% of thiourea at 50% flowering and 50% pod formation. However, the various treatments applied to mustard failed to influence the level of significance in terms of number of days taken to attain 50% flowering. The net return, economic efficiency and B:C ratio due to application of T_{12} and T_{13} though remained comparable but both were proved statistically more remunerative than rest of the treatments.

Effect of water stress on yield determining parameters of contrasting genotypes of Indian mustard (*Brassica juncea* L.)

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Drought is considered as one of the most important limiting factor for oil seed crop Indian mustard (*Brassica juncea* L.) growth and productivity in Rajasthan. This study was carried out in farm of the university of S.K.N. to examine genotypes viz. RB 50, RGN 48, Urvashi, Geeta, RH 819, RGN 229, RH 0406, RH 0749, NRC HB 101 and NRC DR 02 of Indian mustard grown under control and water stress conditions with standard package of practices. Under control condition plots were irrigated at flowering and pod formation stages while in water stress plots were maintained under rainfed condition. Determine the effect of drought on various parameters like plant height, days to 50 percent flowering, number of siliquae per plant, number of seeds per siliqua, test weight, Seed yield, Biological yield (BY) and Harvest index

(HI) and this parameters were recorded at maturity stage and after harvesting. The results of this experiment indicates that the Indian mustard varieties RGN 48 and RB 50 behaved as drought tolerant varieties maintained higher seed yield along with number of siliqae per plant, seeds per siliqua, test weight, seed yield, biological yield and harvest index under water stress condition. The Indian mustard varieties RH 0749 and RH 0406 varieties maintained higher seed yield along with number of siliqae per plant, seeds per siliqua, test weight, seed yield, biological yield and harvest index under control condition**.**

Micro-irrigation improves physiological and productivity traits of Indian mustard (*Brassica juncea L*) under semi arid conditions

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The experiment was conducted to evaluate the effects of micro-irrigation (pressurized irrigation systems) and fertigation on physiological gas exchange traits, photosynthesis, growth, yield parameters and yield of Indian mustard crop during *rabi* season of 2010-12 under semi arid conditions. Three irrigation systems in main plot viz. micro-sprinkler system (MS), drip irrigation system (DS), and check basin (CB) were studied. Four nitrogen levels 0, 40, 80 and 120 kg ha^{-1} were taken in the sub plots. The results revealed that MS, DS significantly influenced dry weight, chlorophyll concentration, photosynthetic rate, photo synthetically active radiation (PAR), internal CO_2 concentration (ICC), primary and secondary branches, main shoot length, total siliquae and 1000 seed weight. The mustard seed yield was increased by 24 % due to micro-sprinkler irrigation (MS) and by 18 % due to drip irrigation in two years. Increase in N-fertigation levels from N0 to N80 had significantly improved mustard yield attributes, seed and oil yield while results of N120 application were inconsistent. This improvement in growth, physiological and yield attributes of mustard due to micro irrigation significantly enhanced seed and oil yield, irrigation water use efficiency, and sustainability yield index and production efficiency. The limited irrigation water could be suitably and efficiently utilized under micro irrigation and fertigation of soluble major elements especially nitrogen. The higher seed productivity is mainly attributed to higher increase in growth, yield attributes and physiological parameters of Indian mustard. Thus proper irrigation and nitrogen fertilizer scheduling under micro irrigation saves irrigation water, enhances nutrient use efficiency and gives better economics. In conclusion, micro irrigation systems at every level of N fertigation out yield the effect of check basin irrigation.

Tillage practices influence on growth, yield and economics of Toria (*Brassica campestris* Var. *Toria*) under rainfed condition of Chhattisgarh

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A field experiment was conducted at Research cum Instructional Farm, Indira Gandhi Krishi Viswavidyalaya, Raipur (Chhattisgarh) during *rabi* season of 2014-15. The experiment was laid out in randomized block design with three replications. The treatment consisted of four tillage practices *viz.* T_1- Zero tillage direct drilling of seeds and fertilizers at 2nd days after harvesting of rice, T_2 -Minimum tillage and line sowing of seeds at 3rd days after harvesting of rice, T_3-Minimum tillage at 6th days after harvesting of rice, T_4-Farmer practice broadcasting seeds and fertilizer at 12th days after harvesting of rice. The results revealed that the plant population m^2 (47.44), plant height (99.44 cm), branches plant^{-1} (1.60), dry biomass (2.79 g plant^{-1}), number of siliqua plant^{-1} (28.35), number of seeds siliqua^{-1} (9.67), pod length (4.70 cm), seed yield (430.0 kg/ha) and stover yield (1218.0 kg/ha) was significantly higher under treatment T_2 (Minimum tillage and line sowing of seed at 3rd DAH of rice), but these are found statistically similar with treatment T_1 (Zero tillage direct drilling of seeds at 2nd DAH of rice). Whereas, test weight (g) and harvest index (%) did not vary significantly by different tillage practices. All growth and yield attributing characters were recorded lowest under treatment T_4 (Farmer's practices - seeds and fertilizers broadcasting at 12th DAH of rice). The gross returns (Rs. 13330 ha^{-1}) was highest in treatment T_2, but net return (Rs. 3908 ha^{-1}) and B:C (1.42) ratio were higher in the treatment T_1. In conclusion, it may be said that minimum tillage and line sowing of seeds at 3rd days after harvesting of rice and/or Zero tillage direct drilling of seeds and fertilizers at 2nd days after harvesting of rice were the better tillage practice as it performed well over the remaining treatments with respect to all growth, yield and economics of toria grown under rainfed conditions of Chhattisgarh.

Prospects of transplanting in rapeseed-mustard

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Rapeseed & Mustard is widely grown in majority of continents with largest area of 8 million ha in Canada followed by 7.5 million ha in China and 5.79 million ha in India. However, the productivity of India is the lowest among the major rapeseed mustard growing countries. It faces many ups and downs in its production, productivity and acreage statistics every year which might be due to poor production technology, limited land availability, poor net returns and many more. Moreover, late harvest of *kharif* crops further responsible for declining area, production and productivity. To address the issue of late sowing in *Brassica* sp. through transplanting, an experiment was conducted during *rabi* season of 2014 at N.E.B. Crop Research Centre of G. B. Pant University of Agriculture & Technology, Pantnagar. The experiment consisting of 12 treatments, having four levels of planting geometry (90 × 60 cm transplanting, 60 × 60 cm transplanting, 75 × 75 cm transplanting, and the conventional planting) in main plots and three genotypes {*Brassica juncea* 'Kranti', *B. carinata* 'RP 09' and *B. rapa* variety yellow *sarson* 'Pant Shweta'} in sub plots was laid out in split plot design with three replications. Transplanting of about two weeks old seedlings was carried out. The results registered better growth parameters, yield attributes and seed yield in the transplanted crops as compared to the conventionally sown crop. Root density as well as stem diameter was significantly superior in transplanted crop as compared to the conventionally sown crop. The transplanting geometry of 60cm × 60 cm remained significantly superior over the other geometries in terms of seed yields. Among the different genotypes, *Brassica carinata* cultivar RP-09 recorded significantly more seed yield over the other two *Brassica* genotypes. The interaction between the planting geometry and

*Brassic*a genotypes also turned out to be significant. The highest seed yield was observed with *B. carinata* transplanted at 60 × 60 cm spacing. Further in future attempts could be made to transplant the *Brassica* seedling soon after the harvest of *kharif* crops using transplanter under irrigated conditions.This will not only reduce the time required for field preparations, but also protect the environment from ill effects of residue burning.

Effect of mustard (*Brassica juncea*) + faba bean (*Vicia faba*) inter-cropping systems on yield, yield attributes and economics of faba bean

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An experiment was conducted during rabi (winter) seasons of 2011-12 and 2012-13 at Agricultural Research Farm of Tirhut College of Agricultue, Dholi (Muzaffarpur); Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur (Bihar) to study the effect of intercropping system of faba bean (Vicia faba) with Indian mustard (*Brassica juncea*) on growth, yield, yield attributes and monetary return of faba bean as pilot trial on sandy loam soil having pH value of 8.6, organic carbon (0.473 %), available nitrogen (250.6 kg/ha), phosphorus (30.42 kg/ha), and potassium (157.3 kg/ha); sulphur (21.46 ppm) and boron (0.2 ppm). There were with ten treatments [T1-(Sole mustard), T2- (Sole faba bean), T3- (Mustard+Faba bean in 1:1), T4- (Mustard+Faba bean in 1:2), T5- (Mustard+Faba bean in 1:3), T6- (Mustard+Faba bean in 1:4), T7- (Mustard+Faba bean in 1:5), T_8- (Mustard+Faba bean in 2:4), T_9- (Mustard+Faba bean in 2:5) and T_{10}- (Mustard+Faba bean in 2:6)] in different row combinations. Based on the statistical analysis of two years pooled data it was found that intercropping system in different row combinations resulted in significant effect on growth, yield, yield attributes and monetary return with the highest number of branches per plant (5.0), number of pods per plant (36.8), number of grains per pod (2.59), grain yield per plant (35.8 g), 100 grain weight (29.03 g) of faba bean, faba bean equivalent yield (3802 kg /ha) and net return (Rs.49588/ha) of intercropping system. Among different row combinations, faba bean intercropped with Indian mustard in 2 : 5 row ratio resulted in the highest number of branches per plant (5.0), number of pods per plant (36.8), number of grains per pod (2.59), grain yield per plant (35.8 g), 100 grain weight (29.03 g)of faba bean, faba bean equivalent yield (3802 kg/ha) and net return (Rs.49588/ha) which is significantly superior to sole faba bean, sole mustard, intercropping systems of faba bean with mustard in 1 :1, 1 : 2 and 1:3 row ratios with respect to faba bean equivalent yield and net returns. Significantly lowest value of number of branches per plant (3.8), number of pods per plant (28.0), number of grains per pod (2.01), grain yield per plant (33.49 g), 100 grain weight (27.89 g) of faba bean, faba bean equivalent yield (3296 kg/ha) and lowest net return (Rs.40070/ha) was recorded in 1 : 1 row ratio of mustard with faba bean (T_3). It was also noticed that intercropping systems of faba bean in four, five and six row ratios with two rows of mustard established better performance than intercropping of faba bean with one, two and three rows with one row of mustard.

Evaluation of bio-efficacy of herbicides on weed dynamics and yield of mustard

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Among the various factors of low productivity of mustard, competition by weeds is also one of the important aspects. A field experiment was carried out during *rabi 2012-13* at *Agricultural Research Station, Ummedganj, Kota* for evaluating the bio-efficacy of herbicides on weed dynamics and yield of mustard. The experimental soil was clay loam, alkaline in reaction (pH 7.5) having organic carbon (0.55 %), available nitrogen (318 kg/ha), phosphorus (23.0 kg/ha) and potassium (284.0 kg/ha). The experiment was laid out in randomized block design comprising ten treatments *viz***.** Pendimethalin (Stomp 30 EC) @ 0.75 kg *a.i./*ha (P.E.), Pendimethalin (Stomp 30 EC) @ 1.0 kg *a.i.*/ha (P.E.), Pendimethalin (Stomp Extra 38.7 CS) @ 0.75 kg *a.i./*ha (P.E.), Oxadiargyl (Raft) 80 WP @ 0.09 kg *a.i.*/ha (P.E.), Trifluralin 48 EC @ 0.75 kg *a.i.*/ha (PPI), Oxyfluorfen 23.5 EC (Goal) @ 0.15 kg *a.i./*ha (P.E.), Quizalofop 5 EC (Targa Super) @ 0.06 kg *a.i./*ha (25-30 DAS), Clodinafop (Topik) @ 0.06 kg *a.i./*ha (25-30 DAS), weedy check and weed free (hand weeding at 20 & 40 DAS) and replicated thrice. The mustard variety Pusa jai kisan was sown on 30th October 2012. Weed data on total density and dry weight of weeds were recorded at harvest using 1.0 m^2 random quadrate from two spots and observations on seed yield and yield attributing parameters were recorded at harvest. All the data were subjected to statistical analyses. Results revealed that among the different herbicidal treatments, pre emergence application of Pendimethalin (Stomp 30 EC) @ 1.0 kg *a.i.*/ha recorded significantly lower down density and dry weight of total weeds at harvest and produced maximum number of siliquae/plant (240.0) and seed yield (1849 kg/ha) as compared to weedy check and post emergence application of Quizalofop 5 EC @ 0.06 kg *a.i*./ha and Clodinafop @ 0.06 kg *a.i*./ha, but remained statistically at par with Oxadiargyl (Raft) 80 WP @ 0.09 kg *a.i./*ha as PE. Although weed free treatment proved its superiority over all the treatments but herbicidal applications (Pendimethalin @ 1.0 kg *a.i.*/ha and Oxadiargyl @ 0.09 kg *a.i*./ha) also gave excellent management of total weeds and resulted in higher yield of mustard.

Effect of date of sowing and planting geometry on seed yield, biological yield and harvest index of Indian mustard

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A field experiment was conducted during 2014-15 in oil seed Block of Dr. N. E. Borloug Crop Research Centre of Govind Ballabh Pant University of Agriculture & Technology, Pantnagar, Udham Singh Nagar, Uttarakhand to assess the effect of different date of sowing and planting geometry on seed yield, biological yield and harvest index of Indian mustard. The experiment was laid out in Split Plot Design (SPD) consisting of three main plot treatments (date of sowing) viz; October 22, November 01, and November 11 and five sub plot treatments (plant geometry) viz; 30 X 10 cm, 30 X 20 cm, 30 X 30 cm, 45 X 15 cm and 45 X 30 cm. The treatments were replicated thrice. Variety of Indian mustard was RGN-73. The seed and biological yield of RGN-73 decreased significantly with delay in sowing from October 22 to November 01 and

further to November 11. A planting geometry of 30 X 20 cm produced the highest seed yield which was significantly superior over the wider geometries of 45 X 15 and 45 X 30 cm. However, 30 X 10 and 30 X 30 cm remained statistically on par with 30 X 20 cm geometry in terms of seed yield of mustard. The geometries, however, did not influence the biological yield statistically and it was non-significant. Highest harvest index was found with plant geometry of 30 X 10 cm which was statistically on par with 30 X 20 and 30 X 30 cm. The interaction between date of sowing and plant geometry significantly influenced the seed yield of mustard. Sowing of Indian mustard on October 22 showed its supremacy under all the plant geometry treatments. The plant geometries of 30 X 30 cm, 45 X 15 cm and 45 X 30 cm performed better in earliest sown crop. Early sowing of crop on October 22 with plant geometry of 30 X 30 cm gave maximum seed yield of 1977.7 kg/ha.

Higher rapeseed-mustard productivity through varietal and temporal adjustment in acidic soils of Manipur under changing climate scenario

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During 2012-13 and 2013-14, an investigation was conducted at Research Farm, Andro of Central Agricultural University, Imphal under Split plot design with three replications with the aim to improve rapeseed-mustard productivity by acclimatize to climate change through a combination of improved input efficiency and adjusting the sowing time of identified varieties. The treatments consisted of four dates of sowing namely, Oct. 13th, 23rd, Nov. 2nd and Nov. 12th in main plot and seven identified varieties, three of each from Yellow sarson (Benoy, Pitambari and YSH 401) and Indian mustard (Rajendra Suflam, NDRE 7 and NRCHB-101) along with one of toria (TS-36) in subplot. Among planting times, early sowing produced the maximum seed yield, production efficiency and attained highest economic efficiency though the consecutive early sowings remained statistically comparable but proved significantly superior over delayed sowings. Conversely, the yellow sarson "Pitambari" gave the maximum seed yield, oil recovery and protein recovery though remained comparable with TS 36 but exhibited significant superiority over rest of varieties. This infers that sowing of Pitambari can't be delayed, whereas TS-36 may be good option for late sowing. However, adapting to climate change through a combination of improved input efficiency and adjusting the sowing time of identified varieties can increase the seed yield by 17 % and net return by 20%.

