



Research Progress Analysis of Sclerotinia rot (*Sclerotinia sclerotiorum*) of oilseed Brassicas through Bibliography

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Sclerotinia rot caused by *Sclerotinia sclerotiorum* (Lib.) de Bary is a major disease of oilseed Brassica in the world. Sclerotinia is a ubiquitous, omnivorous, soil-borne phytopathogenic ascomycetes fungus capable of infecting more than 500 plant species of diverse phylogenetic backgrounds including 278 genera in 75 families of dicotyledonous and a significant number of monocotyledonous plants (Purdy, 1979; Willetts and Wong 1980; Steadman, 1983; Boland and Hall, 1994; Saharan and Mehta, 2008, Sharma, 2014). Yield losses vary with the percentage of plants infected, and the growth stage of the crop at the time of infection. Plants infected at the early flowering stage produce little or no seeds, where as those infected at the late flowering stage although will set seeds but suffer little yield reduction. The disease decreases the value of crop by millions of dollars annually through losses in grain yield and quality of seeds (Purdy, 1979).

The pathogen was first described from Belgium by Madame M.A. Libert (1837) as *Peziza sclerotiorum* Libert. (Libert, 1837). G. E. Masee is considered the proper authority for *Sclerotinia sclerotiorum* (Lib.) Masee, because he had first used the binomial in 1895. However, since de Bary used it in his contributions (de Bary *et al.*, 1884; de Bary, 1886), the name and the authority for the fungus has generally been accepted to be *Sclerotinia sclerotiorum* (Lib.) de Bary. This disease is most frequently occur in cool and moist regions (Purdy 1979; Saharan and Mehta, 2008), but has also been reported in some semi-arid regions where conditions seem unfavourable for disease development. It results in damage of the plant tissue, followed by cell death and development of soft rot or white mould (Purdy, 1979).

The present bibliography on Sclerotinia rot (SR) of oilseed Brassica includes 1389 scientific publications, and very carefully and categorically analyses all aspects of research progress during the past 177 years (1837-2014). Our main objective was not only to compile all scientific literature in one publication, but also categorically arrange the bibliography according to centuries and decades, and identify major research areas and leading research institutions. This comprehensive publication, we hope, will help both the present and future researchers in identifying important research publications, leading research institutions and researchers directly related to their field of research. The analysis of SR research progress based on 1389 publications is summarized below:

Century-wise research progress

In the 19th century, 1 per cent publications were recorded on SR (Fig. 2). Twentieth century can be considered a boom period for SR research since 52% papers were published during this century (Fig. 2). Within the first decade of the 21st century, 47 per cent publications were recorded on SR (Fig. 2). Probable reasons for rapid progress of SR research during 20th and 21st centuries seem to be due to awareness of the disease, economic importance causing heavy yield losses, opening of more research institutes, employment of more research personel, improved facilities, knowledge of recently developed biological sciences, availability of more funds, academic interest, interaction of scientists, and development of new fields of biological sciences.

Decade-wise research progress

The number of research papers published on SR

Table 1: Major reviews (monograph), bibliographies, and books published on genus *Sclerotinia*

Authors	Year	Title	Name of journal /Institution	Vol. & page no.
de Bary A, de Bary HA and Deutschland B	1884	Vergleichend Morphologie und Biologie der Pilze, Mycetozen und Bacterien.	Leipzig : Wilhelm Engelmann	525 p.
de Bary A	1886	Ueber einige Sclerotinien und Sclerotien krankheiten	<i>Botanische Zeitung</i>	44:374-474
de Bary A	1887	Comparative morphology and biology of Fungi. (Translated by H E F Garnsey, revised by I B Balfour)	The Clarendon Press, Oxford	525 p.
Whetzel HH	1945	Synopsis of the genera and species of Sclerotiniaceae, a family of somatic inoperculate discomycetes	<i>Mycologia</i>	37: 648-714
Ingold CT	1960	Dispersal in Fungi	Clarendon, Oxford	206 p.
Ingold CT	1971	Fungal Spores: their liberation and dispersal	Oxford University Press, London	302 p.
Dumont KP and Korf RP	1971	<i>Sclerotiniaceae</i> I. Genetic nomenclature	<i>Mycologia</i>	63:157-168
Dumont KP	1971	<i>Sclerotiniaceae</i> II. Lambertelia Mem.	<i>NY Bot Gard</i>	22: 1-178
Coley-Smith JR and Cooke RC	1971	Survival and germination of fungal sclerotia	<i>Ann Rev Phytopathology</i>	9: 65-92
Alabouvette C and Louvet J	1973	<i>Sclerotinia sclerotiorum</i> . Bibliographie Sclerotionnee (Dec. 1971)	Inform Tech Centre Tech Interpr of Oleag Metrop	31: 7-26
Chet I and Henis Y	1975	Sclerotial morphogenesis in fungi	<i>Ann Rev Phytopathology</i>	13: 169-192
Mordue JEM and Holliday P	1976	<i>Sclerotinia sclerotiorum</i> (sclerotial state)	CMI Descriptions of Pathogenic Fungi and Bacteria No. 513.CMI, Kew, Surrey, UK.	
Kohn LM	1979	A monographic revision of the genus <i>Sclerotinia</i>	<i>Mycotaxon</i>	9:365- 444
Willettts HJ and Wong JAL	1980	The biology of <i>Sclerotinia sclerotiorum</i> , <i>S. trifoliorum</i> , and <i>S. minor</i> with emphasis on specific nomenclature	<i>Bot Rev</i>	46: 100-165
Bell AA and Wheeler MH	1986	Biosynthesis and functions of fungal melanins	<i>Ann Rev Phytopathology</i>	24: 411-451

