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Prevalence, Epidemiology and Forecasting of Alternaria Blight of Indian Mustard (*Brassica juncea*) in India

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Abstract

First appearance of Alternaria blight (AB) disease of Indian mustard (*Brassica juncea*) on leaves occurred between 65 and 98 days after sowing (d. a. s.), 83, 87, 98, 65, d. a. s. having higher frequencies in 2010–11 to 2013-14 respectively, being highest in respective years at 45, 46, 75, 45, 76 d. a. s. The disease first appeared on pods between 67 and 142 d. a. s., being highest at 99 d. a. s. Severity of AB disease on leaves was positively correlated to a maximum daily temperature of 18–27 °C, minimum daily temperature of 8–12 °C, daily mean temperature >10 °C, >92 % morning relative humidity (r. h.), >40 % afternoon r. h. and mean r. h. of >70 % in the preceding week. Location and cultivar-specific models might forecast the crop age at which AB first appeared on leaves, the highest leaves blight severity, and the crop age when blight severity was highest on leaves at least one week ahead of first appearance of the disease on the crop. Keeping in view the normal date of sowing (22 October), the models have been tested in the farmers' field for Bharatpur. Although, data revealed that AB severity decreased by 10% over six locations during 2001 to 2015 on *B. juncea* cultivar Rohini with delayed appearance of AB. There may be defensive difference among age of plant, cultivars and species of Brassica for showing disease response. The AB severity trend on leaves at all six zones was fluctuating between 30 to 50%. AB disease severity trends in zone II [Hisar (HSR), Ludhiana (LDH), Bhatinda (BTH), Sriganganagar (SGN)] showed static trend with $R^2 = 0.036$ ($y = -0.221x + 39.08$) and similar trend was also observed in zone III [Bharatpur (BHP), Kanpur (KPR), Faizabad (FZB), Morena (MOR)] with $R^2 = 0.011$ ($y = -0.201x + 41.10$). Particularly in zone V at Jagdalpur (JAG) and Berhampore (BER), AB severity drastically decreased by $R^2 = 0.661$ ($y = -2.089x + 46.40$). However, AB severity trend on cultivar Rohini and Varuna at Bharatpur was observed below 15% with $R^2 = 0.282$ ($y = -1.106x + 23.50$) since 10 years which was >25% during 2003 to 2006. Only models with reasonable prediction accuracy when tested with an independent data set will allow farmers to aware about status of disease and to make timely and effective fungicidal sprays.

Key words: *Alternaria brassicae, Brassica juncea, epidemiology, forecasting models, weather based regression model and prevalence*

Introduction

Rapeseed-mustard crops are challenged by numerous biotic and abiotic stresses during recent years in India. Fungal diseases are the most important barrier in achieving higher productivity per unit area which is urgently needed for doubling the income of farmers. The exhaustive cultivation of the crops 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 (Saharan et al., 2016). 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 in different parts of the world.

Among them, Alternaria blight (AB) disease caused by *Alternaria brassicae* (Berk.) Sacc., which affects all above-ground parts of the plant, has been reported from all the continents of the world and is considered an important constraint in cultivation of rapeseed-mustard in India. However, total destruction of the Indian mustard due to the disease is rare and usually yield losses at harvest are 17–22 %, and can reach up to 47 % (Saharan et al., 2016). Severity of AB on oilseed Brassicas differs between seasons, regions and individual crops within a region in India (Meena *et al*., 2010). In the absence of stable, desirable and diverse sources of resistance to the AB, fungicides remain the only effective means to manage the disease (Meena *et al*., 2008, 2011a, b). Despite high use of fungicides on rapeseed-mustard crops in India, timing of their application has not been optimal. Crops requiring treatment have been left unsprayed and others sprayed unnecessarily. There is inadequate knowledge on epidemiology of AB of rapeseed-mustard. Survival of the pathogen ranging from 13.3 to 84.5% has been found on intact infected plant debris, and leftover seed after harvest from the surfaces of both unploughed and deep-ploughed fields in tropical or subtropical India (Meena *et al*., 2016), like the situation in temperate conditions (Humpherson-Jones and Maude, 1982).