Physiological basis of heat tolerance in Indian mustard (*Brassica juncea* L.Czern &Coss)

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Temperatures stress due to rise in temperature limits the growth and metabolism resulting in substantial decline in yield potentials of agricultural crops throughout the world. Reproductive stage is more sensitive to heat stress. During seed filling terminal heat stress retards seed growth by affecting all the biochemical events to reduce seed size. Unfavorable temperature may significantly affect rate of photosynthesis, water relation and membrane stability of leaves. The present investigation was intended to explore the genetic variation for heat tolerance at seedling stage under controlled laboratory and field conditions simultaneously. Further, the same set of genotypes (42) was planted at recommended date and one month thereafter to visualize the effect of terminal heat stress. Secondly to identify physiological traits associated with thermo tolerance in Indian mustard. Seedling mortality varied from 14.3% (PRE2011-6) to 45.3% (DRMR15-9) while dry matter/10 seedlings ranged from 30.2 (RK(E)8-1) to 56.2 mg (DRMR1191-2) in the controlled laboratory conditions. In the field sown genotypes mortality ranged from 5.6% (DRMR1165-40) to 60% (NPJ-198) and the dry matter varied from 9.6 (LES-53) to 56.1g in NPJ-190. Genotype DRMR1165-40 showed lower mortality and high dry matter Mean canopy temperature was higher in timely sown genotypes whereas canopy air temperature differential (CATD) was higher in late sown. CATD was comparable in LES-52, PRL202-13, NPJ-199 and PDZ-5 at two plantings dates. However, genotypes KMR(L)15-6, LES-53 and NPJ-196 possessed higher CATD under normal planting. Interception of photosynthetic active radiations by the foliage of genotypes was reduced to 53.7%, LAI by 53.0% and photosynthetic pigments by 9.9% over timely sown genotypes. Chlorophyll did not vary, much in KMR15-4, LES-53 and DRMR-15-9 and RWC in LES-52 when planted at two dates. Terminal heat stress disrupted membranes to variable extent being least in RGN-368. Mean thermal injury was 50% higher in the late sown genotypes and MSI was lowered by 12.7% due to high temperature at terminal stage. Growth parameters suffered a decline of 8.8% in plant height, 12.1% in main raceme length, 48.1% in primary branch number and 18.9% in secondary branches. Terminal heat stress did not affect total siliquae per plant in PDZ-5, seeds per siliqua in NPJ-199 and DRMR-4001, seed weight in PRL202-13,PDZ-4 and RGN337 and also seed yield in NPJ-194.However,average reductions were 14.7%,21.7%,17.3%and 55.7% respectively for the above traits. Based on the studied traits only two genotypes (NPJ-194 and RGN-368) were rated highly tolerant and one genotype (RK (E)-8-1) as moderately thermo tolerant.

Morphological and physiological responses of Indian mustard (*Brassica juncea* L.) genotypes to low light stress

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Growth of autotrophic plants is directly and dramatically influenced by light intensity, which is the driving force of photosynthesis and provide nearly all the carbon and chemical energy needed for growth. Foliar traits like leaf area index and leaf mass per unit area are the important factors influencing leaf light harvesting capacity and photosynthetic potentials. With the changing climatic conditions it was necessary to assess the effect of reduced incoming solar radiations on productivity and identify shade responsive morphological and physiological determinants in Indian mustard. Low light responses of twelve Indian mustard genotypes were investigated during 2014-15 at Punjab Agricultural University, Ludhiana. The light treatments consisted of i)100% PAR i.e. open field and ii) 30% reduction of natural PAR obtained by using nets of specific mesh number. Shading treatment was given for 30 days commencing from mid December to mid January. Rate of photosynthesis declined by 8.38%, 18.2% and 20.9% with corresponding increase in shading duration from10 to 20 to 30 days. Ten days after removal of nets Kranti,PBR477,PBR357 and PHR-2 showed <10% decrease in Pn with a mean decline of 25.3%. Among the leaf traits, leaf area and perimeter showed significant variation with shading. Mean depression in LA was 30.7 % with least decline in RH-749 and RLC-3.SLW did not change in RH-749 and DRMR541-44 and LWR in Varuna and PBR477 with the imposition of shading over natural light. Shading affected SPAD values significantly in DRMR659-49 only. LAI and PAR interception were lowered by 30% shading but Kranti and DRMR654-49 intercepted comparable light under both the treatments. Average depression in SPAD was 6.7%, LAI was 48.2% and PAR interception was 23.3% over control. Low light stress significantly affected growth and yield attributes thus lowering the yield. Plant height was affected to minimum in Kranti (0.6%), RH-749 (4.6 %) and PBR477 (4.7%), main shoot length in NRCHB-101 (9.6%). Number branches were reduced by <10% in 5 genotypes (primary branches) while secondary branches in 4 genotypes. Shading caused no adverse effect on number of siliquae per plant in BPR349-9. Seeds/siliqua was reduced to minimal in RH-749, PHR-2 and RLC3 while seed weight by 0.4% in RH-749. Decline in seed yield and oil content was least in Kranti, NRCHB-101 and PHR-2. These three genotypes holds promise under low light stress and also registered lesser decrease in the studied physiological traits.

Enhancement of source-sink relationship in Brassica through plant growth regulators

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Oilseed crops have an important place in agriculture and industrial economy of India. The country is facing acute shortage of edible oil since last two decades and current annual production of edible oilseeds in the country fulfils only about 50 per cent of the domestic requirements. So, in order to meet the needs of growing demand, reorientation of existing techniques is required to boost the production of oilseed crops. Environmental and physiological factors are the two main factors for lower productivity of *Brassica. Brassica* cultivars are morphologically determinate but the growth of the raceme is indeterminate. Flowering is not, therefore, synchronous. In addition, *Brassica* plant has some inherent major defects like inefficient canopy structure, unproductive lower branches, longer raceme length, poor growth and development of late formed siliquae, inefficient utilization of biomass and lower harvest index. The manner in which total dry matter is distributed among various plant parts is of great significance to its productivity. It is known that partitioning involves the production of assimilates in photosynthetic tissue (source) and its translocation to developing parts (sink). Only about one third of the total dry matter is partitioned into seed yield which indicate poor efficiency of biomass utilization in *Brassica*. Therefore, balance between vegetative and reproductive growth is needed to remove physiological flaws in performance of *Brassica*. This offers a scope for the application of plant growth regulators (PGRs) (retardants for manipulating source sink relations) and defoliants for synchronized maturity and remobilization of assimilates which modifies the physiological processes in plant. PGRs have the potential to enhance the source-sink relationship and stimulate the translocation of photo-assimilates thereby helping in effective flower formation, fruit and seed development and ultimately enhanced productivity of the crops. Growth retardants like mepiquat chloride (MC) are known to reduce the plant height and influence source sink relationship and stimulate the translocation of photosynthates towards sink. The use of defoliants like ethrel and thidiazuron can be tried to check the problem of unsynchronized maturity of *Brassica* and partitioning of assimilates between vegetative and reproductive parts for congenial source/sink ratio and higher crop yield. Defoliation is an important management practice which is commonly used to terminate crop development in preparation for harvest and bringing synchrony in maturity. It influences the source–sink relationship and biomass production of the crop.

Effect of different fertility levels on growth and yield of mustard

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Rapeseed-mustard is the most important oilseed crop in India. Indian mustard is particularly being deep rooted and is able to utilize the nutrients and soil moisture from lower layers of the soil. Therefore, it thrives well under rainfed condition at residual soil moisture on marginal and sub marginal land. Among the agronomic techniques that can increase its productivity, judicious application of nutrients, particularly the nitrogen, phosphorus, potash and sulphur play the important role. Generally soil nutrition management is one of the most significant points in terms of crop production. The continuous downward trend in crop production has been a matter of serious concern. Improving and maintaining soil fertility for productivity enhancement is of paramount importance in sustaining crop production to maximize the yield levels. It is necessary to adopt balanced fertilization schedules taking into consideration of all the deficient nutrient elements. In the present study, therefore, present experiment was conducted during *rabi* season of 2014-15 and 2015-16 at the Zonal Agriculture Research Station, Morena. Twelve treatments of fertility levels were kept under randomized block design with three replications. Based on two years pooled results maximum value of growth parameter and yield of mustard (3190 kg/ha) was obtained under application of 100:40:30 kg/ha NPK followed by 100:20:30 kg/ha NPK. The lowest yield was recorded with fertility levels 60:20:0 kg/ha NPK.

THEME 3

CLIMATE CHANGE MITIGATION STRATEGIES FOR DISEASE AND INSECT PEST MANAGEMENT

Climate variability drives responses of oilseed Brassicas to fungal and viral diseases

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Warmer temperatures, decreased rainfall, greater rainfall variability and extreme weather events associated with climate change, all influence pathogen life cycle, expression and durability of host resistance, development and severity of disease epidemics, pathogen biodiversity including development of new races and pathotypes, and inoculum production of pathogens of oilseed Brassicas. Affected pathogens include fungi blackleg (*Leptosphaeria maculans*), Sclerotinia stem rot (*Sclerotinia sclerotiorum*), Alternaria leaf spot (*Alternaria brassicae*) and white leaf spot (*Pseudocercosporella capsellae*); the oomycetes white rust (*Albugo candida*) and downy mildew (*Hyaloperonospora brassicae*), and the virus *Turnip mosaic virus*. Complex changes in crops and agricultural practices that occur in response to climate change also influence future pathogen race distributions. As Mediterranean climates are naturally highly variable in relation to amount, timing and variability of temperature, rainfall and winds, and provide unique insights into the processes involved in pathogen adaptation to changing climates. The fungal, oomycete and virus pathogens associated with oilseed Brassicas provide excellent examples of abilities of pathogens to adapt to future climate situations. Such abilities not only define their future distribution ranges and severities, but also fundamental for developing pre-emptive management strategies against pathogen threats. As oilseed Brassicas include a range of different species, this makes them ‘model’ plant group for investigating pathogen impacts and interactions under changing climate scenarios. To address this, a number of avenues of investigation are likely to be productive. These include defining how predicted future abiotic stresses will (i) pre-dispose some *Brassica* species to more severe disease, (ii) alter diversity within individual *Brassica* pathogens, (iii) alter the expression of their host resistances against important pathogens, and (iv) impact the relative incidence and severity of their diseases as a consequence of shift in crop species or types made to compensate for abiotic limitations *per se* as imposed by climate change. Dealing with these pathogen aspects is paramount to ensure we capture the benefits and opportunities that alternative oilseed *Brassica* species offer as a means of coping with climate change. Defining pre-emptive breeding strategies to develop environmentally better adapted crops with very high levels of pathotype-independent host resistances and durable host resistances at expected increased temperature and moisture stress levels, is likely to be a fruitful approach. It is clear that despite climate change challenges; there are opportunities to improve current management strategies for increased *Brassica* crop yields despite increased pathogen threats.

Stem rot emerging potential treat to mustard cultivation

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Stem rot of mustard incited by *Sclerotinia sclerotiorum* (Lib.) de Bary is an emerging potential threat to mustard cultivation. Rapeseed mustard is vulnerable to stem rot that has become a major biotic constant in several parts of the country. It is locally known to be Polio because of the symptoms shown like polio as whole plant dwindles and die after poding stage. This potential threat has become an economically important yield reducing factor especially in mustard growing areas and causing 30-90% losses in yield. The incidence of stem rot in five surveyed districts was in the range of 1.17% (Karahal block of Sheopur) to 20.84% (Gohad block of Bhind). The estimated yield losses in the surveyed districts were in the range of 4.287% (Bhind) to 0.771% (Sheopur). While, surveyed village of blocks heavy disease incidence recorded in Bhind, Morena and Gwalior were identified as hot spots, but in Sheopur and Datia were recorded fewer incidences as compared to high incidence in other districts. Isolates of *Sclerotinia sclerotiorum* collected from Morena, Bhind, Gwalior, Datia and Sheopur showed difference in genetic and morphological characters, whereas they did not differ in colour of mycelium and sclerotia and shape of sclerotia. The isolate-1(Bhind) referenced value (100%) differed from other four isolates assessed by RAPD performed. Trial under epidemiological studies were conducted and found that the factors such as temperature and sunshine are highly negatively correlated and relative humidity highly positively correlated with disease infection and further progressive development of the disease. For the prediction of stem rot, temperature less than 25^0 C and more than 65% relative humidity found to be more prone to disease development.

Interception of pathogens during quarantine processing: an effort towards safe import of oilseed and vegetable *Brassica* germplasm in India

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During 1976-2015, a total of ~75000 seed samples of oilseed and vegetable Brassicas germplasm received from different countries were processed for quarantine clearance. Seed health testing resulted in interception of 9 pathogenic fungi and one bacterium in 2020 samples from 23 countries. Decade wise (1976-1985; 1986-1995; 1996-2005; 2006-2015) analysis revealed the highest number of interceptions 817 (40.5%) during 1996-2005 and lowest number of interceptions 239 (11.8%) during 2005-2016. Pest risk analysis of imported Brassicas revealed that there is a risk of introduction of quarantine pathogens. Further, anaylsis of the interceptions showed that among the pathogens, *Alternaria brassicicola* was recorded in most of the infected samples (87.5%) followed by *A. brassicae* (10.5%). Among countries, maximum interceptions were made from Canada (30.5%) followed by USA (20.2%) which indicated that there is high risk of introduction of pathogens along with Brassica seeds from Canada and USA. Among pathogens intercepted, *Leptosphaeria maculans* (syn.: *Phoma lingam*) causing black leg from Australia and Canada and *Xanthomonas campestris* pv. *campestris* causing black rot of crucifers from Canada are potential quarantine pathogens to India, hence the samples infected with *L. maculans* were rejected and incinerated, whereas, samples infected with other pathogens viz., *A.*

brassicae, *A. brassicicola*, *A. raphani*, *A. solani, Botrytis cinerea*, *Sclerotium rolfsi*, *Verticillium albo-atrum* and *X. c.* pv. *campestris* were salvaged before their release. The interceptions of pathogens of quarantine significance to India from different countries emphasizes the need of critical examination of imported oilseed and vegetable Brassicas during the quarantine processing to safeguard our experimental as well as agricultural fields from inadvertent introduction of associated pathogens or more virulent races/ strains of the existing ones in the country.

Resistance responses of *Brassica juncea* carrying introgressed segments from *Diplotaxis erucoides* against alternaria blight

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Alternaria blight is among the most widespread fungal diseases of *Brassicaceae* crops in the world. *Alternaria brassicae* and *A. brassicicola* are the major causal agents. Of these, *A. brassicae* is most ravaging on oil yielding brassicas causing up to 40% economic losses. Variations in intra- and inter-specific yield losses may reflect differences in racial pathogencity and resistance level of the prevalent cultivars. Despite achieving impressive productivity gains through development of a number of improved varieties/hybrids, there is a compelling need to further increase and stabilize the productivity to meet burgeoning needs of the country. This can be achieved through effective utilization of germplasm resources. Well characterized nuclear genes conferring resistance to this serious disease are not available in the primary gene pool. However, a wild species *Diplotaxis erucoides*, is known to carry a high degree of resistance to this disease, thus was used to record the resistance responses of *B. juncea* and *B. napus* carrying introgressed segments from *Diplotaxis erucoides*. A total of 2600 plants of *Brassica juncea* introgression lines were screened by artificial inoculation with ascospores of *A. brassicae* in saline solution (10^5/ml). The inoculation was done twice at 30% bloom at the interval of 10 days. Disease assessment on plant leaves was carried out 100 days after sowing, while disease assessment on pods was done at maturity. A scale of 1-10 was used for rating of entries for reaction to Alternaria blight. During the year 2014-15, a total of 27 *B. juncea* introgression lines showing 40% disease severity were selected. Three introgression lines of *B. juncea* showed up to 20% disease severity, of which introgression line NJE-8 showed highest resistance with disease severity up to 20% on leaves and 10% on pods. Selected introgression lines of *B. juncea* were also crossed with RLC-1 and selected mustard cultivars. Resultant F_1's were also evaluated under aided epiphytotic conditions. Five *B. juncea* combinations showed disease severity up to 30%, were selected for further investigations.