Phillips AJL	1987	Carpogenic germination of sclerotia of <i>Sclerotinia sclerotiorum</i> : a review	<i>Phytophylactica</i>	19: 279–283
Nordin K	1988	<i>Sclerotinia sclerotiorum</i> (Lib.) de Bary - a literature review with emphasis on epidemiology and development of forecasting methods for <i>Sclerotinia</i> stem rot.	Växtskyddsrapporter Jordbruk	5: 77
Gladders P, Davies JML and Hardwick NV	1991	Review of <i>Sclerotinia</i> epidemic in winter oilseed rape in England and Wales	<i>Bull OILB/SROP</i>	16: 1-8
Krüger W	1991	A review on assessment of diseases in oilseed rape - comparison of various methods	<i>Bulletin SROP</i>	14: 91-111
Kohn LM	1992	Developing new characters for fungal systematic: An experimental approach for determining the rank of <i>Sclerotinia</i>	<i>Mycologia</i>	84: 139-153
Willets HJ and Bullock S	1992	Developmental biology of sclerotia	<i>Mycol Res</i>	96: 801–816
Gupta SK and Dohroo NP	1996	Chemical control of <i>Sclerotinia sclerotiorum</i> (Lib) de Bary - a review	<i>Agricul Rev</i>	17: 75-80
Mordue JEM and Holliday P	1998	<i>Sclerotinia sclerotiorum</i>	IMI Descriptions of Fungi and Bacteria. (52) Sheet 513, CABI Bioscience, Bakeham Lane, Egham, Surrey, TW20 9TY, UK.	
Henson JM, Butler MJ and Day AW	1999	The dark side of mycelium; melanins of phytopathogenic fungi	<i>Ann Rev Phytopathology</i>	37: 447–471
Glass NL, Jacobson DJ and Shiu PK	2000	The genetics of hyphal fusion and vegetative incompatibility in filamentous ascomycete fungi.	<i>Ann Rev Genet</i>	34: 165–186
Thaning C	2000	Ways of managing <i>Sclerotinia sclerotiorum</i> inoculum	<i>Acta Univ Agric Sueciae Agraria</i>	124 p.
Erental A, Dickman	2008	Sclerotial development in	<i>Fungal Biol Rev</i>	22: 6-16

MB and Yarden O		<i>Sclerotinia sclerotiorum</i> : awakening molecular analysis of a “Dormant” structure		
Gladdens P, Ginsburg D and Smith JA	2008	Sclerotinia in oilseed rape - a review of the 2007 epidemic in England	<i>HGCA Project Rep</i>	433: 44
Singh R, Singh D, Li H, Sivasithamparam S, Yadav NR, Salisbury P and Barbetti MJ	2008	Management of Sclerotinia rot of oilseed Brassicas—a focus on India	<i>J Oilseed Res</i>	10: 1–27
Saharan GS and Mehta Naresh	2008	Sclerotinia diseases of crop plants: Biology, ecology and disease management	Springer Science, The Netherlands	485 p.
Sharma Pankaj, Meena PD, Verma PR, Saharan GS, Mehta Naresh, Singh Dhiraj and Kumar A	2014	<i>Sclerotinia sclerotiorum</i> (Lib) de Bary causing Sclerotinia rot in oilseed <i>Brassicac</i> : A review	<i>J Oilseed Brassica</i>	6(S) 1-44p.

during different decades in three centuries are presented in figure 1. Obviously, there was a very slow progress of SR research during the last decade of the 19th century. During the 20th century, rapid progress was made in SR research from 6th to 10th decade. A total of 23 publications were published in the 6th decade which increased to 31 in 7th, 153 in 8th, 224 in 9th, and 276 in the 10th decade. During the 21st century, 412 publications were recorded in the first decade. During the present century more progress is expected because more than 246 papers had already been published from 2010-2014 (Table 2).