In India, oilseed Brassicas are sown during late September to November, depending on the crop, prevailing temperature and availability of soil moisture for seed germination. Harvest occurs from February to April. Off-season crops are grown in non-traditional areas including Nilgiri hills and foot hills of Himalayas during May to September and this, coupled with harbouring of the fungal pathogen by vegetable Brassica crops and alternative hosts, could cause carryover of *A.brassicae* from one crop-season to another (Tripathi and Kaushik, 1984; Mehta *et al*., 2002; Saharan *et al*., 2016). Thus, airborne spores of *A. brassicae* form the primary source of inoculum of this polycyclic disease (Kolte, 1985).

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.

Efficient, economical and environment-friendly control of the AB may be obtained through knowledge of its timing of attack in relation to weather factors, which may enable prediction of its occurrence so as to allow farmers to take timely fungicidal sprays for an efficient crop management. Weather is an important factor in the severity of AB of rapeseed-mustard. Empirical models have been developed to relate the occurrence of AB on oilseed Brassicas to temperatures, relative humidity (r. h.) and sunshine hours (Saharan and Kadian, 1984; Sinha *et al*., 1992; Awasthi and Kolte, 1994; Dang *et al*., 1995; Chattopadhyay *et al*., 2005). However, they provide no insight into real-time prediction of the disease on the oilseed *Brassica* crops in different parts of India. Location specific accurate forecast of the crop age at first appearance of the disease and the risk of a blight epidemic would enable farmers to decide on optimum timing of fungicide sprays and to avoid unnecessary pesticide application. Hence, the present study was undertaken to develop forecasts for crop age at time of first appearance of AB, for crop age when blight severity is maximum and for highest severity of the blight on the crop in the season at Bharatpur, India.

Materials and Methods

Epidemic of fungal plant diseases depends on many factors, including temperature and length of period with free water on plant leaf surface, plant resistance, presence of other epiphytic (pathogenic and non-pathogenic) microorganisms, etc. Earlier AB was a principal disease of oilseed Brassica, and now declined doesn’t mean that commercial breeders have been successful in their breeding efforts. It is now essential to test grow varieties of different release dates and look for changes in their disease susceptibility. Another issue may be the soil fertility if agronomic practice has led to greater balanced fertility the necrotic pathogens such as Alternaria will usually decline. Modern practice would probably lead to both of these occurring which could permit a major disease to lose some of former importance. We can also assume that reduced night humidity and general drop of underground water level could be responsible for decreased importance of Alternaria. But, it would be important to show the same trend for other necrotic plant pathogens. 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 diseases.

Field experiment

Field trials at Bharatpur (27° 122 N; 77° 272 E), was laid out in randomized block design with two replications in 2010–11, 2011-12, 2012-13, 2013-14, 2014-15, 2015-16, and 2016-17 post-rainy crop *(Rabi)* seasons with cultivar ‘Varuna’ *(Brassica juncea)* and an important cultivar NRCDR-02 in the locality sown on 10 dates at weekly intervals (01, 08, 15, 22, 29 Oct, 05, 12, 19, 26 Nov and 03 Dec). Each plot measured 3 × 5 m with spacing of 30 × 10 cm, recommended doses of N and P fertilizers (DRMR, 2013) were applied. Insect-pest protection comprised seed treatment with Imidachloprid® (7 g/kg) and spray of Dimethoate 30 EC (1ml/l) at 15-days interval. No protection was taken against any disease.

Weather data recording

Weather data for maximum and minimum daily temperatures, morning [07:00 h Local Apparent Time or LAT calculated on the basis of longitude of a location as per standard norms of the Indian Meteorological Department or IMD relative humidity (r.h.), sunshine hours and rainfall were recorded from standard meteorological observatories at all locations except at Bharatpur. Meteorological observatories at these locations were 110–170 m from the site of experiments and the data recording instruments were installed as per standard specifications of the IMD (Ghadekar 2002). Weather data were recorded at Bharatpur using an automatic weather station (SGS Weather & Environmental Systems Pvt. Ltd.), where apart from recording the weather variables mentioned earlier.

Disease assessment

All experiments relied completely on natural occurrence of the disease severity. Observations for first appearance and gradual progress of AB on leaves of *Brassica juncea* were observed. Observations for percent disease severity (PDS) was recorded twice a week (on Tuesday and Friday) until harvest from 10 randomly tagged plants in each plot of the crop on leaves following the scale of Conn *et al.* (1990). For each assessment date, PDS on leaves on 10-tagged plants from the two replicated plots were averaged to give respective single values.