In-Silico characterization of wrky7 gene in *Brassica juncea*

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Plants face various biotic stresses, and have evolved with basal defense mechanism. *Brassica* is the major oilseed producing crop of India. The yield is compromised due to the attack by *Alternaria Brassicae.* The fungus is responsible for causing up to 42% yield loss both in terms of reduction in yield and quality of the oil. Molecular mechanism of Alternaria blight in *Brassica* shows the involvement of many genes. Among them the WRKY transcription factor plays an important role in plant defense signalling. In the present study *In-Silico* approach was applied to characterize the WRKY 7 gene. The molecular modeling of WRKY7 and MAPK3 genes was done by Phyre 2 and Swiss model followed by protein model validation by molecular docking using Cluspro software. The best model having lowest binding energy, most favorable energy status and interaction was selected.

Gamma rays and EMS induced resistance to Alternaria blight in *Brassica juncea*

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Alternaria blight is an important disease of Indian mustard [*Brassica juncea* (L.) Czern & Coss.] caused by *Alternaria brassicae* (Berk.) Sacc. It causes significant yield losses to the crop under favourable environmental conditions. There is lack of well established sources of resistance against Alternaria blight in Indian mustard. Therefore, the present study was conducted to generate genetic variability through physical and chemical mutagenesis for selection of resistant/tolerant mutants against Alternaria blight. Seeds of cultivars RH 749 and Kranti were treated with gamma rays (90, 100, 110, 120 kR) and Ethyl methane sulfonate (EMS) (0.50, 0.75, 1.0, 1.25%) individually as well as in combination with gamma rays + EMS (90+0.50, 100+ 0.75, 110+1.0, 120+1.25%) to identify resistant mutants against Alternaria blight. The M_1 generation from all the treatments having nearly 500 mutant plants from different treatments having a range of variability selected for Alternaria blight tolerance were grown at ICAR-DRMR, Bharatpur. They were again screened at four locations including Bharatpur, Kangra, Hisar and Pantnagar. Out of 500 M_2 mutant progenies, only 8 M_2 mutants *viz.,* Kranti-15-EMS 0.75% (P 10 to P 15), Kranti-15-EMS 1.0 % (P 5) and Kranti-15-G+E 90+0.5 % (P 14) showed moderate resistance to Alternaria blight (AB) on leaves and pods at Pantnagar and Bharatpur. While, 8 mutants Kranti G 90 Kr (P 15), Kranti-15, G-120 Kr (P 8), Kranti-15, EMS 0.5% (P 1), Kranti-15, EMS 1.0 % (P 16), Kranti-15, G+E 100+0.75 % (P 8), RH 0749-15, EMS 0.5% (P 9), RH 0749-15, EMS 1.25 % (P 15), RH 0749-15, G+E 90+0.5 % (P 1) revealed tolerance against Alternaria blight at CCSHAU, Hisar. Further studies on screening and advancement of the progenies are in progress.

Biotechnological applications for management and development of resistance against Alternaria blight in *Brassica juncea*

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Mustard crop has a major contribution in oilseed production in India. There is difference in potential yield and realized yield in the field due to attack by biotic agents like bacteria and fungi. Alternaria blight disease caused by *Alternaria brassicae* is one among the important diseases of Indian mustard causing up to 47% yield loss. The major problem is the absence of proven source of transferable resistance in any of the hosts. Development of *de-novo* resistance can be an alternative approach, but for this basic understanding of interactions between fungal pathogens and their host plants is required. The biotechnological approaches allow us to reveal the hidden mechanisms and targets of plant defense response. MAP kinases are one of the major signaling module activated when plants are attacked by pathogens. Among the various MAP kinases, MPK3 has potential role in providing defense against biotic stress. Functional characterization of the above kinase is done by over expressing it in *Brassica juncea* cultivar Varuna. MPK3 over expressing Brassica plant shows tolerance against Alternaria blight. For elucidation of resistance pathway Phospho-proteomic and expression studies of different interacting kinases and other defense related genes was done at different time intervals post inoculation with *Alternaria brassicae* spores. Further *in-silico* approach was also utilized to find out the interacting partners of MPK3. WRKY transcription factor was found out to be the major downstream target.

Study of tolerance of transgenic Brassica harboring MAPK3 gene against Alternaria blight by calculating the disease index and activities of antioxidative enzymes.

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Rapeseed - Mustard is the crop that has a contribution of 32% for oilseed production in India. Despite of all the efforts put into the field to increase the production a considerable lack is observed between the potential yield and the realized yield. The reason is plants been sessile life forms are subjected to a number of biotic and abiotic stress. Alternaria blight disease caused by *Alternaria brassicae* is one among the important diseases of Indian mustard causing up to 47% yield loss. The major problem associated with the disease is that there is proven source of transferable resistance in any of the hosts. So need arises to develop *de-novo* resistance, but for it the basic understanding of the interactions between fungal pathogens and their host plants is required. The future potential of genetic engineering technology remains promising given the recent scientific advances that have been made in enhancing resistance to a broad range of pathogens in many plant species. As a result of plant pathogen interaction reactive oxygen species are produced, and it has been proposed that it plays a critical role in induced tolerance by activating stress response related factors like antioxidant enzymes, MAPKs, transcription factors, pathogenesis related proteins and dehydrins . Reactive oxygen species exert toxic effects to the cells by damaging the nucleic acids, lipids and proteins. Plants have evolved themselves with anti-oxidant defense mechanism which can either enzymatic or non-enzymatic. The more the

anti-oxidants are produced, more resistance is shown by the species against the stressor. The work was performed to assess the efficiency of transgenic Brassica against the Alternaria Blight disease. Percent disease index was recorded followed by estimation of different anti oxidants spectrophotometrically in both transgenic and wild *Brassica juncea* plants. The activity of ascorbate peroxidase, guaiacol peroxidase, catalase, proline was increased in transgenic plants in the later stages of infection while melonadialdehyde content got decreased in transgenic plants which shows that less lipid peroxidation is experienced by it.

Identification of significant loci for resistance against *Sclerotinia sclerotiorum* in *Brassica juncea-Erucastrum cardaminoides* introgression lines

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Sclerotinia stem rot caused by *Sclerotinia sclerotiorum* is a major threat to Oilseed Brassica production systems across the world. Complete resistance against this pathogen has never been reported. We had previously reported success in introgression of the high level of resistance to *Sclerotinia* stem rot in *B. juncea* from wild crucifers (Garg et al. 2010). The present research reports screening of *B. juncea-E. cardaminoides* ILs against a virulent isolate of *S. sclerotiorum* and subsequent mapping of QTL regions that are responsible for *Sclerotinia* resistance. One hundred genome-wide marker loci were used to genotype 96 *B. juncea-E. cardaminoides* introgression lines (ILs). Introgression lines were also phenotyped over two seasons (season I, 2011/2012 and II, 2014/2015) utilizing a field stem inoculation method to assess their resistance to Sclerotinia stem rot. Population structure analysis identified three distinct population groups. The LD level for linked markers was significantly higher than that for unlinked markers, suggesting that physical linkage strongly influenced LD in this IL panel. 14 marker loci (6 and 8 markers involving A and B genomes) were identified to be significantly associated with resistance to *S. sclerotiorum.* The range of phenotypic variation explained by marker loci in the B genome ranged from 12.64 to 48.64 percent in season I and from 1.36 to 31.26 percent in season II. This is the first study to map the QTL regions responsible for resistance *S. sclerotiorum* in *B. juncea-E. cardaminoides* ILs. These findings not only contribute significantly to our understanding of resistances to Sclerotinia stem rot available in *E. cardaminoides,* but the availability of the marker candidates for marker-assisted selection will, for the first time, allow rapid introgression of these critical resistances, into new cultivars of *B. juncea* initially and subsequently, to other crop and horticultural *Brassica* species.

Development of new white rust resistant line of Indian mustard

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Indian mustard (*Brassica juncea* L. Czern & Coss) is a major oilseed crop with more than 80% share in the acreage of oilseed brassicas grown in India. Foliar diseases, particularly Alternaria blight, white rust and downy mildew are major contributors limiting crop productivity. White rust caused by *Albugo candida* (Pers. ex Lev.) is widely prevalent and most destructive disease of mustard causing up to 50-89.8% yield loss. Research towards development of resistant varieties is vigorously perused for the past more than four decades. Resistant sources, both exotic and Indian, have been identified and utilized to improve the inherent ability of new varieties. Indigenous sources developed particularly from adapted germplasm are potentially more useful for their direct use in breeding by conventional breeding methods especially if they possess agronomically desirable traits related to yield. Further the dynamic changes in race composition of the pathogen often result in short lived efficiency of host resistance in the improved cultivars. Development of new resistance source from mustard germplasm collected from Uttarakhand hills (GP-11-222) from village-Van, Block-Dewal of district Almora (Altitude 7612m, Longitude 79^0 37.454; Latitude 30^0 11.45) was grown in the field during 2011-12. This germplasm showed segregation for several traits including reaction against white rust disease, and selection under field conditions yielded 22 plants with resistance to white rust. Screening of descendants of selects from 2011-12 to 2014-15 in the field under artificially inoculated condition resulted in 14 promising lines. During 2015-16 these 14 selected lines were screened in the field as well as in the glasshouse under controlled condition by the pathologist. All the 14 lines were completely free from white rust infection at cotyledonary stage. At true leaf stage three lines *viz.*, PWR-13-8-7, PWR-13-8-8 and PWR-13-8-13 were found moderately resistant to white rust, while one line PWR-13-8-14 was found highly resistant against white rust. Besides being highly resistant to white rust disease, PWR-13-8-14 possess a favorable combination of agronomically important traits *viz*., flowering in 48-53 days, maturing in 130-135 days, attaining plant height 190-200 cm, having long raceme 51.4cm, 8 primary branches/ plant and 12 seeds/siliqua. Further studies to verify its resistance response, genetic control and allelic relationship with other known sources for resistance to white rust are needed.

Evaluation of Brassica germplasm for resistance to Alternaria blight and white rust disease

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Rapeseed-mustard is an important group of oilseed crops after soybean and palm oil. India is one of the leading producers of oilseed *Brassica*. While *Brassica napus* is the important crop in most European countries, *Brassica juncea* is predominantly grown in most parts of India. The importance of these crops is increasing due to advantages over other oilseed crops such as high yield potential, low moisture requirement and higher return at low cost production. Among the various biotic stresses that confront these crops, diseases cause a significant loss in seed yield. And among the various diseases, Alternaria blight caused by *Alternaria brassicae* and white rust caused by *Albugo candida* are important diseases of rapeseed-mustard. Although chemical control for these diseases is available, development of resistant cultivars is always a desirable option in disease management. Therefore, an attempt was made to screen *Brassica juncea* lines against these two diseases to find source(s) of resistance, if any. One thousand Brassica germplasm lines from National Bureau of Plant Genetic Resources, New Delhi were evaluated for their resistance against these two diseases during 2015-16 crop season under field conditions. Entries were sown in 3 m paired rows. Observations on the disease incidence were recorded 100 days after sowing from 10 randomly selected plants. For white rust disease 165 lines were found free from disease which will be further confirmed during the next crop season. No entry was free from Alternaria blight disease. Minimum disease (25.3% PDI) was recorded on EC699012 followed by 26.8% PDI on EC699014. Among the test entries, maximum 27.8% lines were in 10-20% PDI for white rust disease followed by 26.2% lines in 30-40% PDI class and 26.0% lines in 20-30% PDI class. For Alternaria blight most of the lines were in 40-50 (44.9% lines) and 50-60% PDI (48.5% lines) classes. Thus, out of the 1000 lines screened none was found resistant to Alternaria blight, while a few were found promising which will be confirmed in the next season.

Development of white rust resistance in Indian mustard, *Brassica juncea* through mutagenesis

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Indian mustard (*Brassica juncea* L.) is a major Rabi oilseed crop of the Indian subcontinent occupies more than 80% of the total rapeseed-mustard cultivated area and contributes nearly 27% of edible oil pool in India. It is widely grown as an oilseed crop in northern parts of India. The crop faces numerous unfavorable conditions (biotic and abiotic stresses) including various pests and diseases that causes extensive yield losses. White rust caused by *Albugo candida* is a serious disease of Indian mustard causing considerable yield losses. Therefore, the present study was undertaken to develop resistant mutants against white rust in Indian mustard. The experiment was conducted during 2015-2016 consisted of 650 M_2 mutants of RH 749 and Kranti arises from different treatments of gamma rays and EMS mutagens during 2014-15. Among these, 142 white rust free mutant plants were selected at ICAR-DRMR, Bharatpur under field conditions. Of them, 6 M_3 mutants [DRMR (M)-16-1, DRMR (M)-16-9, DRMR (M)-16-23, DRMR (M)-16-38, DRMR (M)-16-41, DRMR (M)-16-82] were found highly resistant against white rust under epiphytotic conditions in off season nursery (2016) at Wellington, Tamil Nadu. M_4 generation of these mutants has been planted at DRMR during 2016-17 for generation advancement and further studies.

Biochemical basis of resistance in Indian mustard, *Brassica juncea* (L.) Czern&Coss varieties against *Sclerotinia sclerotiorum* (Lib.) de Bary

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Indian mustard, *Brassica juncea* (L.) Czern&Coss is widely cultivated as vegetable oil, condiments and spices for improved flavour of human diet and as fodder crop for livestock feeding. Mustard is attacked by many biotic and abiotic agents, but Sclerotinia rot caused by *Sclerotinia sclerotiorum* (Lib.) de Bary most devastating at present time. It has become a serious disease of cruciferous in some parts of India like Rajasthan, Haryana, Madhya Pradesh and Bihar. The present study deals with biochemical defense responses in Indian mustard varieties infected with *Sclerotinia sclerotiorum* causing Sclerotinia rot or white rot or stem rot. Eleven varieties *viz*., Bio-902, Kranti, Varuna, Manihari, Aravali, RRN-505, Navgold, NRCDR-2, Laxmi, RGN-48 and NRCDR-601 were selected. Total soluble sugar, total phenol and total protein in leaves of healthy and infected plants were estimated at 30 & 45 DAS, respectively. The total soluble sugar was decreased maximum (37.79%) in infected plants of Manihari variety followed by Varuna (33.33%), NRCDR-601 (31.00%), RGN-48 (29.34%) and minimum in Bio-902 (20.17%) as compared to healthy ones. Minimum disease incidence was recorded in Kranti (10%), as it also resulted in minimum reduction in total soluble sugars. The total protein content was decreased maximum (5.56%) in infected plants of Manihari variety followed by Varuna (5.21%), NRCDR-601 (5.02%) and it was found minimum in Kranti (2.21%). Total protein content in infected leaves was lower as compared to healthy ones. After infection, varieties showing higher reduction in total protein content, except few were highly susceptible and showed higher disease incidence while varieties with less reduction were moderately resistant. Phenol content was increased maximum (4.71%) in infected plants of Kranti variety followed by Laxmi (4.17%) and it was increased minimum in Novgold (1.12%), Manihari (1.27%), Aravali (1.35%), Bio-902 (1.44%) and Varuna (1.53%). It is cleared that variety Kranti and Laxmi showedlowest disease incidence (10.00% and 13.33%,respectively) as these had higher level of increased total phenol in infected leaves (5.34 and 5.24 mg/g dry leaf) and lower leaves in healthy leaves (5.10 & 5.03 mg/g dry leaf). Varieties like Novgold, Manihari, Aravali, Bio-902, Varuna had low level of increased phenol content and showed maximum disease incidence (20.00 to 36.66%). The total soluble sugar and protein were decreased in all the infected plants while the total phenol content was increased in infected plants as compared to healthy ones. Low disease incidence was recorded in varieties showing decreased level of sugars and protein content and increased level of phenols after infection, thus imparting resistance against this pathogen.