Major research areas identified and emphasized

Since its first report in 1837, more than 15 major research areas have been identified and emphasized by the SR researchers during three centuries. Results in Table 3 clearly indicate that maximum attention of scientists has been on 15 major research areas including symptoms, losses, distribution, incidence, survival and ecology (70), mycelium, histopathology, inoculum and morphology (50),

infection, pathogenesis and inoculation (73), sclerotia (117), apothecia and ascospore (108), epidemiology and forecasting (63), morphological variability, genetic diversity and mycelial compatibility group (MCG) (67), enzymes, toxins and biochemistry (116), screening and resistance (139), genetics and molecular aspects (69), detection techniques (21), general disease management (94), chemical control (122) followed by mycoparasitism and bio-control (185) and other studies on *S. sclerotiorum* (95). These aspects have been described detail in a recent review on SR by Sharma *et al.*, (2014b) and in a book by Saharan and Mehta (2008).

Publication of historical significance

Each year, although several publications are being published on SR in the form of research papers, reviews, book chapters, scientific popular articles, conference proceedings, abstracts of group meetings, workshops, adhoc research scheme reports, key note addresses, and circulars for farmers, all have not been considered worth quoting in this publications of the twenty three

Table 2: Decade-wise research progress during 20th and 21st century

Decade wise	No. of publications	% publications
1900-1909	1	0.07
1910-1919	-	-
1920-1929	3	0.21
1930-1939	4	0.28
1940-1949	10	0.72
1950-1959	23	1.66
1960-1969	31	2.24
1970-1979	153	11.06
1980-1989	224	16.19
1990-1999	276	19.95
2000-2009	412	29.79
2010-2014	246	17.78
Total	1383	

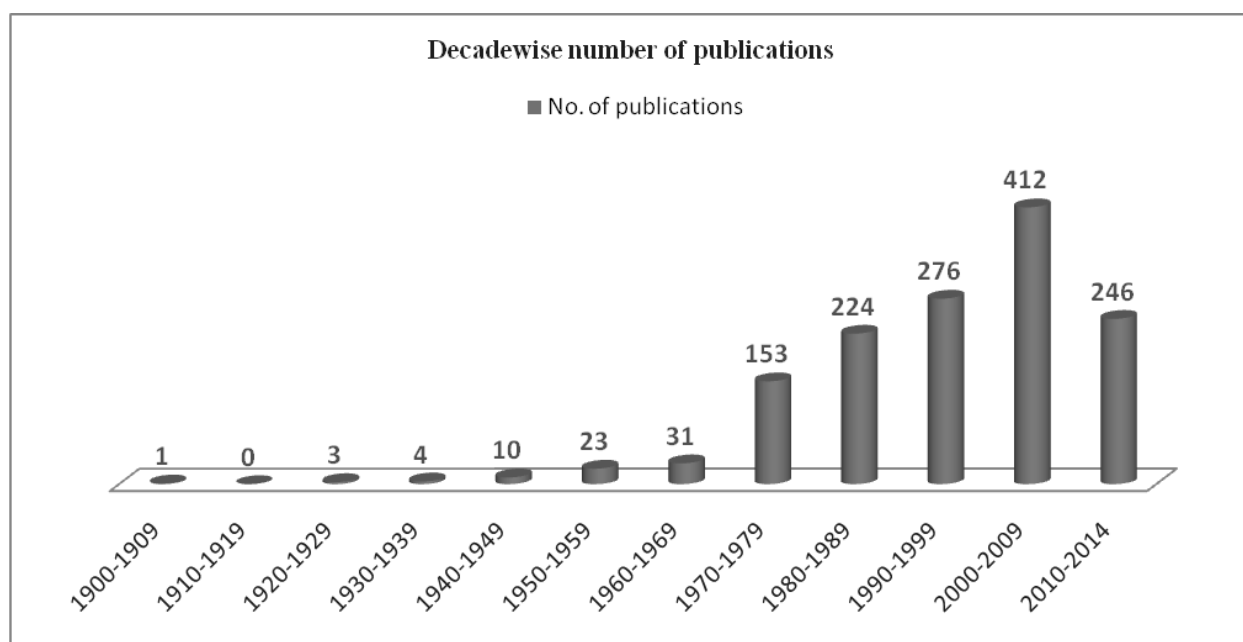


Figure1: Number of research papers published in different decades.