Development of Forewarning models for Alternaria blight

The extent of the influence of weather on diseases severity mainly depends not just on weather parameters measured over a long time interval, but also on dynamic changes which can occur over short time intervals. Thus, a weather-based model can be an effective scientific tool to thwart the impending attack of pest by forewarning so that timely plant protection measures can be taken up. For timely control, merely the idea about the expected population count below or above the threshold level could be enough, which can be obtained from models based on qualitative data. The extent of influence of weather on pathogen inoculum build up depends not only on the total magnitude but also on the distribution of weather variables over small time intervals. But use of data in small time intervals will increase the number of variables in the model and in turn a large number of model parameters will have to be evaluated from the data. This will require a long series of data for precise estimation of the parameters, which may not be available in practice. Thus, a technique based on relatively smaller number of model parameters and at the same time taking care of entire weather distribution could be the best option. This can be achieved by taking weighted accumulation of weather variables, giving weights according to their importance in different time periods. In this study, objective weights, where correlation coefficients between variables to forecast and weather variables were taken as the indicators of relative importance in respective weeks were used. In this approach, two indices were developed for each weather variable; one as total value of weather variables and the second one as weighted total, weights being correlation coefficients between variable to forecast and weather variables in respective weeks. The first index represents the total amount of different weather variables received by the crop during the period under consideration while the other one takes care of distribution of weather variables with special reference to its importance in different weeks in relation to the variable to forecast. Similarly, for joint effects of weather variables, weather indices were developed as weighted accumulations of product of weather variables (taking two at a time), weights being correlation coefficients between variable to forecast and product of weather variables considered in respective weeks (Chattopadhyay *et al.*, 2005; Agrawal *et al.,* 2007). The form of the model was:

$$Y = a_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i \neq i'}^{p} \sum_{j=0}^{1} b_{ii'j} Z_{ii'j} + e$$

Where,

$$Z_{ij} = \sum_{w=n_1}^{n_2} r^{j}_{iw} X_{iw}$$

$$Z_{ii'j} = \sum_{w=n_1}^{n_2} r^{j}_{ii'w} X_{iw} X_{i'w}$$

Y variable to forecast

x_{iw} value of i^{th} weather variable in w^{th} week

r_{iw} correlation coefficient between Y and X_{iw}

$r_{ii'w}$ correlation coefficient between Y and product of X_{iw} and $X_{i'w}$

p number of weather variables considered

n_1 initial week for which weather data were included in the model

n_2 Final week for which weather data were included in the model

ε error term

Stepwise regression technique is an improvement over forward/backward selection process in the sense that it rechecks at each step the importance of all previously included variables. The partial F value for each variable in the regression equation at any stage is evaluated and checked for significance. Further, any variable which provides non-significant partial F value, is removed from the model. The process is continued until no more variables are admitted to the equation and no more are rejected.

Results and Discussion

Epidemic of fungal plant diseases depends on many factors, including temperature and length of period with free water on plant leaf surface, plant resistance, presence of other epiphytic (pathogenic and non-pathogenic) microorganisms, etc. Earlier AB was a principal disease of oilseed Brassica, and now declined doesn't mean that commercial breeders have been successful in their breeding efforts. It is now essential to test grow varieties of different release dates and look for changes in their disease susceptibility. Another issue may be the soil fertility if agronomic practice has led to greater balanced fertility the necrotic pathogens such as Alternaria will usually decline. Modern practices would probably lead to both of these occurring which could permit a major disease to lose some of former importance. We can also assume that reduced night humidity and general drop of underground water level could be responsible for decreased importance of Alternaria. But, it would be important to show the same trend for other necrotic plant pathogens. 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 diseases.

Alternaria blight Severity Trends of Oilseed Brassica in India

In India, the limited efforts have been made to study the trends for any disease of oilseed Brassica crop. In view of the fact that some isolates of *A. brassicae* sporulated at 35°C temperature (Meena *et al.*, 2016), and several isolates had better infertility under higher RH, it seems that as per current changes towards warmer and humid winters, survival of such isolates could cause more threat to the oilseed Brassica due to AB in times to come. The vast dissimilarity existing between representative isolates of *A. brassicae* also indicates their capability to acclimatize in the varied climatic conditions (Meena *et al.*, 2012).