Identifying key defensive determinants of *Brassica* against different feeding guilds, Fungal, *Sclerotinia sclerotiorum* invasion and Aphid, *Lipaphis erysimi* infestation

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Oilseed Brassicas are attacked by various feeding guilds *viz.*, aphid, *Lipaphis erysimi* and fungal, *Sclerotinia sclerotiorum* invasion, leading to heavy productivity losses. Genetic variation for resistance to mustard aphid does not exist in cultivated *Brassicas*. In contrast, wild Brassicaceae species are known to carry significant variation in their resistance responses to these biotic stresses. This allows them to deter insect feeding. Brassica group at Punjab Agricultural University have introgressed genomic segments responsible for resistance against *L. erysimi* and *S. sclerotiorum* from wild species into the cultivated germplasm and the introgression lines show excellent variation for resistance to mustard aphid infestation and fungal infection. This enthused us to investigate defensive traits associated with resistance to both feeding guilds and to scrutinize interplay/differential responses of wild crucifer species and their introgression lines against *L. erysimi* and *S. sclerotiorum* invasion. For the present studies, *Brassica fruticulosa* (resistant donor) and PBR-210 (susceptible) were employed for analysis of a set of defensive enzymes, alonwith fifteen *Brassica* genotypes. Catalase, peroxidase and total phenols were higher in *B. fruticulosa* and resistant genotypes. NADH oxidase declined in *B. fruticulosa* while upregulated in PBR 210 following aphid infestation; lower status in resistant genotypes than susceptible genotypes.The expression of these defensive components prompted us to validate them on a set of *B. juncea-B. fruticulosa* introgression lines for further selection of genotypes comprising good resistance traits. Multivariate analysis determined that *B. fruticulosa* and some introgression lines expressed resistance against *L. erysimi* infestation, depicted by low phenotypic and high defensive trait values.For studies involving Sclerotinia stem rot, we inoculated three wild crucifers *viz*., *Erucastrum abyssinium*, *B. fruticulosa*, *E. cardaminoides* along with their respective introgression lines. Four *S. sclerotiorum* isolates (white, black, red and blue) were used for stem inoculation. Polyphenol oxidase was found to be key defensive trait against *S. sclerotiorum*. The expression of NADH oxidase was concomitant to progress of lesion length, thus, aided increased susceptibility to fungal infestation. Taken altogether, POD expression was up-regulated following pathogen invasion while it was down-regulated after aphid feeding. Though the activity declined after aphid attack but resistant genotypes could maintain POD level that was relatively higher than susceptible genotypes. Higher levels of peroxidase, H_2O_2, total phenols and lower expression of NADH oxidase contributed in deterring pathogen and aphid infestation.

Screening of Indian mustard germplasm for resistance to major diseases

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Field evaluation of about 2,000 accessions of Indian mustard (*Brassica juncea*) conserved in the Indian National Gene bank at National Bureau on Plant Genetic Resources (NBPGR), New Delhi was carried out to identify sources of white rust (*Albugo candida*) and *Alternaria* blight (*Alternaria brassicae*) resistance. The germplasm was screened at multiple disease hotspots at Pantnagar, Bhatinda and Ludhiana during cropping season of 2014-15 & 2015-16 and in 2015-16 at Hisar. We screened the germplasm under natural epiphytotic conditions as per the method described by Fox and Williams (1984). The level of resistance varied across locations against both the diseases, and was found higher against white rust as compared to *Alternaria* blight. Twenty three accessions viz. IC265495, IC265513, IC020167, EC657030, EC699003, EC766091, EC766133, EC766134, EC766136, EC766140, EC766142, EC766143, EC766144, EC766145, EC766148, EC766152, EC766164, EC766191, EC766192, EC766193, EC766230, EC766232, EC766402 showed complete resistance against white rust (PDI=0) across test locations. This germplasm is in further evaluation under artificial epiphytotic conditions at Pantnagar and Ludhiana. None of the germplasm accessions showed complete resistance against *Alternaria* blight, however, 63 accessions showed moderate resistance (<10% disease severity) across locations. These identified germplasm accessions could be useful sources of resistance for both conventional and molecular breeding to develop mustard varieties with resistance to these diseases.

Identification of *Brassica* genotypes as host differentials for *Albugo candida* isolates

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Rapeseed-mustard are important oilseed crops throughout the world which rank third after oil palm and soybean in production of vegetable oils, while second in the production of oilseed proteins after soybean. The oomycetes pathogen, *Albugo candida* causes globally devastating white rust disease of mustard (*B. juncea*) and some rapeseed types (*B. rapa* var. toria and yellow sarson). Sources of resistance have been reported in oilseed Brassicas against *A. candida*, but their utility and effectiveness in breeding for disease resistant cultivars is limited due to lack of information on occurrence and distribution of pathotypes and screening techniques. To get the true picture of *A. candida* races and virulence spectrum, it is necessary to develop host differentials for each crucifer species. In the present investigation,

identification of host differentials has been undertaken which might be useful for development of resistant varieties. On the basis of the preliminary studies on phenotypic disease reactions on 11 different *Brassica* genotypes at cotyledonary and true leaf stage against 10 different *A. candida* isolates, the *Brassica* genotypes used in the present investigation, could be placed in different groups as host differentials: Group I: EC 399301, Rohini, EC 399313, EC 399299, EC 399296 and *B. nigra;* Group II BIOYSR; and Group III: GSL-1, EC 414293, PBC 9221 and NRCDR 515.

Evaluation of Mustard Germplasm for Resistance Sources against *Albugo candida* the Cause of White Rust Disease

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A total of 70 *Brassica juncea* lines of Pantnagar (series of PWR, PRD and PAB) were evaluated to select resistant sources against *Albugo candida* (white rust disease) in field under natural conditions. Among PWR lines (14 no.), all were found immune; among PRD lines (29 no.) 23 lines were moderately resistant and 13 lines were susceptible; among PAB lines (27 no.) 16 lines were moderately resistant and 11 lines were susceptible against white rust disease. All these lines (70 no.) were further tested at cotyledonary and true leaf stage in glasshouse under controlled epiphytotic conditions for the confirmation of the results. The observations on incubation period, latent period, pustules size, pustules shape, phenotypic disease reaction (0-7 scale) and disease index (0-6 scale) were measured. The PWR lines (14 no.) free from disease under field conditions were also free from the disease at cotyledonary stage while at true leaf stage none of the lines were free from the disease (01 line- highly resistant, 03 lines-resistant and 10 lines-moderately resistant). However, all the PRD (29 no.) and PAB (27 no.) lines were susceptible at both the leaf stages under glasshouse conditions. In resistant PWR lines (04 no.) the incubation period at true leaf stage was ranged from 12-19 days while latent period from 18-26 days. However, in PRD and PAB lines the incubation period was from 7-10 days and latent period from 13-17 days. The study revealed that glasshouse study is essential for the testing of resistant sources against white rust disease at true leaf stage rather than at cotyledonary stage and at field conditions. As at cotyledonary leaf stage, the lines which were free from the disease, showed appearance of the disease at true leaf stage in the present studies.

Studies on cultural, morphological, pathogenic and molecular variability of *Alternaria brassicae*, the causal agent of blight disease of rapeseed-mustard

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In India, rapeseed-mustard is most important oilseed crop after soybean and contributes around 26.1% of the total oilseed production. Among *Brassica* oil seed crops, Indian mustard (*B. juncea*) is commonly cultivated in most of the Indian states. *Alternaria blight* disease caused by *A. brassicae* has been reported from all the continents of the world causing up to 47% yield losses with no proven source of resistance. The present investigation was carried out to study the cultural, morphological, pathogenic and molecular variability among *A. brassiace* isolates collected from different *Brassica* spp. and from different geographical locations of India (Pantnagar, Karnal, Punjab, Bihar, Jammu and Kangra) to exploit them in breeding programme during screening for resistance sources and selection of host differentials. In the present study, *A. brassicae* isolates (20 nos.) showed the existence of genetic diversity. Significant variation in cultural, morphological, pathogenic and molecular variability was observed in *A. brassiace* isolates with respect to geographical locations and *Brassica* spp. Maximum radial growth (82.0 mm) was in AB-*B. juncea* Pantnagar isolate, while minimum in AB- *B. caulorapa* (49.67 mm) on PDA. Variations were also observed in colony colour, appearance, margin and zonation number. Substantial variations were found in spore morphology regarding conidial length, width and number of septa. Average conidial length and width were varied from 28.97-6.57 x 185.25-28.22 μm. Maximum spore length and width was in AB-*B. carinata* isolate (185.25 x 25.62 µm), while minimum in AB-*B. caulorapa* (28.97 x 6.75µm). Number of horizontal and vertical septa ranged between 3.50-14.75 and 0.75-5.0, respectively. All the isolates were pathogenic to *Brassica* spp. AB-*B. juncea* Pantnagar isolate was most virulent, while AB-*S. alba* was least. RAPD (18 no.) and ISSR (4 no.) primers generated a total of 310 reproducible and scorable polymorphic bands ranged from 100 to 1350 bp which displayed genetic polymorphisms among the *A. brassicae* isolates. On the basis of cultural, morphological, pathogenic and molecular variability, the *A. brassiace* isolates has been categorized into 5 major groups. Group I: AB-*R. sativus,* AB-*B. pekinensis,* AB-*B. oleracea,* AB-*B. botrytis* and AB-*B. caulorapa*; Group II: AB-*B. juncea* Pantnagar, AB-Yellow sarson, AB-Toria, AB-*B. nigra,* AB-*R. oleifera,* AB-*B. juncea* Karnal, AB-*B. juncea* Punjab and AB-*B. juncea* Bihar; Group III: AB-*B. napus,* AB-*B. carinata,* AB-*E. sativa* , AB-*S. alba*; Group IV: AB-*B. juncea* Kangara and AB-*B. juncea* Jammu; Group V: AB-*B. rugosa.* The different *Brassica* spp. (08 nos.) used in the present investigation to differentiate different *A. brassicae* isolates (09 nos.) as host differentials has been categorized into 4 major groups on the basis of differential phenotypic disease reactions. Group I: Varuna, PT-303, PYS-6 and *B. nigra*; Group II: PBN-9501 and Kiran; Group III: *E. sativa*; Group IV: *S. alba*. Among different methods of culture preservation of *A. brassicae* isolates, 10% glycerol at -20ºC was best in terms of sporulation (66.66%) followed by PDA at 4ºC (65.71%) and could be used for the preservation of *A. brassicae* isolates at least two years.

Screening of advanced rapeseed-mustard genotypes for resistance against mustard aphid (*Lipaphis erysimi* Kalt.)

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Present day varieties are nutrient responsive and are highly prone to attack by insect pests and diseases. Climate change is emerging as one of the major threats for rapeseed-mustard production system as with other crops. The insect-pests and diseases scenario is changing and new pests are emerging. The biology, behavior and epidemiology of existing insect pests and diseases are also adversely affecting the production and income of farmers. Hence, screening of emerging genotypes/varieties against insect pests and diseases has become more indispensable for successful breeding programme. Sixty six advanced rapeseed-mustard breeding genotypes were screened for their reaction against mustard aphid (*Lipaphis erysimi* Kalt.) at Tirhut College of Agriculture, Dholi (Muzaffarpur), Bihar during 2015-16. Aphid Infestation Index (AII) varied from 1.2 to 3.8. Minimum AII (1.2) was observed in SAG- 07 (Bhawani), SAG-13 (YST 151), SAG-17 (DRMR 1165-40), SAG-42 (CS 700-3-3-6), SAG-45 (PDZ 4), SAG-47 (DRMRIJ 13-38), SAG- 48 (RGN 337) and SAG-66 (Varuna); whereas maximum AII (3.8) was observed in 66-197- 3 (susceptible check). Thirty three entries *viz*., SAG -01, SAG- 03, SAG -05, SAG -08, SAG- 09, SAG -13, SAG- 14, SAG -15, SAG- 17, SAG -19, SAG- 20, SAG- 23, SAG -24, SAG- 25, SAG -30, SAG- 31, SAG -35, SAG- 36, SAG- 40, SAG- 41, SAG -42, SAG- 45, SAG -46, SAG- 47, SAG- 48, SAG- 52, SAG- 53, SAG- 57, SAG -58, SAG -59, SAG- 60, SAG- 61 and SAG- 66 were recorded with resistant reaction against mustard aphid, *Lipaphis erysimi* (Kalt.).

Bioecology and management of painted bug, *Bagrada hilaris* (Brumeister) on rapeseed-mustard

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The study conducted on bioecology and management of painted bug, *Bagrada hilaris* on RH 30 revealed that the mean number of eggs laid by a female were 63.68±0.69 on soaked mustard seeds. The average pre-oviposition period, incubation period, nymphal period and adult longevity period for male and female was found as 4.69±0.11 days, 5.14±0.007 , 24.66±0.50 days, 18.6 ± 0.36 days, and 17.30±0.14 , 19.21±0.45, respectively. Population dynamics study showed that the pest reached its peak population twice in the cropping season, once at the seedling stage, and another at the maturity. The maximum population was observed with its first and second peak on 48th SW, and 12th SW, respectively. The pest population had significant positive correlation with maximum temperature (r=0.629) and sun shine hours (r=0.517). However, the correlation with minimum temperature (r=0.315), was non-significantly positive. Morning relative humidity (r= -0.673) and evening relative humidity (r= -0.692), showed highly negative significant correlation with the pest population. Wind speed (r= -0.418), had a significant negative effect on painted bug population. All weather parameters contributed to *B. hilaris* population fluctuation to the extent of 69%. Bioefficacy studies of various insecticide revealed that seed treatment with imidacloprid 600 FS @ 5 ml/kg seed (mean per cent reduction over control 84.4%) was most effective in managing painted bug population at initial stage of crop and it was found at par with thiamethoxam 35 FS @ 5 ml/kg seed (mean per cent reduction over control 82.80%). Among the insecticides applied as foliar spray at seedling stage, imidacloprid 17.8 SL (83.88%) and thimethoxam 25 G (82.00%) found to be most effective. The treatment with nimbecidine was found least effective but superior over control (53.58%) against the painted bug. Based on the economic returns, imidacloprid 17.8 SL (1:9.92), imidacloprid 600 FS (1:7.80) and thimethoxam 25 G (1:5.47) were adjudged as best treatments for the effective management of painted bug.

Molecular methods for detection of *Albugo candida* (Pers.) Kunze causing white rust in rapeseed-mustard

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Albugo candida, biotrophic, the oomycete pathogen, causes white rust disease in rapeseed-mustard globally. The characteristic symptoms of the disease are formation of white to cream-coloured pustules on leaves, stems, and inflorescences, sometime stag head galls formation takes place as the result of inflorescence infection. The pathogen causes significant losses in oilseed brassicas. A prerequisite to the control of diseases is detection and proper identification of the causal organism. Traditional methods have some limitation such as relatively slow process and requiring skilled person for reliable identification of the pathogen. Recently, the potential of molecular methods for the detection of plant pathogen has been recognized. Molecular techniques based on DNA analysis are very useful for pathogen detection as they are highly specific and sensitive. Internal transcribed spacer (ITS) based primers are used for routine detection of *A. candida*. Real-time PCR is the most rapid method, reproducible and accurate to detect the target pathogen in the plant. The proteomic study is currently being used to explore the molecular mechanisms of defense responses by *Brassica juncea*. PCR-based marker, such as random amplified polymorphic DNA (RAPD) has an advantage as it doesn't require prior information about genomic sequences. RAPD markers are usually dominant because polymorphism is detected with the presence or absence of bands. RAPDs are used successfully as genetic markers in genetic studies of *A. candida*. Amplified fragment length polymorphism (AFLP) markers also have been used for genetic analysis and genome mapping of this devastating pathogen.

Morphological and pathogenic variability in *Albugo candida* causing white rust disease in rapeseed- mustard

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The oilseed crops especially *Brassica* species play a pivotal role in agricultural economy of the world. *Albugo candida* causes globally devastating white rust disease in mustard (*B. juncea*) and some rapeseed (*B. rapa* var. toria and yellow sarson). Studies on variability of *A. candida* isolates were under taken for their deployment in host plant resistance to this disease. The

present investigation revealed morphological and pathogenic diversity among *A. candida* isolates collected from different geographical regions and from different *Brassica* spp. The size of sporangia of different *A. candida* isolates ranged from 16.35-22.50 μm. The sporangial germination varied from 77.01-91.07 and 74.05-91.53% after 7h of incubation at 10°C. The pustule shape of different *A. candida* isolates varied from circular raised pinhead pustules to circular scattered raised pinhead pustules. Among different *A. candida* isolates collected from different places, Alwar and Pantangar isolates were most virulent, while Morena and Ludhiana isolates least virulent. On the basis of morphological and pathogenic variability, different *A. candida* isolates could be categorized in different groups as: Group I: Delhi, Morena Bharatpur, Mathura and Jammu; Group II: Hisar, Navgao and Pantnagar; Group III: Ludhiana, and Badaun and Group IV: Alwar. Among different *Brassica* isolates collected from different *Brassica* spp., Yellow sarson isolate was most virulent, while mustard local isolate was least virulent. On the basis of pustule shape, different *A. candida* isolates were categorized in different groups as Group I: *Erucua sativa*, *Raphanus sativus,* Katili and Mustard local isolates; Group II; Toria, Yellow sarson, and Banarasi rai; Group III: *B. nigra, B. juncea* and Ornamental rai.