major publications listed in Table 1, 3 were monographs on genus *S. sclerotiorum*, 22 were review papers on fungal melanin, sclerotial development, epidemics, disease assessment and disease management, one bibliography, and six books on *Sclerotinia* and related aspects including the book authored by de Bary. Out of 1389 publications reported so far, some are of classical, conceptual, fundamental, applied, and scientific nature which

have helped greatly in SR research developments and comprehension in the following major areas:

Disease symptoms, losses, distribution, incidence, survival ecology and reports of *Sclerotinia sclerotiorum*: (Aghajani *et al.*, 2008; Aggarwal *et al.*, 1997; Adams and Ayers, 1979; Anonymous, 2005a,b; Alizadeh *et al.*, 2006; Barari *et al.*, 2000; Chattopadhyay *et al.*, 2005;

Table 3: Major research areas emphasized

S.No.	Major research area	No. of publications	% publications
1.	Disease symptoms, losses, distribution, incidence, survival ecology and reports of <i>Sclerotinia sclerotiorum</i>	70	5.03
2.	Mycelium, histopathology, inoculum and morphology of <i>S. sclerotiorum</i>	50	3.59
3.	Infection, pathogenesis and inoculation of <i>S. sclerotiorum</i>	73	5.25
4.	Sclerotia of <i>S. sclerotiorum</i>	117	8.42
5.	Apothecia and ascospore of <i>S. sclerotiorum</i>	108	7.77
6.	Epidemiology and forecasting of <i>S. sclerotiorum</i>	63	4.53
7.	Morphological variability, genetic diversity and MCG of <i>S. sclerotiorum</i>	67	4.82
8.	Enzymes, toxins and biochemistry of <i>S. sclerotiorum</i>	116	8.35
9.	Screening and resistance to <i>S. sclerotiorum</i>	139	10.0
10.	Genetics and molecular aspects of <i>S. sclerotiorum</i>	69	4.96
11.	Detection techniques	21	1.51
12.	Management of <i>S. sclerotiorum</i>	94	6.76
13.	Chemical control of <i>S. sclerotiorum</i>	122	8.78
14.	Mycoparasitism and bio-control of <i>S. sclerotiorum</i>	185	13.31
15.	<i>S. sclerotiorum</i> : a study	95	6.83
Total		1389	