Over the period of 15 years (2001 to 2015), AB severity data were analyzed to study the disease severity trends at different agro-climatic conditions in the country. Data revealed that the AB severity decreased by 10% over the six locations during 2001 to 2015 on *B. juncea* cultivar Rohini. There may be defensive difference among cultivars and species of Brassica for showing disease response. The AB severity trend on leaves at all six zones was

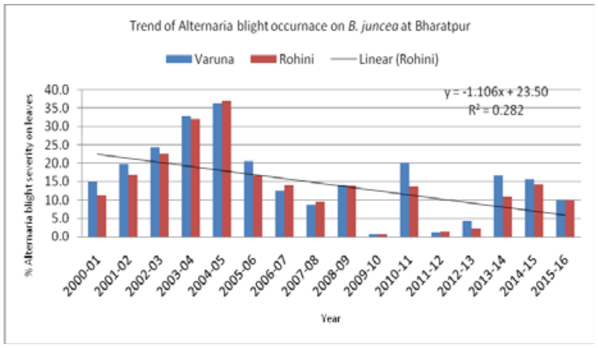

Fig 1a: Occurrence of Alternaria blight of oilseed Brassica in Bharatpur, India

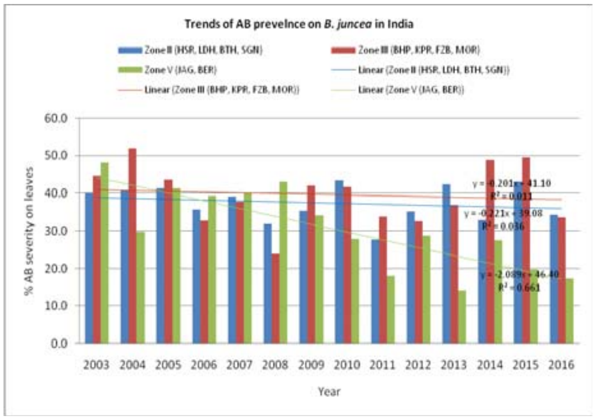

Fig 1b: Prevalence of Alternaria blight on oilseed Brassica in different parts of India

Table 1: Model for various characters for Alternaria blight in mustard in different date of sowing along with coefficient of determination

Date of Sowing (data used)	Model	R^2
15 Oct. (44 SMW to 4 SMW)	$Y_1 = 137.95726 + 0.08010\,Z_{151} - 0.00021223\,Z_{340}$	0.6424
	$Y_2 = -36.59254 + 0.02982\,Z_{451}$	0.7022
22 Oct. (44 SMW to 4 SMW)	$Y_1 = 151.56931 + 0.10776\,Z_{151} - 0.00030993\,Z_{340}$	0.7637
	$Y_2 = -30.53894 + 0.02412\,Z_{451} + 0.00421\,Z_{241}$	0.7303
29 Oct. (44 SMW to 4 SMW)	$Y_1 = 163.66121 + 0.13656\,Z_{151} - 0.00052505\,Z_{340}$	0.9581
	$Y_2 = -38.55225 + 0.03510\,Z_{451} - 0.03996\,Z_{241}$	0.7979

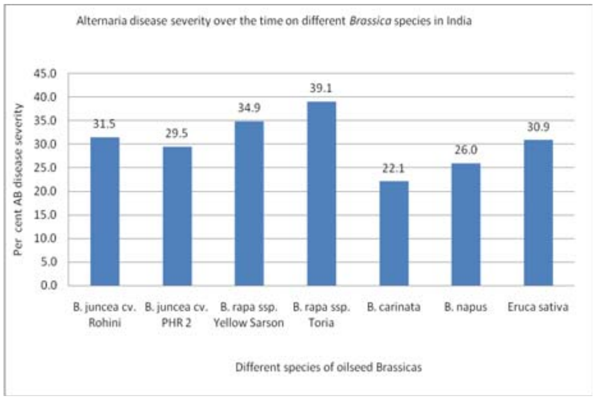

Fig. 2: Prevalent AB disease severity trends on different *Brassica* species in India