Grouping of white rust, *Albugo candida* isolates using diverse Brassica genotypes

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The white rust disease of mustard is one of the major problems in all the mustard growing regions of world. Still we are lacking in resistant sources in mustard against this disease. Among various factors one could be due to non-availability of diverse *A. candida* isolates that could be used for selection of resistant sources. Considering the problem, we collected 15 *Albugo candida* isolates from different geographical regions of India, and purified on susceptible *B. juncea* cultivar, Varuna. All the fifteen *A. candida* isolates were cross inoculated on 19 diverse *Brassica* genotypes with the purified fresh sporangial suspension ($2.5x10^4$ sporangia/ml) at the initiation of true leaf stage i.e., 12 days after sowing. On the basis of more or less similar phenotypic disease reaction, and pustule shape produced by different *A. candida* isolates on different *Brassica* genotypes, we classified them in 8 different groups as: Group 1: Pantnagar; Group 2: IARI, Hisar and Meerut; Group 3: Kanpur, Bihar; Group4: Morena and Alwar; Group 5: Jammu and Simour; Group 6: Bangalore and Karnataka; Group7: *B. napus* (Pantnagar) and Group 8: *B. nigra* and Katili weeds (Pantnagar). Among different *A. candida* isolates Pantnagar (*B. juncea*) isolate was found most virulent, while Morena (*B. juncea*) isolate was most aggressive. The study revealed that *A. candida* isolates collected from different geographic regions has wide range of diversity and the isolates belonging to different groups could be used for testing of resistant sources in *Brassica* against white rust disease under controlled conditions.

Morphological and cultural variability in *Alternaria brassicae* isolates of Indian mustard, *Brassica juncea (*L. Czern & Coss.) collected from different districts of Uttar Pradesh

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Variation in morphological characteristics among twenty five isolates of *Alternaria brassicae,* the causal agent of Alternaria blight of rapeseed-mustard, were studied. All the isolates showed high *in vitro* variability in respect of average number of spot size (mm), average number of spot/10cm^2, radial growth (mm), conidia length and width (µm), number of transverse and longitudinal septation, beak length (mm) and number of septa. These samples were isolated and purified by single spore technique to study the morphological and radial growth behaviour on PDA at 25±1^{0}C. The samples collected from Varanasi district have minimum spot size (4.26 mm) having light brown spot papery growth with concentric rings , followed by Amethi district (4.36 mm) with same symptoms of district Varanasi. The Sonbhadra district have minimum number of spot/10 cm^2 (8.36) having dark brown spot with concentric rings followed by Faizabad district (8.73) having dark brown irregular shape spot with concentric rings. The maximum number of spot size was observed from Jaunpur district i.e., 10.93 with whitish to brown irregular spot, and maximum of spot was from Baharaich district (16.35/10 cm^2) having small dark brown spot with clear concentric rings. The cultural characteristics such as growth behaviour and colony character were studied at 20 and 25^{0}C. the pure culture of isolates collected from Ajamgarh have minimum growth i.e. 36.66 and 49.75 mm followed by isolates collected from Ghaziabad 40.25 and 52.32 with creamy white to light brown colony characters at 20 and 25^{0}C, respectively. Isolates collected from Lakhimpur district had maximum growth i.e., 60.25 and 75.35 with light brown colony characters both at 20 and 25^{0}C. Isolates collected from Basti have maximum (105.3 µm) where as isolates collected from Barabanki have minimum (35.3 µm) conidial length. The conidial breadth also ranges from 8.5 to 29.5 µm. The transverse septation varied from 4 to 13 and longitudinal from 0 to 6.0.The average beak length varied from 14.30 to 169.70 µm. The longest (105.3) of conidia was of isolate Basti and smallest (35.3) of Barabanki district. The beak septation number ranges from 0-8. The beak septation of conidia ranged from 1.2 to 4.7 µm. The maximum beak septation was found in Gazipur (4.70 µm) followed by Baharaich (3.5 µm) and Varanasi (3.2 µm) where as minimum in isolate barely and Amethi (1.2 µm). These variations in conidial size may be due to variation in medium concentration and locations/sites of different field. The cultural and morphological differences in *A. brassicae* isolates indicates significant variation in the pathogen, it may be attributed due to environmental variation and racial differences.

Pathogenic and molecular variability among *Alternaria brassicae* isolates causing black spot in rapeseed-mustard

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Rapeseed-mustard is one of the most edible oilseed crops after groundnut, contributing to 26.1% total oilseed production in India. Indian mustard (*B. juncea*) is one of the major oilseed crops cultivated in India. Among various diseases, black spot disease caused by *Alternaria brassicae* is highly destructive causing up to 47% yield losses across the world, with no proven sources of resistance. Present investigations were carried out on pathogenic and molecular variability among twenty *A. brassiace* isolates collected from different geographical regions of India (Pantnagar, Karnal, Punjab, Bihar, Jammu and Kangra), from different *Brassica* spp. (Pantnagar). Maximum disease index was recorded in mustard cultivar Varuna with AB- *B. juncea* Pantnagar isolate (49.2%), followed by AB- *B. juncea* Karnal (42.5%), AB-Toria (41.8%) and AB-Yellow sarson (39.6%), while minimum with AB- *S. alba* isolate (18.8%). These 20 *A. brassicae* isolates were placed in 5 groups. Group I: AB-*B. napus*; Group II: AB-*B. carinata*, AB-*E. sativa* and AB-*S. alba*; Group III: AB-*B. juncea* Kangara, AB-*B. juncea* Jammu; Group IV: AB-*B. juncea* Punjab, AB-*R. oleifera*, AB-*B. nigra*, AB-*B. juncea* Bihar, AB-*B. juncea* Karnal, AB-*B. juncea* Pantnagar, AB-Yellow sarson, AB-Toria,; Group V: AB-*B. rugosa*, AB-*B. pekinensis* AB-*B. botrytis*, AB-*R. sativus*, AB-*B. caulorapa*, AB-*B. oleracea*. Genetic variation among these isolates was analyzed with random amplified polymorphic DNA and inter-simple sequence repeat primers in which the mean similarity coefficient was found to be 0.73 and 0.84, respectively. RAPD and ISSR marker based dendrograms grouped these isolates into two major groups (Group A and Group B). Both the groups were differentiated at similarity coefficient of 0.59 and 0.67 by RAPD and ISSR markers, respectively. Group A contained 5 isolates and designated Cluster I. Group B contained 15 isolates and was further divided into 4 Clusters i.e., II, III, IV and V by both the marker systems.

ITS-Marker based identification of *Orobanche/Broomrape* species affecting mustard cultivation in India

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Broomrapes or *Orobanche* spp. are obligate root parasitic plants responsible for devastating losses in rapeseed-mustard. Among *Orobanche* spp., *O. cernua*, *O. crenata*, *O. ramosa* and *O. aegyptiaca* are prevalent species affecting mustard cultivation in India, particularly in Rajasthan, UP, Haryana, Madhya Pradesh, Gujarat, Bihar, Punjab and West Bengal. *Orobanche aegyptiaca* and *O. ramosa*, both belongs to section *Trionychon* Wallr., and *O.cernua*, *O. cumana*, and *O. Crenata* belongs to the section *Osproleon* Wallr. *Orobanche* attaches itself to the roots of host plant and derives nutrition from there, leading to drastic growth and yield reduction of host. *Orobanche* infestation in mustard crop fields can cause 28.2% average reduction in yield. *Orobanche* species identification is problematic due to differences in host preference and has been extremely difficult to identify based on morphological characteristics. Therefore, we utilized species specific ITS-based molecular markers to identify major *Orobanche* species infesting mustard crop fields of Rajasthan, India. *Orobanche* samples *viz.*, tissue, inflorescence, stem, flower buds were collected from different mustard growing regions of western Rajasthan. Genomic DNA was extracted from all the samples and subjected to PCR analysis using *Orobanche* spp. specific primers and universal control primer (U-555). Universal control primer was added to detect any false positives. *Orobanche ramosa* and *O. cernua* specific primers failed to yield any amplicon whereas a 350 bp PCR product specific to *O. aegyptiaca* species was amplified and detected in all the samples, confirming major abundance of this species in Rajasthan. As expected, the universal control primer amplified a PCR product (555 bp) of genomic DNA extracted from all *Orobanche* samples. This study represents an important step towards the development of DNA based diagnostic tests for *Orobanche* in soils and crop seed lots that could help in avoiding contamination of *Orobanche* in mustard crop fields. DNA based diagnosis specific to *Orobanche* species can help in development of an '*Orobanche* map' showing the 'hot spots' to be aware of in mustard fields and timely management recommendation to farmers.

In-Vitro evaluation of different culture media against *Sclerotinia Sclerotiorum* causing sclerotinia blight of mustard

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This study was aimed to investigate the maximum growth of *Sclerotinia sclerotiorum* in different culture media at Department of Plant Pathology, College of Agriculture, RVSKVV, Gwalior, M.P. Six artificial media were evaluated for their influence on the growth of *S. sclerotiorum* and the findings revealed that Potato dextrose agar media was best as it showed maximum growth of the fungus (85.25 mm) followed by mixed meal agar (69.25 mm), Sorghum meal agar (65.75 mm), Pearl millet meal agar (60.75 mm), Pea meal agar (57.75 mm), at the stage of seventh day. Corn meal agar was found comparatively less suitable as it showed minimum growth of fungus mycelium (51.50 mm). In all the tested media, growth of the fungus was initiated on second day after inoculation. The trend of pathogen growth during 3rd to 7th day was almost similar in all the test media. Potato dextrose agar medium was significantly superior over all the tested media.

Management of *Alternaria* blight disease of mustard

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Mustard is one of the most important oilseed crops being cultivated throughout the world attacked by several diseases. Alternaria leaf spot is one of the worst and destructive diseases caused by *Alternaria brassicae* resulting in up to 60% yield losses. Since there are no resistant sources against this disease, farmers are totally dependent on fungicides. The fungicides like Mancozeb and Ridomil MZ are commonly used by farmers, but these fungicides are not much

effective against this disease. Therefore, field experiments were conducted at NEBCRC, Pantnagar during 2013-14 and 2014-15 using few new fungicides and botanicals + *Trichoderma* + animal waste (for organic growers) to manage this disease. The seeds were sown on October 10 during both the years. Ten different treatments viz., Difenaconazole (0.05%), Propiconazole (0.05%), Nativo -Tebuconazole+Trifloxystrobin (0.05%), Tebuconazole (0.05%), Hexaconazole (0.05%), cow urine + Garlic bulb + *Trichoderma* (5:5:1%), Cow urine + Garlic bulb + Eucalyptus **+** *Trichoderma* (5:5:5:1%), Manocozeb (0.2%) and Rizomil MZ (0.2%) as standard check and water as check were evaluated, each with three foliar applications at 45, 55 and 65 days after sowing. Percent disease severity was recorded at maximum disease pressure (90 DAS). Among different fungicides, Nativo- Tebuconazole + Trifloxystrobin and Tebuconazole were found best with no occurrence of disease followed by Difenoconazole (5.5%), Propiconazole (17.5%) as compared to Mancozeb (11.1%), Riziomil MZ (20.3%) and check (43.5%). Maximum yield was obtained with Nativo- Tebuconazole + Trifloxystrobin (25.0q/ha) followed by Tebuconazole (24.5q/ha), Difenoconazole (23.2q/ha), as compared to Mancozeb (21.6 q/ha), Ridomil MZ (20.6q/ha) and check (15.1 q/ha). Under organic farming Cow urine + Garlic bulb + Eucalyptus **+** *Trichoderma* was best with a disease severity and yield of 26.7% and 17.6.0 q/ha as compared to check (43.5% and 15.1 q/ha), respectively.

Effect of bio-agents on antioxidant enzyme activity of Indian mustard (*B. juncea*) against A*lternaria* blight

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Indian mustard (*Brassica juncea*) is one of the major oilseed crop cultivated in India and around the world. It is extensively grown traditionally as a pure crop as well as intercrop in marginal and sub-marginal soils in the eastern, northern and north-western states of India, and mainly attacked by *Alternaria brassicae* (Alternaria blight) causing up to 47% yield losses. Management of *Alternaria brassicae* is mainly based on the chemical pesticides which are not considered as safe. Therefore, eco-friendly alternative strategies such as use of bio-control agents (fungi and bacteria) which also induces resistance and plant vigour, are being used for disease management in the present scenario. Therefroe, a glasshouse experiment was conducted to observe the role of bio-agents in stimulating antioxidant enzymes in Indian mustard (*B. juncea*) against Aletrnaria blight (*A. brassicae*). The bio-control agents, *Trichoderma harzianum* and *Pseudomonas fluorescens* were used alone and in various combinations as seed treatment. The plants treated with different bio-control agents were more developed than non-treated plants throughout the experiment. Bio-chemical analysis revealed that application of bio-control agents result in alteration in various defense related antioxidant enzymes in leaves from treated plants *viz.*, Ascorbate peroxidase, catalase, superoxide dismutase, guaicol peroxidase, glutathione reductase, phenyl alanine ammonia lyase, polyphenol oxidase, lypoxigenase and peroxidase. Among various treatments evaluated for their efficacy in the induction of various defense related compounds and antioxidant enzymes, Th1 + Th2 was found best as it increased the activity of several antioxidant (APX, GPX, CAT, SOD, POD, LOX and PAL), and amount of other non-enzymatic (total ascorbate, reduced glutathione, total chlorophyll and Carotenoid) antioxidants. These treatments accelerated and increased the plant's ability to activate the defense and resist to stresses.

Evaluation of fungicides against mycelial growth of *Sclerotinia sclerotiorum* under *in-vitro* conditions

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Present studies were conducted on efficacy of different fungicides on mycelial growth of *Sclerotinia sclerotiorum* under *In-vitro* conditions at Department of Plant Pathology, College Of Agriculture, RVSKVV, Gwalior, M.P. The experiment was laid out in complete randomized design (CRD) having 7 treatments including untreated control and replicated three times. Six fungicides *viz.,* Carbendazim 50% WP (0.1%); Mancozeb 75% WP (0.2%); Blitox-50 50% WP (0.2%), Thiophanate methyl 70% WP (0.1) Hexaconazole 5% SC (0.1%) and Ridomil (0.1%) belonging to different groups were evaluated against *S. sclerotiorum* using poisoned food technique. Findings revealed that all the treatments were significantly superior over control. At 7th days after inoculation Thiophanate methyl and Carbendazim were most effective (0 mm), followed by Blitox-50 (15.30 mm), Ridomil (16.70mm) Hexaconazole (18.70mm) and Mancozeb (28.70mm), while maximum of 90mm growth was recorded in control . Thiophanate methyl and Carbendazim were significantly superior over all other fungicides.

Efficacy of fungicides against Sclerotinia rot, *Sclerotinia sclerotiorum* (Lib.) de Bary in Indian mustard

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Indian mustard [*Brassica juncea* (L.) Czern & Coss] a major oilseed crop, belongs to family *Crucifereae* (*Brassicaceae*). It suffers from more than 30 diseases. Among these, Sclerotinia rot caused by *Sclerotinia sclerotiorum* (Lib.) de Bary, is a major disease. The present investigations aimed to carry out the *in vitro* efficacy of fungicides against Sclerotinia rot. Seven fungicides [propineb (antracol), carbendazim (bavistin), carbendazim + mancozeb (companion), mancozeb (indofil M-45), cymoxanil + mancozeb (moximate), metalaxyl- M + mancozeb (ridomil gold) and captan + hexaconazole (steam)] were evaluated with three (50, 100 and 150 ppm) concentrations against the *S. sclerotiorum* under laboratory conditions to find per cent growth inhibition of the pathogen using poisoned food technique. Increase in concentration of the fungicides resulted in increased inhibition of mycelial growth of the pathogen. Among the test fungicides, carbendazim and carbendazim + mancozeb completely inhibited the mycelial growth of *S. sclerotiorum* at all concentrations followed by captan + hexaconazole with inhibition of 94.44, 100 and 100% at 50, 100 and 150 ppm, respectively. Propineb was found least effective, while mancozeb and metalaxyl- M + mancozeb at 50 ppm were on par with each other.