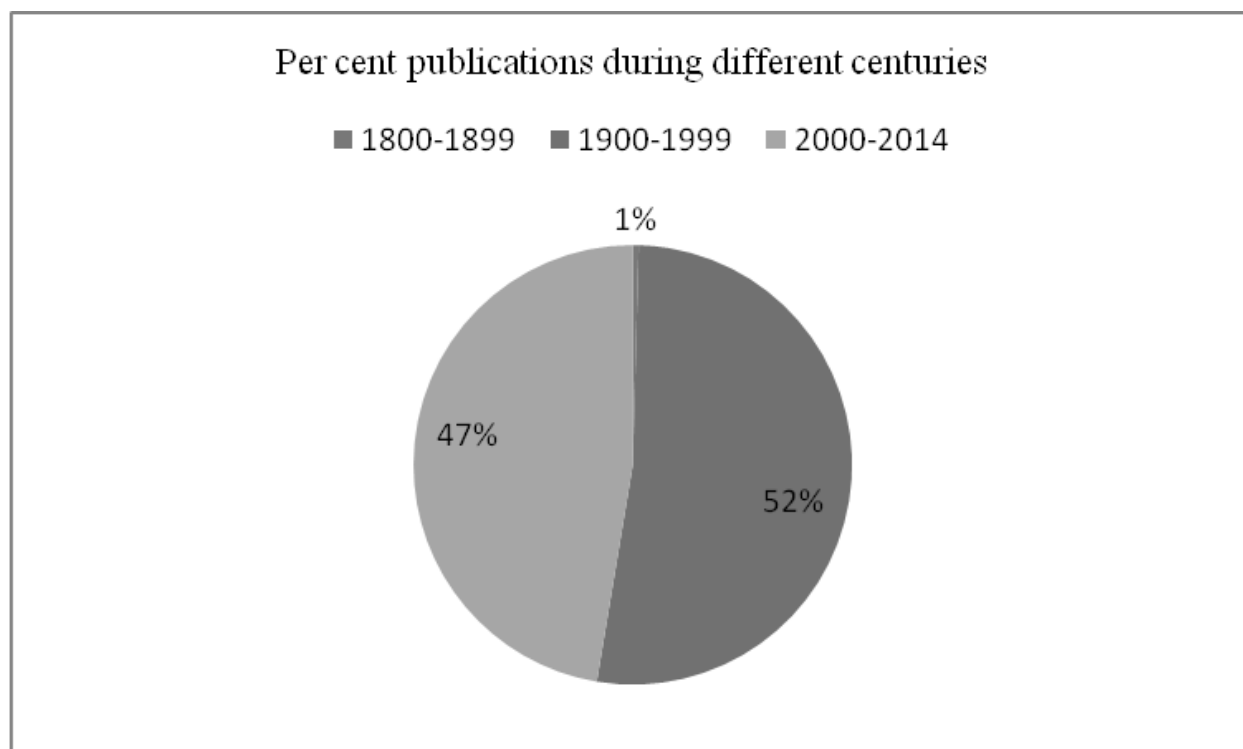


Figure 2 : Percentage of research papers published in different centuries

Chaudhury, 1993; Chauhan *et al.*, 1992; Chen and Wu 1990; del R y'o *et al.*, 2007; Dueck and Sedun, 1983; Dunker and Tiedemann, 2004; Ekins *et al.*, 2002; Franke and Hindorf, 1983; Grogan and Abawi, 1975; Hims, 1979a; Hind-Lanoiselet *et al.*, 2005; Huang and Kozub, 1993; Ilum e *et al.*, 2007; Isakeit *et al.*, 2010; Keay, 1939; Kirkegaard *et al.*, 2006; Kohli, 1992; Kohn, 1979; Kruger, 1976a; Lamey *et al.*, 1998; Liu and Sun, 1984; Minuto *et al.*, 2005; Morrall and Dueck, 1983; Nordin and Svensson, 1987; Ono and Kouno, 2007; Poslu n  *et al.*, 2013; Roy, 1973; Sansford, 1998; Saxena and Rai, 1987; Sharma, 2014; Sharma and Sharma, 2001; Shimada *et al.*, 2006; Shrestha, 1986; Shukla, 2005b; Singh and Singh, 1986; Takeuchi and Horie, 1996; Tziros *et al.*, 2008; Verma and Morrall, 1984; Verma, 1982c; Yadav *et al.*, 2013; Yang, 1959; Young *et al.*, 2012; Zizzerini and Tosi, 1985).

Mycelium, histopathology, inoculum and morphology of *S. sclerotiorum*: (Abawi and Grogan, 1975; Adams and Tate, 1976; Calonge, 1970; Carbone *et al.*, 1995; Christias and Lockwood, 1973; de Bary, 1887; Ghasolia and Shivpuri, 2009; Goswami *et al.*, 2012; Gugel and Morrall, 1986; Henson *et al.*, 1999; Humpherson-Jones and Cook, 1977b,c; Jones *et al.*, 1974; Jones, 1970; Kohli and Kohn, 1996; Kohn, 1995; Kohli *et al.*, 1995; Kohn *et al.*, 1990; Le Tourneau, 1979; Lumsden, 1979; Morrall *et al.*, 1972; Nagy and Fischl, 2002; Qandah and Mendoza, 2012; Purdy, 1979; Saito, 1974b; Steadman *et al.*, 1994; Sumida *et al.*, 2014; Tariq and Jeffries, 1984; Vakilizarj *et al.*, 2013; Wong and Willetts, 1975, 1979; Wu *et al.*, 2008; Ziman *et al.*, 1998; Ziman, 1997).

Infection, pathogenesis and inoculation of *S. sclerotiorum*: (Adams and Ayers, 1983; Baghbanimehmandar *et al.*, 2006; Bashi *et al.*, 2012; Brun and Renard, 1983; Calistru *et al.*, 2013a; Choudhary *et al.*, 2012; Du *et al.*, 2008; Franceschini *et al.*, 1990; Frenkel *et al.*, 1998; Garg *et al.*, 2010b,c; Gerlagh *et al.*, 2003; Held and Haenseler, 1953; Heran *et al.*, 1999; Huang and Hoes, 1976; Huang *et al.*, 1998; Hung *et al.*, 1998; Jammaux *et al.*, 1995; Jiang, 2001; Jones, 1976; Kapoor, 1983; Kreitlow and Sprague, 1951; Li *et al.*, 2007; Li *et al.*, 2008; Li *et al.*, 2005; Liu, 1996; McLean, 1958; McCartney *et al.*,

2001a; McLaren *et al.*, 1987; McLaren *et al.*, 1989; McQuilken *et al.*, 1994; Neergaard, 1958; Ni *et al.*, 2014; Newton *et al.*, 1973; Nie *et al.*, 2010; Pandey *et al.*, 2013; Pierre *et al.*, 1992; Poussereau *et al.*, 2001a,b; Price and Calhoun, 1975a; Purdy, 1958; Rahmanpour *et al.*, 2010, 2011; Rollins, 2003; Scheibert-Bohm *et al.*, 1981; Sharma and Meena, 2013; Shi *et al.*, 2013; Singh and Tripathi, 1993; Singh *et al.*, 1994a; Singh and Singh, 1979; Starzycka and Starzycki, 1997; Thompson and Kondra, 1983; Wang and Tang, 2013; Young and Werner, 2012; Young *et al.*, 2007; Zang *et al.*, 2010).