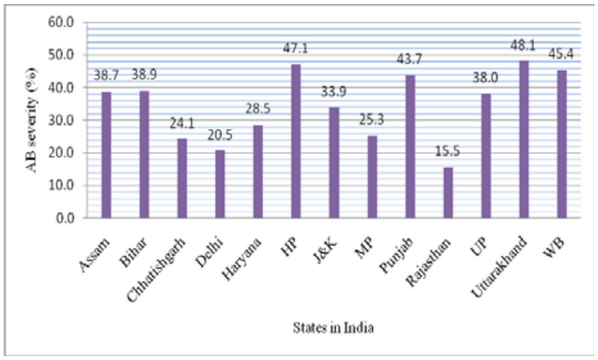

Fig. 3: Prevalence of AB disease severity in India

fluctuating between 30 to 50%. AB disease severity trends in zone II [Hisar (HSR), Ludhiana (LDH), Bhatinda (BTH), Sriganganagar (SGN)] showed static trend with $R^2 = 0.036$ ($y = -0.221x + 39.08$) and similar trend was also observed in zone III [Bharatpur (BHP), Kanpur (KPR), Faizabad (FZB), Morena (MOR)] with $R^2 = 0.011$ ($y = -0.201x + 41.10$). Particularly in zone V at Jagdalpur (JAG) and Berhampore (BER), AB severity drastically decreased by $R^2 = 0.661$ ($y = -2.089x + 46.40$). However, AB severity trend on cultivar Rohini and Varuna at Bharatpur was observed below 15% with $R^2 = 0.282$ ($y = -1.106x + 23.50$) since last 10 years which was higher than 25% severity during 2003 to 2006 (Fig. 1). There are combinations of a number of factors including availability of susceptibile host cultivars, source of virulent pathogen inoculums in the vicinity and favourable micro climate as well as cultural conditions. Now a day, there is slight change towards increased spacing, application of recommended dose of nitrogen and reduced scheduled irrigation may be among reliable reasons of decreased AB severity in northern parts of the country.

AB severity was highest on *B. rapa* ssp. Toria (39.1%) followed by, *B. rapa* ssp. Yellow Sarson (34.9%), *B. juncea* (31.5%) and *Eruca sativa* (30.9%) (Fig 2). Although, *B. carinata* (22.1) and *B. napus* (26.0%) were least affected with AB and mainly used for developing resistance in *B. juncea* through traditional breeding in India. In India, occurrence of AB disease devastating rapeseed-mustard was prevalent in different states including Uttarakhand (48.1%), Himachal Pradesh (47.1%), WB (45.4%) Punjab (43.7%), Bihar (38.9%), Assam (38.7%), Uttar Pradesh (38.0%), Jammu & Kashmir (33.9%), Haryana (28.5%), Madhya Pradesh (25.3%), Chhatishgarh (24.1%), Delhi (20.5%), and Raj. (15.5%) since fifteen years (Fig 3).

Forewarning models for AB using weather indices based approach

Ecofriendly and economic control of AB requires knowledge regarding appearance of disease and its interaction with weather factors. The disease progression under field conditions as influenced by environmental conditions and dates of sowing was measured for the development of model.

Field experiment

Severity of AB on leaves and pods were higher in later sown crops (Table 2). First appearance of Alternaria blight disease on leaves of mustard occurred between 101 and 134 d. a. s., 120, 119, 118, 123, 132, 128, 133, 115, 134 d. a. s. having higher frequencies in 2001-02, 2002–03, 2003–04, 2004–05, 2005–06, 2006–07, 2010–11, 2011–12, and 2012–13 respectively, being highest at 123 d. a. s. Among several epidemics studied in this investigation, one on leaves of cv. Varuna and Rohini at Bharatpur from 2000–01 to 2015-2016 has been illustrated in Fig. 1, where the first appearance of the disease in later sawn crops although takes place later than that in other planting dates but results in higher severity.

Forewarning models

Forewarning models for prediction crop age (in days) at peak severity of AB (Y_1) and maximum severity (in %) of AB (Y_2) at Bharatpur for different date of planting (15 Oct, 22 Oct and 29 Oct,) were developed using Maximum temperature (X_1), Minimum temperature (X_2), Relative humidity in morning (X_3), Relative humidity in evening (X_4) and Bright sunshine hour (X_5) are presented in Table 1. The models were developed using the data from 2001-02 to 2013-14 for prediction and validated from 2014-15 to 2017-18. The observed and predicted based on the developed models on crop age at peak severity & maximum severity of AB on leaves at three different date of sowing are presented in Figure 4. It can be seen that the predicted and observed values are in good agreements with the observed ones.