Evaluation of fungicides aginst mycelial growth of *Alternaria brassicae* under *in-vitro* condition

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Present study was conducted at Department of plant Pathology, College Of Agriculture, RVSKVV, Gwalior, M.P. during 2014-15 to know the efficacy of different fungicides on mycelial growth of *Alternaria brassicae* under *In-vitro* conditions. Findings concluded that the treatments were significantly superior over control. At 7th days after inoculation, Dificonazole and Propiconazole absolutely checked the mycelial growth (0 mm) followed by Hexaconazole (25.25 mm), Mancozeb (34.25mm) and Ridomil (38.25mm), while a maximum of (85.75mm) growth was recorded in control. Dificonazole and Propiconazole were significantly superior over all other fungicides.

Bio-Efficacy of chemical and bio-pesticides against mustard aphid, Lipaphis erysimi (kalt.) on Indian mustard (*Brassica juncea*)

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Mustard aphid, Lipaphis erysimi (Kalt.) is the most serious insect-pest of rapeseed-mustard and responsible for causing the yield losses ranging from 35.4 to 96%. A field experiment was carried out to study the management of L. erysimi in mustard crop during Rabi season, 2015-2016 at Crop Research Centre of SVPUA&T, Meerut. Experiment was laid out in randomized block design with four different chemical insecticides and two different bio-pesticides. Insecticides and bio-pesticides used in experiment were thiamethoxam 25 WG @ 25g a.i./ha, imidacloprid 17.8 SL @ 20g a.i./ha, acephate 75 SP @ 350g a.i/ha, dimethoate 30 EC @ 300g a.i./ha, neem oil 2% @ 1 ltr/ha and Beauveria bassiana CFU 1×10^8 @ 2 kg/ha. Result revealed that all the treatments were found significantly effective in reducing the infestation of mustard aphid. The most effective treatment was found acephate 11.67 aphid/10 cm apical shoot 10 Days after spray followed by imidacloprid (15.33), dimethoate (20.00), thiamethoxam (24.33), Beauveria bassiana (26.67) and neem oil (45.00) whereas 143.67 aphid/10 cm apical shoot was recorded in untreated plot. The maximum seed yield 1635 kg/ha was recorded in acephate treated plot followed by imidacloprid (1415 kg/ha) and dimethoate (1305 kg/ha) and highest cost benefit ratio 1: 10.36 were obtained from imidacloprid which is followed by thiamethoxam (1:8.33) and acephate (1:6.96). The lowest seed yield and C:B ratio was obtained from neem oil (1133 kg/ha) and (1: 3.79) among all the treatments.

Pest management in oilseed *Brassica* following integrated approaches

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Due to resilience to grow under diverse agro-climatic conditions and sustainability towards biotic stresses, *Brassica* has gained prime position among oilseeds in India. The crop can be ravaged by several pests, mainly aphid (*Lipaphis erysimi*), painted bug {*Bagrada hilaris* (*cruciferum*)}, Sclerotinia rot (*Sclerotinia sclerotiorum*), white rust (*Albugo candida*), Alternaria blight (*Alternaria brassicae*), and Broomrape (*Orobanche aegyptica*). Integrated pest management (IPM) approach follows the principles of understanding of the crop, pest and the environment and their interrelationships to enable advanced planning with emphasis on routine monitoring of crop pest conditions, balancing of cost/benefits of all management practices. IPM approaches for management of pests of mustard is needed to enhance crop productivity. Keeping this in view, validation of IPM approaches along crop stages was undertaken in collaboration with KVK Mahindergarh (28^{o}18’16.7’’N, 76^{o}08’30.7’’E), Haryana and KVK Navgaon, (27^{o}30’51.7’’N, 76^{o}45’19.0’’E), Alwar, Rajasthan on 40 ha during two Rabi crop season. The determinants of cost and returns in crop production were compared across the IPM technology and farmers’ practices. IPM approach which includes improved cultural practices (soil application of $ZnSo_4$ @15kg/ha) and use of bioagents {seed and soil application of *Trichoderma harzianum* (IIHR-Th-2 strain)} in combination with host plant resistance (recommended variety of the region) was found superior over farmers practices for better management of pests and increasing the seed yield/incremental benefit cost ratio. The average cost of cultivation/ha was higher by Rs. 1297 in the IPM technology adopted plots. But the gross returns, which were higher by 13.6% (Rs. 6554) compensated for increase in expenditure. Each additional rupee invested in the adoption of IPM technology in mustard gave Rs. 5.1 in return thus giving good economic logic for adoption of the technology. Though the cost of plant protection chemicals, labour inputs and fertilizers were not significantly different in two systems of production, the perception of incidence of selected biotic stress was significantly different. At the same level of use of plant protection chemicals, fertilizers and labour inputs, the IPM technology plots had lesser incidence of biotic stress resulting in higher yield levels. In addition to lesser incidence of pests, higher yield and economic benefit, the IPM technology is sustainable.

Integrated management of foliar diseases of Indian mustard [(*Brassica juncea* (L.) Czern. and Coss.]

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Mustard crop is the most important group of Rabi oil seed crops, and contributes a major share to the vegetable fat economy of the country. Among the various causes of low productivity, diseases are most important ones. This crop suffers from a number of diseases among them; downy mildew (*Peronospora brassicae*), Alternaria blight (*Alternaria brassicae*, *A. brassicicola*), and white rust (*Albugo candida*) are the most destructive diseases causing economical losses at different crop stages. Series of experiments were conducted during Rabi 2012-2013 and 2013-2014 at Student Instructional Farm of NDUAT, Kumarganj, Faizabad, U.P. A management schedule was tried to develop by integrating the varieties, their sowing dates and fungicidal applications through various modes. There were two varieties of Indian mustard (Varuna and NDR-8501) with their two dates of sowing (20 October and 10 November), seed treatment of Apron 35SD and their foliar sprays with (mancozeb, quintal, folicur and nativo) chemicals were tested in split plot design. The observations were recorded regarding the incidence and severity of downy mildew, Alternaria blight and white rust. Mean lower severity of Alternaria blight was noted in third date of sowing and downy mildew severity decreased with delayed sowing while, white rust decreased in early sowing. Cultivar NDR-8501 proved better in respect of lower diseases severity and higher yield as compared to Varuna. Among fungicides quintal @ 0.2% was found most effective in reducing the downy mildew severity followed by mancozeb @ 0.25%, and nativo @ 0.05% proved most effective in managing the Alternaria blight severity and increasing seed yield followed by folicur @ 0.2% while spraying of quintal @ 0.2% proving most effective against white rust. Maximum seed yield and benefit cost ratio was obtained with nativo @ 0.05% followed by folicur @ 0.2% and quintal @ 0.2%, respectively. Minimum disease severity and maximum seed yield with higher benefit cost ratio was recorded with genotypes NDR-8501 sown on 20 October sprayed with nativo @ 0.05% as compared to control, which was also reflected through the observations on thousand seed weight.

Biointensive integrated management of *Lipaphis erysimi* on Indian mustard

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We evaluated bioefficacy of various biointensive pesticides against mustard aphid, *Lipaphis erysimi* in Indian mustard at CCS HAU, Regional Research station, Rohtak, Haryana during Rabi 2015-2016. Dimethoate was found to be most effective in reducing aphid population after 3, 7 and 10 days of spray. There was 95.03% aphid reduction after ten days of spray over control. The next effective treatments were *Verticillium lecanii* @ 10^8 CS/ml + NSKE @ 5% followed by NSKE @ 5% + clipping of infested twigs and *Beauveria bassiana* @ 10^8 CS/ml + NSKE @ 5% with 88.52, 87.77 and 86.91% per reduction in aphid population over control after ten days of spray. Neem seed methanol extract @ 5 % was found to be least effective with 75.33% reduction in aphid population. Highest seed yield was recorded in treatment viz.,

dimethoate 30EC (1702 kg/ha) followed by *V. lecanii* @ 10^8 CS/ml +NSKE @ 5% (1635 kg/ha), NSKE @ 5% + clipping of infested twigs (1626 kg/ha) and *B. bassiana* @ 10^8 CS/ml + NSKE @ 5% (1617 kg/ha). The lowest seed yield (1517kg/ha) was obtained in neem seed methanol extract @ 5 % whereas the yield obtained in control was only 1384 kg/ha. Dimethoate was also found highly cost effective with highest cost benefit ratio (1:14.92) followed by NSKE @ 5% + clipping of infested twigs (1:13.81) and NSKE @ 5% (1:11.41), whereas treatment with neem seed methanol extract @ 5 % was least economic.

Insecticidal activity of plant extracts against cabbage butterfly, *Pieris brassicae* (Linn.)

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Investigation were carried out to study insecticidal activity of aqueous extracts of different plants namely Goat weed *(Ageratum conyzoides* L.), Congress grass (*Parthenium hysterophorus* L.), Wild-sage (*Lantana camera* L.), Makoi (*Solanum nigrum)*, Bhang (*Cannabis sativa*)*,* Madar (*Calotropis gigantean*), Senna (*Cassea angustifolia*) leaves and seed against cabbage butterfly, *Pieris brassicae (Linn.)* mustard during 2015 in the Department of Entomology, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar under laboratory conditions. The aqueous extract of *A. conyzoides, C. sativa, C. gigantean* leaves, *L. camera* showed significantly higher mortality (88.3, 84.9, 88.9 and 84.1%, respectively) in second instar larvae, which was found at par with the extract of *C. angustifolia* seed and *S. nigrum* (83.7 and 83.3%). *Calotropis angustifolia* leaves and *P. hysterophorus* were least toxic resulting in 78.3 and 74.9% larval mortality. Maximum larval mortality was observed in 10% concentration.

Trichoderma formulations for the management of mustard diseases under organic farming

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Among different *Trichoderma* formulations (W.P. and liquid based with the CFU of 4.1 to 4.8×10^{11}) significantly maximum CFU was observed in paraffin oil (9.9×10^9 & 3.7×10^{10}) followed by talc (9.7×10^9 & 3.1×10^{10}) based formulation on 11 months of storage at 28^0C & and 4^0C respectively. These formulations were applied as soil application (along with vermicompost) followed by seed treatment @10g or ml/kg seeds and two foliar applications at 45 and 60 DAS. The observations on population dynamics (CFU/g soil) in rhizosphere were recorded at 30, 60, 90 and 120 DAS while observations of foliar diseases viz. downy mildew at 15 DAS (cotyledonary stage), white rust and Alternaria blight at 75 DAS using (0-6 rating scale). The *Trichoderma* population on phylloplane (CFU/leaf) under glasshouse was also recorded and it was maximum in paraffin oil (2.4×10^4) followed by talc (1.5×10^4) based formulation at 15 days after second spray (75 DAS) as compared to commercially available talc (5.2×10^3). Among different formulation paraffin oil was found best in significantly reducing downy mildew, white rust and Alternaria blight diseases. In paraffin oil based formulation minimum occurrence of downy mildew (5.7%), white rust (13%) and Alternaria blight (32.6%) as compared to commercially available talc (23.3, 29.0 & 48.0%) and check (27.4, 45.0 & 60.0 %) respectively. Significantly maximum yield (kg/ha) was observed in paraffin oil (1460.0) as compared to commercially available talc (1030.0) based formulations and check (1010.0). The study revealed that paraffin oil l based *Trichoderma* formulations could be used in reducing downy mildew, white rust and Alternaria blight of mustard under organic farming.

Bio-efficacy of some commercially available neem formulations on diamond back moth, *Plutella xylostella* (L.) in cabbage, *Brassica oleracea* var. *oleracea*

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Two field experiments were conducted during two consecutive Rabi seasons at the Experimental Farm, Division of Entomology, IARI, New Delhi to study the effect of commercially available neem formulations, neemazal, neemgold and nimbecidine having 50000, 1500 and 300 ppm azadirachtin, respectively against the diamondback moth, *Plutella xylostella* on cabbage. The bioefficacy in a descending order was: neemazal > nimbacidine > neemgold. During first year the maximum population reduction over control was found after 7 days of application *viz.*, 74.52, 70.17 and 55.68% due to neemazal, nimbecidine and neemgold, respectively. A similar trend was found in second year. Thus, neemazal was most effective against the diamondback moth, *P. xylostella*.

In -vitro evaluation of botanicals against *Alternaria brassicae* in mustard

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The present experiment was carried out to know the efficacy of different botanicals on mycelial growth of *Alternatia brassicae* with thirteen botanicals at 10% of concentration in a completely randomized block design (CRD) replicated three times at Department of plant Pathology, College of Agriculture, RVSKVV, Gwalior, M.P. during 2016-17. The botanicals were evaluated through poisoned food technique and observations were taken at 3rd and 7th days after inoculation. Findings revealed that extract of all thirteen botanicals significantly inhibited mycelia growth in comparison to control against *A. brassicae. Allium sativum* (Bulb), *Nicotiana tabacum* L., *Eucalyptus globules* L., *Parthenium hysterophorus* L., and *Datura alba* L. showed (100%) mycelial growth inhibition against *A. brassicae* at 3rd and 7th day after inoculation followed by *Calotropis procerea* (87.99%), *Piper nigrum* L., (77.34%), *Ocimum santcum* (75.99%) and *Ginger officinalis* rhizome (75.20%), and were significantly superior to all other tested extracts. *Curcuma longa* and *Azadirachata indica* inhibited (20.00%) growth followed by *Lawsonia inermis* (66.39%) and *Lantana camara* (36.00%). At 7th day after inoculation, *A. sativum*, *N. tabacum*, *P. hysterophorus,* and *E. globules* showed 100% mycelial growth

inhibition followed by *Datura alba* and *Piper nigrum* L. *viz*., 87.16 to 79.63 %. *Calotropis procerea, O. santcum, A. indica* and *G. officinalis* exhibited 77.77 to 74.07% followed *by L. inermis. Curcuma longa* and *L. camara* exhibited mycelial growth between (66.66-57.41%).

Effect of mustard aphid, *Lipahis erysimi* (Kalt) incidence on yield and quality of *Brassica* genotypes

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The experiment was laid out under sprayed and unsprayed conditions during Rabi 2016-17 at research farm of CCS HAU Regional Research Station, Rohtak to assess quantitative and qualitative losses caused by mustard aphid in various *Brassica* spp. (*B. juncea, B. napus* and *B. rapa*). The crop was sown on 25 October, 2016 in plot size 2.7 x 1.6 m in paired row designed with 13 replications. The aphid population per top 10 cm twig, yield, 1000 grain wt., shining (colour) score and oil content were found maximum in variety BSH 1 (10.48), RH 0749 (17.95 q/ha), RH 0749 (6.39 gm), HNS 0901 (9.75) and BSH 1 (42.3%), respectively, being minimum in HC 212 except the yield and grain wt. of BSH 1 in protected plots. Similar type of performance of these varieties regarding above mentioned parameters were recorded in the unprotected plots. Maximum percent reduction in aphid population, yield, 1000 grain wt., shining (colour) score and oil content was found in RH 0749 (89.85), BSH 1 (32.26), HC 212 (14.65), HC 212 (3.75) and HC 212 (2.07), respectively, while minimum in HNS 1213 (87.70), HC 212 (15.97), RH 0749 (7.67), HNS 0901 (1.03) and HNS 0901 (0.95), respectively. The differences among protected and unprotected plots in all the varieties for all the parameters were significant, except in the variety HNS 0901 for oil content.