Sclerotia of *S. sclerotiorum*: (Adams, 1979; Alexander and Stewart, 1994; Anas and Reeleder, 1987; Bacon *et al.*, 1972; Bajoriya *et al.*, 2009; Bakr and Grewal, 1988; Bakr, 1989; Bell and Wheeler, 1986; Blum *et al.*, 2002; B rner, 1985; Butler *et al.*, 2009; Calotelo, 1974; Chen and Dickman, 2005; Chen *et al.*, 2004; Chet and Henis, 1975; Coley-Smith and Cooke, 1971; Colotelo, 1973, 1974; Diamantopoulou *et al.*, 2000; Dillard *et al.*, 1995; Dimopoulou, 1975; Dittmer and Weltzien, 1990; Duan *et al.*, 2013b; Dueck *et al.*, 1981; Duncan *et al.*, 2006; Erental *et al.*, 2008; Ervio *et al.*, 1964; Ethur *et al.*, 2014; Finck and Bome, 1985; Finck, 1989; Fravel *et al.*, 2002; Garcia *et al.*, 2012; G rriz *et al.*, 2008; Hao *et al.*, 1998; Harada *et al.*, 1974; Harel *et al.*, 2005; Harvey *et al.*, 1995; Hedke and Tiedemann, 1998; Honey, 1928; Huang and Kozub, 1991, 1993, 1994; Huang *et al.*, 1993, 1998; Huang, 1981, 1982; Humpherson-Jones and Cook, 1977; Ivancia, 1992; Kakoti and Saikia, 1997; Khare and Bompeix, 1979; Kim, 1976; Lazarovits *et al.*, 2000; Leiner and Winton, 2006; LeTourneau, 1966, 1976; Litkei and V r s, 1984; Liu and Paul, 2007; Luo *et al.*, 1987; Makkonen and Pohjakallio, 1960; Marukawa and Satamura, 1977; Marukawa *et al.*, 1975a; Melouk *et al.*, 1989; Merriman, 1976; Morrall *et al.*, 1978; Morrall, 1977; Mosa *et al.*, 2000; Nisikado and Hirata, 1937; Pottinger *et al.*, 2008; Prasad and Deb, 1988; Rai and Dhawan, 1978; Russo and Van Etten, 1985; Russo *et al.*, 1982; Saito, 1969, 1974a, 1977; Sansford and Coley-Smith, 1992; Schuhmann, 1975; Sharma *et al.*, 2010; Singh *et al.*, 1995; Singh *et al.*, 1985; Smith and Boland, 1989; Vaughan and Jones, 1979; Wang and LeTourneau, 1972; Weete *et al.*, 1970; Willetts and Bullock, 1992; Zhang *et al.*, 2004).

Apothecia and ascospore of *S. sclerotiorum*:

(Achbani *et al.*, 1995; Atkins *et al.*, 2013; Bedi, 1958,1962,1963a,b; Ben-Yephet and Bitton, 1985; Börner,1987; Bourdôt *et al.*, 2001; Bremer *et al.*, 1999; Caesar and Pearson,1983; Casale and Hart,1986; Cerkauskas *et al.*, 1983,1985; Chen *et al.*, 2006; Christiansen, 1966; Clarkson *et al.*, 2003; Codron,1974; Cui *et al.*, 2000; Dickson and Fisher,1923; Duniway *et al.*, 1977; Feng and Thaning, 2001; Garg *et al.*, 2010; Harthill and Underhill, 1976; Henderson,1962a; Henson, 1940; Hirst, 1959; Huang and Erickson, 2004; Huang and Kozub,1989; Hunter *et al.*, 1982; Ingold, 1960,1971; Jayachandran *et al.*, 1987; Jones, 1974; Jones *et al.*, 2004; Kapoor *et al.*, 1987; Kapoor, 1994; Köpmans, 1993; Korf and Willetts, 1975; Kosasih and Willetts, 1975; Krüger, 1975a,1976b,1980a; Lefol and Morrall, 1996; Lefol, 1998; Letham, 1975; Li *et al.*, 1999a; McCartney and Lacey, 1992; McCartney *et al.*, 1999; McLean,1958a; Mila and Yang, 2008; Mitchell and Wheeler, 1990; Mylehrest and Wheeler, 1987; Neto, 1955; Newton and Sequeira, 1972; Olivier and Séguin-Swartz, 2006; Penaud *et al.*, 2012; Phillips, 1987; Purdy, 1956; Qandah and del Rio Mendoza, 2011; Radulescu and Crisan,1961; Ratkos, 1982; Reis *et al.*, 2011; Saito, 1973; Schwartz and Steadman, 1978; Sharma and Meena, 2011; Silva *et al.*, 2011; Singh and Singh, 1984; Singh *et al.*, 1995b; Singh and Tripathi, 1996; Singh and Singh, 1987; Singh *et al.*, 1991; Singh and Singh,1983; Steadman and Cook, 1974; Stelfox *et al.*, 1978; Tapke, 1946; Teo and Morrall, 1985a,b; Teo *et al.*, 1985; Terui and Harada,1966; Thaning and Nilsson, 2000; Twengstrom *et al.*, 1998b; Venette *et al.*, 1999; Venturoso *et al.*, 2014; Wang *et al.*, 1996; West *et al.*, 2008; Williams and Stelfox, 1979,1980a,b; Williams *et al.*, 2001; Wu and Subbarao, 2008; Wu *et al.*, 2007).