Table 2a: % severity of Alternaria blight on leaf of cv. Varuna (2013-14)

SOWN ON	3 Jan	7 Jan	10 Jan	17 Jan	21 Jan	24 Jan	28 Jan	31 Jan	4 Feb	7 Feb	11 Feb	21 Feb	25 Feb	28 Feb	4 Mar	7 Mar	11 Mar
01-Oct	0	0	0	0	0	0	0	0	0.2	0.2	0.1	2.2	2.5	2.5	2.5	2.5	harvest
08-Oct	0	0	0	0	0	0.3	0.2	0.2	0	0.2	0.3	3.1	3.5	3.5	3.5	4.0	12.5
15-Oct	0	0	0	0	0	0.5	0.3	0.3	0.2	0.3	0.4	6.1	6.1	6.8	7.0	7.0	16.0
22-Oct	0	0	0	0	0	0.2	0.2	0.2	0.8	0.5	0.5	9	4.7	2.5	3.0	3.0	16.5
29-Oct	0	0	0	0	0	0.6	0.6	0.6	0	0.5	0.6	7.5	7.2	7.2	7.5	7.5	9.0
05-Nov	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.4	0.4	1	1.6	2.4	6.0	7.0	15.5
12-Nov	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.5	0.6	5	6.1	6.1	6.1	7.0	9.5
19-Nov	0	0	0	0	0	0	0	0	0	0	0.3	4.6	5.7	6.2	6.2	7.8	12.5
26-Nov	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.8	3.8	4.2	4.2	4.2	4.9
03-Dec	0	0	0	0	0	0	0	0	0	0	0	1	2.2	2.2	2.2	2.2	2.4

Observed and predicted severity of AB on leaves at 15 October sowing

Different ranges of weather variables of one week preceding the assessment date were used as independent variables to identify the boundary and favourable conditions that positively influenced the dependent variables or disease severity on leaves and pods, through regression analysis. Correlations of timing (crop age in days after sowing or d. a. s.) of first appearance of the blight on leaves and pods, highest severity of AB on the crop leaves, pods and crop age (d. a. s.) at highest severity of leaf and pod blight with weather variables were studied.

Linear prediction models based on the weather parameters as independent variables and crop age (d. a. s.) at time of first appearance of the disease on leaves, pods of the crop, highest severity of the disease on leaves, pods in the season and crop age (d. a. s.) at highest severity of the disease at each week starting from week of sowing as dependent variables were fitted by multiple stepwise regression (Draper and Smith, 1981) using data of the initial three years. Based on correlation coefficients between dependent variables under study with the respective weather parameter (i) in different weeks, a composite weather variable (zi) was developed as the weighted sum of the weather variable in different weeks starting from the pre-sowing week up to the week of prediction (Agrawal *et al.*, 1986; Desai *et al.*, 2004). Similarly, interaction terms (zij) were developed as weighted sums of product between two weather variables, weights being correlation coefficients of the dependent variable under study with products of weather variables in respective weeks. The important weather indices were selected through stepwise regression.

Models were fitted for prediction of the dependent variables viz., highest disease severity and crop age (d. a. s.) at highest disease severity of the disease for different date of crop sowing. Weekly weather on Maximum temperature (X1), Minimum temperature (X2), Relative humidity in morning (X3), Relative humidity in evening (X4) and Bright sunshine hour (X5) from 45 SMW to 4 SMW were considered for models development. Statistical Analysis System (SAS) Software Release 9.2 (copyright 1999–2001 by SAS Institute Inc., Cary, NC, USA) was used for development of models using weather indices based regression analysis. The models have been tested keeping in view the normal date of sowing in the farmers' field for the location viz., 22 Oct for Bharatpur (Fig. 4).