Investigation on incidence of *Diaeretiella rapae* (M'Intosh) on *Lipaphis erysimi* (KALT.) In field during 2015-16

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Field studies were carried out on the population build-up of *Lipaphis erysimi* (Kaltenbach) and its parasitism by *Diaeretiella rapae* on different species of *Brassica* during Rabi season of 2015 at Crop Research Centre, Pantnagar. The occurrence of *D. rapae* parasitizing *L. erysimi* in *Brassica alba*, *B. campestris* cv. BSH-1, *B. carrinata, B. nigra, Eruca sativa* cv. T27, *B. juncea* L. cv. Varuna, YST-151 and GSC-6 were evaluated. The correlation coefficients between aphid population and *D. rapae* and its hosts on different *Brassica* species with different abiotic factors revealed contradictory results. Except for a few instances, the weather parameters showed low order of associations with *L. erysimi* and its parasitism by *D. rapae.* Thus, the ecological factors exhibited little impact on the population buildup of mustard aphid and its parasitism by *D. rapae* on different species of *Brassica*. *Brassica nigra* harbored relatively higher populations of the aphid, while, *B. carrinata and E. sativa* cv. T-27 had lower aphid population. The present finding showed highest population of aphid on *B. nigra*, while *B. carrinata* had the lowest aphid population. Maximum number of mummified aphid population

was found on BSH-1, while minimum number of mummified aphid population was found on *B. carrinata*. The lowest level of parasitism of *L. erysimi* by *D. rapae* was found on T-27, being highest in *B. alba*. It was noticed that the correlation of the population for *L. erysimi* and its parasitism by *D. rapae* with weather parameters were non-significant in most of the *Brassica* varieties.

Incidence of mustard flea beetle, *Phyllotreta cruciferae* on different *Brassica* varieties

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Field experiment was conducted to study the population dynamics of flea beetle on different varieties of *Brassica* spp. at different dates of showing at Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, India. Eight varieties of *Brassica* spp. including *Brassica campestris* cv. BSH-1, *Brassica alba, Brassica carinata, Brassica nigra*, *Eruca sativa* cv. T-27, *Brassica juncea* cv. Varuna, YST-151 and GSC-6 were sown on five different dates starting from October 3 to December 3, 2015 at fifteen days interval. The mustard flea beetle, *Phyllotreta cruciferae* (Goeze) is the most abundant and damaging pest in Brassicas in this region. The adults are active leaf-feeders that can, in large numbers, rapidly defoliate and kill plants. Symptoms of flea beetle feeding are small, rounded, irregular holes, heavy feeding makes leaves look as if they had been peppered with fine shot. Yield losses of 10% or more are not uncommon where flea beetles are present in relatively high numbers. The aim of this study was to generate information on occurrence and abundance of flea beetle associated with this crop in Uttarakhand. During 20015-2016, the pest was first noticed on 2nd week after sowing (WAS) on all *Brassica* spp. but infestation did not show any significant differences among the varieties in first and second sowings. Peak populations of mustard flea beetle were recorded on 3rd followed by 4th and 5th dates of sowing. Thus, the general trend showed that the flea beetle was quite active during October, November and December infesting the early vegetative stage, but later decreased significantly could be due to cooler temperature of January and hardening of the leaf tissues. *B. alba, B. nigra* and T-27 varieties as a group harbored relatively higher population of flea beetle than other *Brassica* spp.

Push-Pull strategy for management of pollen beetle, *Meligethes aeneus* in oilseed rape, *Brassica napus*

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The push-pull strategy is a behavioral manipulation method that uses repellent/deterrent (push) and attractant/stimulant (pull) stimuli to direct the movement of pest or beneficial insects for pest management. Changing attitudes towards replacing broad-spectrum insecticides with

new technologies, particularly semiochemical tools, to manipulate the behavior of natural enemies for improved biological control will enable improved push-pull strategies to be developed and used more widely. *Meligethes aeneus* is more active from early March to late May. Green to yellow bud stage is the most critical stage for this insect. Adult beetles bite into buds and lay eggs which hatch in 7 to 10 days. Larval feeding reduces bud numbers so pod set is hampered. In worst cases stalks can be left pod-less causing significant yield loss. The technology is based on novel strategies that combine a push-pull philosophy for saving oilseed rape, *Brassica napus* from pollen beetle, *M. aeneus*. The strategy involved a combined use of trap and repellent plants, where in *M. aeneus* are repelled from *B. napus* and simultaneously attracted to the trap crop. Turnip rape, *Brassica rapa* has previously shown potential for trap crop, whereas lavender, *Lavandula angustifolia* repels the *M. aeneus*. Simulations using a spatially explicit individual based model indicated that a perimeter trap crop was the most appropriate arrangement. In field trials, a perimeter *B. rapa* trap crop significantly reduced the abundance of the pollen beetle, *M. aeneus* in plots of *B. napus* compared with plots without a trap crop. Growth-stage related visual and olfactory stimuli were partly responsible for the preference for *B. rapa* by *M. aeneus*. *Lavandula angustifolia* when intercropped with *B. napus* not only reduced infestation of *B. napus* by *M. aeneus*, but also increased its parasitism by natural enemy. The entomopathogen *Metarhizium anisopliae* also shows promise for use with the trap crop. Thus, the pollen beetle is managed effectively by using this push-pull philosophy for sustainable crop production by resource-poor farmers.

Effects of rapeseed-mustard pesticides on bees (Hymenoptera: Apidae) colony health and foraging ability

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World as well as Indian oilseed scenario is mainly driven by Rapeseed (*Brassica napus*) due to its healthy edible oil. India is the third largest rapeseed-mustard producer in the world after China and Canada with 12% of world's total production. About 35% of the world food crop production depends on pollinators, mostly honey bees (*Apis mellifera*) which are the most economically valuable pollinators of agricultural crops Worldwide. Shortage of healthy bees is a serious matter of concern. Scientists have long been concerned that pesticides especially the neonicotinoid class may have sub-lethal effects on bees impairing their development and behavior. An important cause for significant reduction in bee's population is due to Colony collapse disorder (CCD) or Fall-Dwindle Disease. Neonicotinoid insecticides besides controlling pests in a variety of agricultural crops; they also affect non-target organisms such as pollinators mainly bees (Apoidea) due to their systemic nature. Few studies are also available on the toxicity of pesticide mixtures to pollinators. CCD depends on factors like entire daily intake of a pesticide (at least up to 10 ppb per forager bee), season of crop growth (CCD is less pronounce in early summer or spring) etc. As per CIB & RC (2016), registered insecticides such as chlorpyriphos (20% EC), dimethoate (30% EC), imidacloprid (70% WS) and thiamethoxam (25% WG) used in India to control mustard insect pests affect honey bees. Many studies highlighted the high toxicity of several neonicotinoids to bees and mitigation measures are needed to minimize pollinator exposure where identified hazards may occur. Many countries decided to ban the neonicotinoids which have been linked to a plunge in the bee population. But exposure to clothianidin seed-treated canola against flea beetles has no long-term impact on honey bees. Many similar arguments came about studies regarding unrealistic and non-field situation exposure scenarios. Among the species of wild bees, most affected are buff-tailed bumble bee (*Bombus terrestris*), the spined mason bee (*Osmia spinulosa*), and the furrow bee (*Lasioglossum fulvicorne*). The peer reviewed literature concluded that neonicotinoids cause harm to bees and safer alternatives are urgently needed. Media programmes need to be conducted for people awareness. Future research studies should be conducted with field realistic concentrations, relevant exposure and evaluation durations.

Population dynamics of mustard aphid, *Lipaphis erysimi* Kalt. in various *Brassica* spp.

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To determine the role of weather parameters on population buildup of mustard aphid, field experiment was conducted during *Rabi* season of 2015-2016 at Regional Research station, Samargopalpur, Rohtak, Haryana. Three rapeseed-mustard varieties i.e., RH 0749, HNS 0901 and BSH 1 belonging to three *Brassica* spp. i.e., *B. juncea*, *B. napus* and *B. rapa* were grown under timely and late sown conditions. Aphid population was recorded at weekly interval starting from the initial appearance to final disappearance of the pest. Ten plants were selected at random from each *Brassica* spp. in each replication. The numbers of aphids were recorded from top 10 cm top portion of the terminal shoot. The study revealed that mustard aphid was available in the field from 3rd SMW (standard meteorological week) (January) to 11th SMW (March). The peak aphid population (23.33-86.05 aphids/10 cm main apical shoot) was recorded during 9th SMW in all *Brassica* species (both timely & late sown), except in BSH 1 (timely sown) in which it attained peak (31.98 aphids/10 cm main apical shoot) in 6th SMW. Under timely sown conditions, evening relative humidity showed significantly negative correlation with aphid population in RH 0749 and HNS 0901. However under late sown conditions, the aphid population had significantly positive correlation with maximum temperature in these genotypes.

Assessment of avoidable yield losses in crop Brassicas by various insect-pests

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A five year field study was carried out from 2011-12 to 2015-16 crop seasons at Punjab Agricultural University, Ludhiana, India to assess the avoidable yield losses in *Brassica juncea* and *B. rapa* due to different insect-pests. The experiment was laid out in a randomized block design with three replications under protected and unprotected conditions. The protected plots were sprayed with thiamethoxam 25 WG @ 100 g ha^{-1} and dichlorvos 85 SL @ 500 ml ha^{-1} against mustard aphid, *Lipaphis erysimi* (Kaltenbach) and cabbage caterpillar, *Pieris brassicae* (L.), respectively. Data on the insect-pests were recorded at weekly intervals while yield data

were recorded at harvest. The loss in seed yield due to mustard aphid and cabbage caterpillar infestation varied from 6.5 to 53.7% over the years. The years 2012-13 and 2014-15 did not witness any outbreak of mustard aphid as well as cabbage caterpillar and the yield losses ranged from 6.5 to 18.6% among different genotypes, while these ranged from 42.3 to 53.7% during 2015-16 which was an outbreak year. Based on the five years pooled data, it was evident that the two *B. juncea* varieties NRCDR 2 and PBR 91 suffered about 24% yield loss and harboured significantly higher mustard aphid and cabbage caterpillar population than *B. rapa* BSH 1 which suffered 18.3% yield loss, and matured earlier than the other two genotypes. From the present study it can be concluded that losses due to insect-pests in oilseed *Brassica* ranges from 6.5 to 53.7% depending upon pest pressure and the variety. Timely pest management is suggested to avoid such losses in mustard.

Assessment of avoidable yield losses due to *Lipaphis erysimi* Kalt. in various *Brassica* spp.

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Insect pests are important biotic threats for rapeseed-mustard production system from germination to harvest. About 50 insect species have been found infesting rapeseed-mustard in India (Sharma and Singh, 2010), out of which about a dozen species are considered as major pests. The present investigation was carried out at Regional Research Station, CCS Haryana Agricultural University, Samargopalpur, Rohtak during 2015-16 *Rabi* season, with the objective to generate location specific information on amount of damage inflicted by insect pests in oilseed *Brassicas*, and to identify genotypes that suffer least damage. Three *Brassica* genotypes *viz*., RH 0749, HNS 0901 and BSH-1 were sown on a plot size of 4.2 m x 3.0 m in three replications in paired plot design under timely and late sown conditions. Thus two parallel sets of experiment were planted under protected and un-protected field infestation conditions. Dimethoate 30EC (0.025%) was sprayed twice at economic threshold for protection from the insect-pests (painted bug and aphid) under protected conditions. Yield attributes and seed yield decreased significantly with delay in sowing under both protected and unprotected conditions. The avoidable losses in terms of seed yield varied from 9.26 to 17.48% under timely sown and 20.11 to 32.62% under late sown conditions, being lowest in HNS 0901 and highest in BSH 1. Avoidable oil content losses in all three *Brassica* spp. ranged from 3.38 to 6.34% under timely sown and 4.92 to 8.14% under late sown conditions, being lowest in HNS 0901 and highest in BSH 1. Germination percentage was not significantly affected by mustard aphid in these *Brassica* species.

Adaptation of technologies for the management of stem rot in mustard through OFT on farmer's field in Rajasthan

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Zone IIIb of Rajasthan State is known as mustard bowl and has higher productivity (13.53 q/ha) as compared to national average (12.62 q/ha). During Rabi 2014-15 mustard was grown in about 7.38 lakh hectare and the average productivity was 17.22 q/ha. India is although a main mustard growing country, but is lagging behind the other countries in productivity of Mustard. In present scenario of non-availability of host resistance, there is need to develop cost effective and eco-friendly integrated management strategy. Use of bio-control agent is advantageous, as they are often effective against wide range of soil borne pathogens. An eco-friendly integrated disease management technology, particularly use of *Trichoderma* and garlic extract have been validated on large area of farmer's field during Rabi 2011-12 and 2012-13 in five villages of District Dholpur (Rajasthan) in the form of on farm trials. Results showed that seed treatment with *Trichoderma* @ 10 gm/kg seed + garlic extract @ 25 gm/kg seed gave highest yield (21.12 qt/ha in 2011-12 and 21.12 qt/ha in 2012-13), and B:C ratio (1: 5.76 in 2011-12 and 1: 5.76 in 2012-13) is higher than farmers local practice.

Assessment of avoidable yield losses in rapeseed-mustard due to insect pests

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Insect pests cause enormous yield loss in rapeseed-mustard production system from germination to harvest. Therefore, it is highly important to assess the avoidable losses caused by insect pests in different rapeseed-mustard genotypes, as a result of insecticide treatment. For these studies, two mustard genotypes viz., BSH 1 and NRCDR 2 were grown in eight rows of 5 m row length per replication, and there were 8 replications in a Completely Randomized Block Design. There were two sets of experiments viz., one protected and another unprotected for each test genotype. The protected sets of experiments were sprayed with recommended insecticides when aphids reached economic threshold level during the crop duration. The observations were recorded on number of aphids from (10 cm top twig)/10 plants, numbers of mustard sawfly larvae/10 plants, painted bugs (adult + nymph)/10 plants, number of flea beetle/10 plants, cabbage caterpillars/10 plants per replication across the 8 replications before and after insecticide applications. The protected and unprotected trials were harvested and yields were recorded separately for each replication for each test genotype. There was no infestation of mustard sawfly, painted bugs and flea beetle, while cabbage caterpillars were recorded in both the test genotypes but the numbers were very few below ETL; however the test genotypes were heavily infested with aphids, and the experiment may be considered to be more for assessment of yield losses due to aphids. There were no significant differences in number of aphids/plant before the application of first insecticide spray in both BSH 1 and NRCDR 2 genotypes. However, there was significant reduction in numbers of aphids/plant after application of insecticides i.e., it was

72.8%, 85.3%, and 91.0% reduction after 1st, 2nd and 3rd sprays, respectively incase of BSH 1, while it was 91.4% and 78.3% reduction after 1st and 2nd sprays, respectively in NRCDR 2. Conversely, the aphid populations consistently increased in both the genotypes after 3rd week of February, 2016. The yields of both BSH 1 and NRCDR 2 were significantly higher under protected as compared to unprotected conditions. Need based insecticide protection from aphids resulted in 66.3% and 25.4% increase in seed yields of BSH 1 (3 sprays) and NRCDR 2 (2 sprays), respectively. Present studies indicate high variability in aphid infestation and avoidable losses in different rapeseed-mustard genotypes in space and time, and timely pest management is suggested to avoid such losses.

THEME 4

PLANT VARIETY PROTECTION, COMMERCIALIZATION AND TECHNOLOGY DISSEMINATION

Potentiality of Oilseed *Brassica* in Bundelkhand Region

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The Bundelkhand Region of central India is a semi-arid plateau that encompasses 6 districts of northern Madhya Pradesh (MP) and 7 districts of southern Uttar Pradesh (UP). The region has lagged behind agriculturally due to its typical geographical terrain and climatic condition. In general the productivity of various pulses and oilseeds prominently grown in Bundelkhand is low primarily because of moisture stress at different crop growth stages. In oilseeds, the productivity of the zone is just 45% of the state average and 29% of the highest yielding zone as reported by the National Rain fed Area Authority. The overall contributions of cereal, pulse and oilseed crops to the *rabi* season cropping intensity are 44, 41 and 3% respectively in Bundelkhand zone of U.P. Mustard (*Brassica juncea)* is one of the important *Rabi* oilseed crop in this region being cultivated on about 0.86 lakh hectares with the average productivity of 547 kg/ha. The "Mar" and "Parwa" soils of this region are more suitable for the cultivation of Mustard but the productivity is low due to cultivation of poor quality seeds of local cultivars, improper nutrient management and lack of plant protection measures. Variation in gap for the use of improved seeds in mustard crop ranged between 51-68% in Bundelkhand region. Cultivation of mustard as a mixed crop with wheat, barley and non adoption of line sowing caused further yield reductions. The farmers' were motivated to adopt line sowing using seed-drill and adopt improved variety seeds (NRCHB-101, NRCDR-2, DRMR IJ-31, RH-749 and RH-406) in forty demonstrations conducted at farmers' fields in this region. It was observed that the crop growth was distinctly superior with the adoption of line sowing and improved variety seeds over farmers' practices. The mustard crop has the potentiality to double the income of farmers' by technological interventions under moisture stress conditions usually prevalent in the Bundelkhand region and also result in increased cropping intensity under climate adversities.