Epidemiology and forecasting of *S. sclerotiorum*:

(Abawi and Grogan,1979; Aghajani *et al.*, 2010; Ahlers, 1986; AICRP-RM, 2009; Boland and Hall, 1987; Bom and Boland, 2000a,b; Buchwald, 1986; Davies *et al.*,1999; Gindrat *et al.*, 2003; Gladdens *et al.*,1991, 2008; Gohari and Ballester, 1991; Gugel and Verma, 1986; Horning, 1983; Huang *et al.*,1998; Ivic', 2008; Jajor *et al.*, 2010; Koch *et al.*, 2006, 2007; Krüger, 1974,1975b,1987; McCartney *et al.*,

2001b; McDonald and Boland, 2004; McLaren *et al.*, 2004; Mehta, 2014; Milinko *et al.*, 1989; Morrall and Dueck, 1982; Nordin, 1988; Nordin *et al.*, 1992; Sharma *et al.*, 2009b, 2010; Sigvald *et al.*, 1991; Singh and Tripathi, 1998; Singh *et al.*, 2000; Singh and Agrawat,1989; Sun *et al.*, 2010; Torrington *et al.*, 1991; Turkington, 1991; Turkington and Morrall, 1993; Turkington *et al.*, 1988,1991a,b; Turner *et al.*, 2002; Twengström and Sigvald, 1993; Twengstrom *et al.*, 1988a; Twengström, 1996,1999; West *et al.*, 2013; Zhang *et al.*, 1999).

Morphological variability, genetic diversity and

MCG of *S. sclerotiorum*: (Anderson and Kohn, 1995; Arbaoui *et al.*, 2008; Atallah *et al.*, 2004; Attanayake *et al.*, 2012,2013; Barari *et al.*,2008, 2010a,b,2011,2012,2014; Barbetti *et al.*, 2014; Basha and Chatterjee, 2007; Boland and Smith, 1991; Carpenter *et al.*, 1999; Chen *et al.*, 2010; Choudhary and Prasad, 2012; Clarkson *et al.*, 2009; Colagar *et al.*, 2010; DRMR, 2009-10,2010-11; Durman *et al.*, 2001,2003; Ford *et al.*, 1999; Ghasolia and Shivpuri, 2007; Glass and Kuldau, 1992; Glass *et al.*, 2000; Goyal *et al.*, 2013; Irani *et al.*, 2011; Irzykowski *et al.*, 2005; Karimi *et al.*, 2011,2012a,b; Kohn *et al.*, 1991; Kohn, 2001; Kull *et al.*, 2000,2004; Leslie, 1993; Li *et al.*, 2000; Ling *et al.*, 2011; Litholdo *et al.*, 2011; Liu *et al.*, 2006; Meinhardt *et al.*, 2002; Mert-Türk *et al.*, 2007; Noonan *et al.*, 1996; Ojaghian and Xie, 2012; Osofee *et al.*, 2005; Price and Colhoun,1975; Purdy,1955; Schafer and Kohn, 2006; Sedun *et al.*,1989; Sexton and Howlett , 2004; Sexton *et al.*, 2006b; Sharma *et al.*, 2009c,2013a; Steadman *et al.*,1998; Sun *et al.*, 2005; Vakilizarj and Rahnama, 2009; Wong and Willetts, 1975; Zandoki *et al.*,2005a,b).