Conclusion

The above discussion suggests that the disease and pest

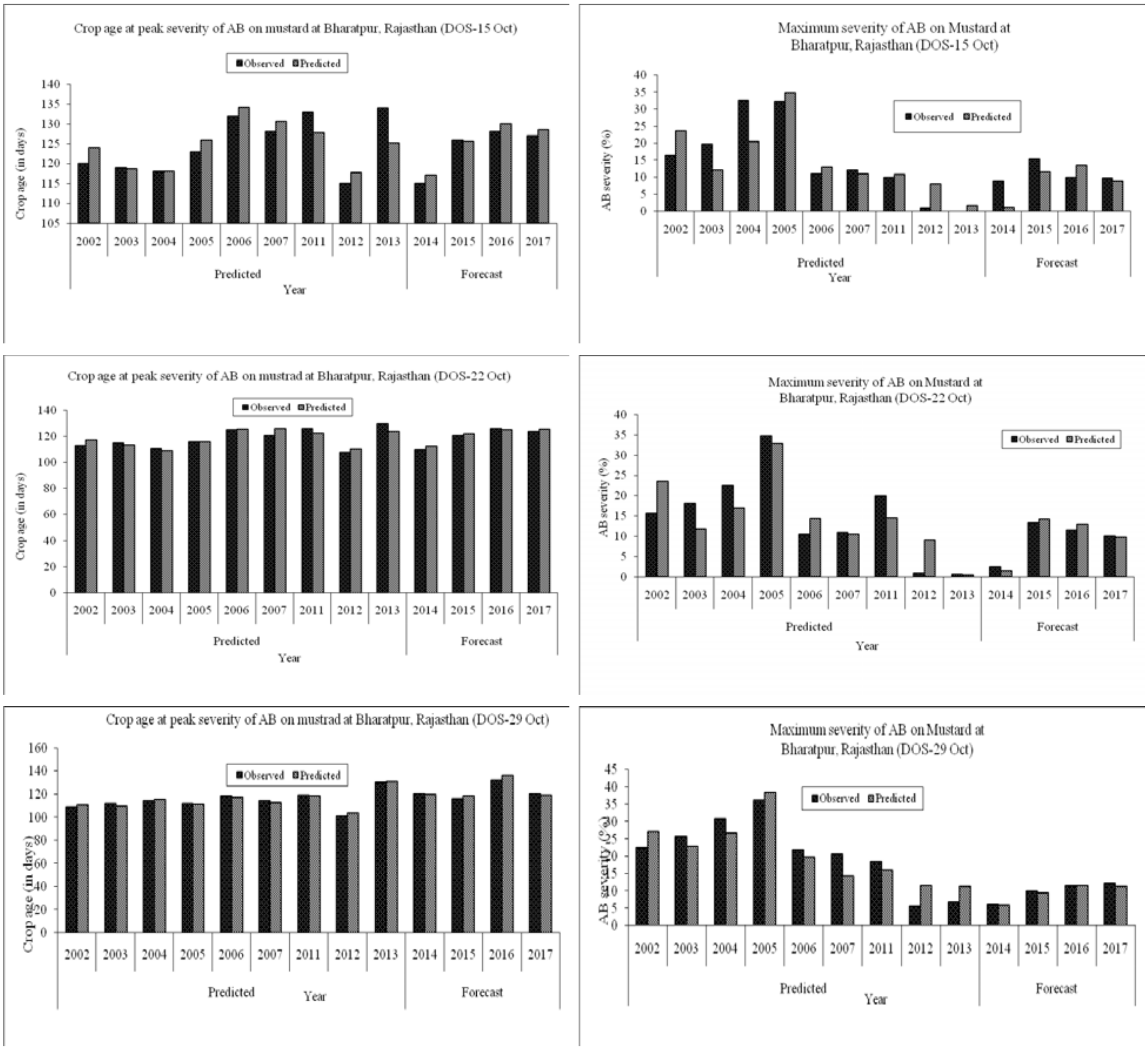

Figure 4: Crop age at peak and maximum per cent severity of AB on Indian mustard for 15, 20 and 29 October sowing dates at Bharatpur

management in mustard can be best achieved by adopting an integrated approach i.e. use of early maturing and disease tolerant variety, and early October sowing and need-based strategy of fungicide use. Hence, as per available literature, this seems to be the first report of devising location specific improved prediction models for forecast of the disease of oilseed Brassica crop and map of AB disease in India. In years of appearance of AB on crop before the decision week, farmers may be advised about the risk expected. Further, the forecasts need to account for the edge of inaccuracy in order to maintain the confidence of resource poor mustard farmers of India in the forecast system. A high priority over the next decade should be the collation of accurate disease and weather data and development of models to forecast the effects of climate change on other plant diseases to provide the necessary foresight for strategic adaptation to climate change.

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