Problems and Prospects of Oilseed Brassica in Uttar Pradesh

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India has a prime place in area as well as in production of oilseeds among the major oilseeds producing countries of the world but it is not sufficient against the requirement for ever growing population of the country. The demand of edible oils would be about 20 million tonnes per annum by the year 2020 against the projection of production of edible oils to about 7 million tonnes per annum during the same period as reported by National Council of Applied Economic Research. To fulfill the gap of 13 million tonnes per annum, the efforts will have to be made to accelerate growth rate of production of oilseeds by 15% per annum against existing growth rate of 4% per annum. For accelerating the production of oilseeds, Uttar Pradesh can play a dominant role in years to come considering rich soil and agro-climatic condition. In spite of favorable agro-climatic condition, the average yield of oilseeds in general and oilseed *Brassica* in particular is much lower as compared to Rajasthan and Haryana. Among various oilseed crops, rapeseed-mustard accounted for lion's share being 84.3% but the farmers are not confident to get good yields due to poor adoption of improved technologies including broadcast sowing and mixed cropping, inadequate availability of inputs like seeds, sulphur and weather adversities leading to higher incidence of pests and diseases. Besides, small and marginal farmers in this region prefer to grow cereals in comparison to oilseeds to meet their domestic needs. During Rabi 2016-17, different *Brassica* species (*B. rapa, B. juncea, B. carinata, B. napus, B. nigra and Eruca sativa*) were grown on the RLBCAU farm at Jhansi for the first time and it was observed that different species can be cultivated successfully in the Bundelkhand region having aberrant climatic conditions. The performance of mustard was comparatively better with one protective irrigation and further research is needed to accelerate the production and productivity of this crop in this region.

Farmers perspective for Rapeseed-Mustard cultivation in Bundelkhand region

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The Bundelkhand region of Uttar Pradesh comprises seven districts including- Jalaun, Jhansi, Lalitpur, Hamirpur, Mahoba, Banda and Chitrakoot. The vagaries of monsoon in this region often result in frequent droughts and water scarcity leading to fluctuations in productivity of different crops from year to year compared to other zones of UP. Among various factors, lack of rain water conservation, inadequate irrigation facilities, low input use, unimproved farm implements, poor adoption of improved technologies primarily seeds and seeding techniques and poor socio-economic status are the key constraints in increasing production and productivity of oilseeds and pulses in this region. Considering these facts, forty 'Front Line Demonstrations' (FLD) were conducted on the farmer's field in four villages (Kanchanpur, Dhikauli, Koat Baheta and Mawai) of Babina and Badagaon blocks of Jhansi district with five improved varieties i.e. NRCHB-101, NRCDR-2, DRMR IJ-31, RH-749 and RH-406 for the first time by RLBCAU, Jhansi, during the *Rabi* season of 2016-17. Growing seeds of improved varieties using line sowing at 45 cm distance resulted in vigorous seedling growth, proper root development, early stem elongation, rapid foliage development and excellent siliquae formation. These traits can be successfully exploited in mustard if seeds are grown at appropriate time in second week of October along with maintaining an optimum plant population. Adoption of improved variety itself can enhance productivity by 20 to 25% depending upon land resources, soil condition, and level of management. Line sowing using 4 Kg seeds/ha, one protective irrigation at 35 DAS and soil test based nutrient application to mustard was beneficial for yield enhancement. The farmers were educated for mustard cultivation in Bundelkhand region and were informed about the benefits of adoption of improved seeds and seeding techniques over the local practices. They were of the opinion that cultivation of improved variety seeds and line sowing in mustard holds promise in this region and can lead to enhanced productivity and profitability of farmers in this region.

Information processing in agriculture research: Role of the scientific societies in India

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Public and private research institutions have played important role in sustainable development of agriculture sector in India. The role of scientific societies is equally important and is committed to accelerate the growth and development of agricultural research, education and extension in the country. The purpose of this study explores the quantitative and qualitative growth of the agricultural societies in India and their role in the paradigm shift of agricultural research information dissemination in the country. The information about agricultural societies in India were obtained by several means such published literature & internet and analyzed. The information collection methodology used in study is Forward-Backward Information Search (FBIS). The agricultural societies have grown manifold over the past four decades in India, These societies generally share a common objective to fortify agriculture science discipline, and they achieve this objective through several activities such as publishing journals, organizing conference/seminar/meetings, recognizing achievement of scientists, etc. There are about 116 societies in agricultural sciences so far information collected for this study. This study was necessary for the practical purpose to identify the role of scientific societies are playing in agriculture development in India. However some similar studies have been conducted previously but they do not give the detail information on societies.

Design, implementation and application of web-based expert tool for selecting climate resilient crop varieties.

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The area of rapeseed-mustard being grown in India has been classified in to five major agro-ecological zones. The basic climatic conditions targeted for developing the resource efficient varieties are rainfed and irrigated. About 30% of total rapeseed-mustard cultivation area in country is under rainfed condition. In erratic behavior of climatic conditions, it is imperative to the farmers be informative with the available technologies suitable for their situations. In India, rapeseed-mustard researchers have developed the improved varieties performing well in rainfed, irrigated and in both rainfed and irrigated conditions. The availability of the information about these varieties is scattered and by means of several forms. The challenge was to organize the information electronically so that the farmers of the country could be benefited from this information for increase in rapeseed-mustard production. For this purpose, a web based expert system of crop variety selection has been developed. The system was developed by applying knowledge engineering approaches with scientific knowledge base in backend. The system suggests the varieties of farmer's/ advisor's choice based on location for climatic conditions such as rainfed or irrigated or for both conditions. The system carries detailed information about 160 notified varieties that have been stored in its knowledge base. The important feature

implemented in this expert system is that it is bilingual i.e. in English and Hindi languages (which can be easily understood by the Indian farmers and all concerns).

Technologies of Rapeseed-Mustard: An analysis

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India is the second largest rapeseed-mustard growing country in the world contributing about 25 and 15 per cent, respectively, to world’s acreage and production. The crop commodity is the important group of oilseed crops in India. Oilseed sector as a whole and rapeseed–mustard in particular, has witnessed a significant increase in production in the last decade. However there has been fluctuation in production and productivity of rapeseed-mustard over the period which affects the sustainability of production. Research results show that there is vast scope to increase the present productivity level of rapeseed-mustard in the country. The improved technology developed for mustard crop at research stations and tested at farmer’s field for its viability and feasibility has convincingly established the superiority of the technology over the traditional practices. Despite the technological advancement in mustard for last two decades to attain higher yields, the vast gap exists between the actual yields obtained at farmer’s field and the yield obtained at the research farms which shows the low adoption of recommended technologies by the farmers. Even in areas, where the adoption of modern varieties is relatively high, farmer’s yield of mustard are often lower than the known potential yield of this crop. The factors preventing farmers from achieving the full potential of the new technology may be economic, infrastructural, climatic, technological, etc. There is a need to educate farmers in adoption of improved technology. Keeping in view of this, a complete study of profitability of mustard cultivation, adoption pattern of scientific recommendation of rapeseed-mustard cultivation and perceptions of farmers along with field level extension workers about constraints affecting adoption of technologies disseminated through various programmes was carried out.

Mustard FLDs performance in Jhalawar district of Rajasthan

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A good position in oilseed crops along with high yield potential in both rainfed and irrigated condition is mustard containing from 37-49 % oil content. It is the major growing oilseed crop during *Rabi* in the Jhalawar with low productivity i.e. equal or less than 1600 kg/ha. Wide gap between improved package of practices (IP) and farmers practice (FP) was the major reason behind low yield of mustard. To identify the gap and performance of the FLDs conducted by Krishi Vigyan Kendra, Jhalawar, present study was done during *Rabi* 2009-10. The FLD site was purposively selected at the adopted village of KVK *i.e.* Chunabhati and Bhopatpura of Jhalarapatan block in the district Jhalawar. The total 25 farmers (11 form Chunabhati and 14 from Bhopatpura) were selected for the study. Total area was 10 ha and 0.4 ha of each FLDs. The variety of mustard was Bio-902 demonstrated along with the packages of practices. The critical input was Seed, DAP and Urea was distributed to the participatory farmers. Training was

conducted before implementing the FLDs of participatory farmers. Field visits were conducted as per need. Field day was conducted at the time of maturity. The variety was very much liked by the participatory farmers. The result of the study shows yield under IP ranged from 1625 to 1950 kg/ha. The per cent increase in yield with IP over FP was recorded in the range of 18.75. The average Net Return (Rs./ha) and Benefit Cost Ratio (BCR) of the Improved Practices (IP) and Farmer practices (FP) were found 9000 and 8450 and 1.29 and 1.21, respectively. The increment was found in the yield and economic returns were due to the inclusion of packages of practices along with the new variety. On the basis of this study, it was concluded that yield gap in mustard can be overcome, to make the mustard more remunerative, through the wide publicity of the improved practices by adoption of various extensions methodologies, methods including front line demonstrations with technology backup need to be done.

Factors affecting attitude of farmers towards bio-control measures of plant protection in mustard production technology

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Biological control is the latest concept in India and it is viewed as an entirely safe technique to the environment. In recent years, concerns have been raised over the effects of the overuse of agricultural pesticides on the environment and human health. Bio-control can be used as an alternative to the chemicals in Integrated Pest Management (IPM) systems. Incorporation of biocontrol practices into pest management systems can result in reduced pesticides usage. There are wide scopes for the Indian farmers to adopt biological means of pest control to reduce hazardous effect of pesticides. On other hand, farmers might be facing certain problems in adoption of recommended biocontrol measures. Therefore, there is a need to analyze the situation and factors those responsible for not obtaining the desired rate of adoption pertaining to bio-control measures for plant protection in mustard production technology. For the adoption of recommended bio-control measures for plant protection, there must be positive attitude of the farmers towards bio-control measures of plant protection. The present study was undertaken at Krishi Vigyan Kendra, Jhalawar which is operational area of Agriculture University Kota, Rajasthan. During this, eleven training course were conducted on all components related plant protection and protection techniques of mustard especially emphasis on biocontrol measures and in total 330 farmers trained. Seven respondents from each training course were selected at random and hence total 90 respondents were selected for the study. The relationship between characteristics of the farmers and their attitude towards use of bio-control measures of plant protection was determined and tested with the help of Karl Pearson's (1978) coefficient correlation test. In light of the objectives, pretested well-structured interview schedule was prepared in Hindi version. Required information was collected through personal interview technique. The action of individual farmer is governed by socio personal, economic, communicational and psychological factors involved in situation. A farmer shows different degrees of attitude towards various aspects of the bio-control because of the difference in their personal characteristics. It is concluded from the study that independent variables viz., education, extension contact, training received, economic motivation, risk orientation, scientific orientation and knowledge of farmers had positive and significant connection with the attitude of farmers

towards bio-control measures of plant protection. More efforts should be made by the extension agencies to establish in depth extension contact with the farmers and their background factors which influence the attitude of farmers towards bio-control measures of plant protection in terms of change in behavioral components must be reckon within training programme, government and extension functionary should conduct training at grass root level in order to create awareness about bio-control measures.

Survey of farmer's fields for outbreak of diseases in oilseed Brassica

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Survey has been conducted during Rabi seasons of 2014-15 and 2015-16 to observe natural occurrence of the diseases prevailing in farmer's field of Bihar in order to assess the disease scenario of the region in changing climatic conditions. During the survey of different locations of two districts viz. Samastipur and Muzaffarpur of Bihar, it has been observed that the three diseases viz. *Alternaria* blight, white rust and *Sclerotinia* stem rot occur at varying degree of incidence and intensity causing severe losses to the crop. During Rabi 2014-15, *Alternaria* blight disease severity ranged from 5 to 40%, white rust severity from 5 to 15%, and *Sclerotinia* stem rot severity ranged from 5 to 30% at 10 different locations of above mentioned districts. Similar trend of disease severity for white rust during Rabi 2015-16 were observed. *Alternaria* blight disease severity ranged from 45 to 80%, white rust severity from 5 to 15%, and *Sclerotinia* stem rot ranged from 15 to 45% at eight different locations of Samastipur and Muzaffarpur. Conclusively, Bihar as hot spot of *Alternaria* blight also recorded increasing trend in severity of *Sclerotinia* stem rot.

Potential area for enhancing the rapeseed-mustard production in India

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In India, rapeseed–mustard is grown in diverse agro-climatic conditions ranging from north-eastern/north-western hills to down south under irrigated/rainfed, timely/late sown and mixed cropping. The average contribution of rapeseed-mustard to the total oilseed acreage and production in India is about 22.2% and 22.6%, respectively. Its average productivity is 1145 kg/ha as compared to 1135 kg/ha of total oilseeds. The rapeseed-mustard production trends represent fluctuating scenario with a high production of 8.17 mt from 6.90 million hactares (mha) during 2010-11. The yield levels also have been variable during the last 5 years. Due to change in economic status and food habit of Indian population the per capita consumption of edible oil increased up to 14.2 kg/yr. The data shows that, the domestic production of edible oil is about 8.9 mt, however the consumption has increased upto 18.9 mt. This gap in demand and supply is being filled by import of edible oil, which is about 10.0 mt. The rapeseed-mustard crop has more than 40% oil content is only the potential oilseed crop can bridge this gap of demand and supply. The districts wise Information collected from different sources shows that, in India the mustard crops are grown in 485 out of 672 districts. In present article an in-depth analysis made to identify the potential area for expending net mustard grown area in country. The maximum potential of rapeseed-mustard crops is being exploited almost in 103 districts covering about 4634 thousand hectares with the average productivity of 1280 kg/ha. The 118 districts of average productivity 490 kg/ha hold about 607 thousand hectares area (10% of total area) are comes from nontraditional area mainly Assam, Chhattisgarh, Madhya Pradesh, Uttar Pradesh odisha, J&K, etc. Out of 118 districts of both categories 80 districts are 26 of Assam, 14 of Chhattisgarh, 12 of Madhya Pradesh, 10 of Uttar Pradesh, 9 of Odisha, 9 of J&K and remaining 38 of other states. This pocket may be of interest of policy planner and researchers because the area in this pocket is considerably high. The productivity of these districts is low, there may be several reasons of lower productivity but the non adoption and availability of high yielding cultivar for this region may be one of the major reason. An estimate/hypothesis shows that the national production can be increased by 6.2% only by increasing productivity upto national averages in these districts. The 71 districts account about 50 thousand hectare area having the average productivity 1500kg/ha which is far above with the national average productivity. Under these categories major districts are of Gujarat (15), Madhya Pradesh (12), Haryana (9), Jharkhand (5) and remaining are of other states. This pocket may also be of interest to expend the area of rapeseed-mustard. Since the productivity in these states is high, the crop may be more remunerable as compare to other competing crops. Therefore suitable planning may be made for adoption of rapeseed-mustard crop in this pocket by replacing other less remunerable crops. The 94 districts (21 of Maharastra, 19 of Odisha, 13 of Karnataka , 8 of Jharkhand and remaining 33 districts are of other states) occupying about 18 thousand hectare area have the average productivity 405 kg/ha. The area is less and the average productivity is also low and mustard grown area is wide spread geographically, therefore concentrate efforts may not be more fruitful to expend mustard area in this pocket and 99 accounting 209 thousand hectare area with an average productivity of 405 and 972 kg/ha respectively. Out of 94 district of LA-LP category Since in LA-LP category, the area is less and the average productivity is also low and mustard grown area is wide spread geographically, therefore concentrate efforts may not be more fruitful to expend mustard area in this pocket. The 99 districts, 27 of Uttar Pradesh, 22 of Bihar, 13 of Punjab and remaining 37 are of other states accounting 209 thousand hectare area with an average productivity of 972 kg/ha may suitable for rapeseed-mustard Production.

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