Enzymes, toxins and biochemistry of

***S. sclerotiorum*:** (Bashi *et al.*, 2010,2013; Bateman and Beer,1965; Cessna *et al.*,2000; Chen *et al.*,2010; Collmer and Keen, 1986; Corsini and Le Tourneau, 1973; Cotton *et al.*, 2002,2003; Cruikshank, 1983; Culbertson *et al.*, 2007; Deena and Kohn, 1995; Dhawan and Srivastava, 1987; Dhawan, 1980a,b,1983; Dixit *et al.*,2012; Dong *et al.*,2008; Duan *et al.*,2014; Durman *et al.*,2005; Dutton and Evans,1996; Echandi and Walker, 1957; Errampalli and Kohn, 1995; Foster *et al.*,2012; Fraiset-Tachet

and Fevre, 1995, 1996 ; Girard *et al.*,2004; Guo and Stotz, 2010; Guimarães and Stotz, 2004; Harel *et al.*,2006; Hegedus *et al.*,2008; Heller and Witt-Geiges,2013; Huang, 1983b; Huang and Yeung, 2002; Huang *et al.*,2008; Kachroo and Kachroo, 2007; Keets *et al.*,1998; Khare and Bompeix, 1976; Kim *et al.*,2008; Kohn and Korf, 1975; Kolattukudy, 1985; Li *et al.*,1999 a,b,2001,2003,2004, 2004 a; 2008; Liu *et al.*,1997,1998, 2010; Lung *et al.*,1994; Magro *et al.*,1984; Marciano *et al.*,1982; Martel *et al.*,2002; Maxwell, 1973; Overell, 1952; Pedras and Ahiahonu, 2004; Pedras *et al.*,2004, 2010; Penn and Daniel, 2013; Qi *et al.*,2004; Rachim and Nicholas, 1985; Rahmanpour *et al.*,2014; Rai and Dhawan, 1976a,b; Rai *et al.*,1979; Riou *et al.*,1979,1992; Rollins and Dickman, 1998,2001; Rowe, 1993; Sharma *et al.*,2001; Sharma *et al.*,2014b; Starratt *et al.*,2002; Starzycka and Starzycki, 2011; Starzycka *et al.*,2002; Stephen *et al.*,2000; Tariq and Jeffries, 1987; Tariq *et al.*,1985; Thompson *et al.*,1995; Trevethick and Cooke, 1971; Van den Berg and Yang, 1969; Vautard-Mey *et al.*,1999; Vega *et al.*,1970; Waksman *et al.*,1991; Walz *et al.*,2008; Waksman, 1988; Wang and Tourneau, 1973; Watpade and Mehta, 2012,2013; Williams *et al.*,2011; Wong and Willetts,1974; Wu *et al.*,2004; Xu *et al.*,2011; Yadav *et al.*,2012; Yarden *et al.*,2014; Yu *et al.*,1999a,b; Zhang *et al.*,2001; Zhao *et al.*,2006; Zou *et al.*,2006).

Screening and resistance to *S. sclerotiorum*:

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Moinard *et al.*,2009; Morrall and Verma, 1987,1988; Morrall *et al.*,1983,1984a,b,1985,1989; Naito and Tani, 1952; Pan *et al.*1997a,b,2000; Pan, 1998; Paul and Beineke, 1993; Pelmus *et al.*,1988; Penaud *et al.*,2013; Qi *et al.*, 2011; Qin *et al.*,2011; Ren *et al.*,2010; Ritchie *et al.*,2013; Sharma and Kapoor, 1998; Sharma *et al.*,2011; Shen, 1992; Shi *et al.*,2000a,b; Shivpuri and Gupta, 2001; Singh and Kapoor, 1996; Singh *et al.*,1994b,2003; Singh, 1998; Spitzer *et al.*,2012; Stiers *et al.*,1980; Terhardt and Johnen, 2012; Thompson *et al.*,1984; Thwin and Mitchell, 1990; Tripathi *et al.*,2010; Twengström, 1996; Verma and McKenzie, 1982; Verma and Morrall, 1987; Verma *et al.*,1983,1985,1986,1987; Verma, 1984; Vozenilková and Sbornik,1996; Wang *et al.*,2009; Xie *et al.*,1999; Yarden *et al.*,1986; Zewain *et al.*,2004).

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Table 4: Leading institutions involved in research on *Sclerotinia sclerotiorum* of oilseed Brassica in the world

S.N.	Name of Institute	Country
1.	Cátedra de Microbiología Agrícola/INBA (CONICET/UBA), Universidad de Buenos Aires, Buenos Aires	Argentina
2.	Universidad Nacional del Sur, 8000 Bahía Blanca	Argentina
3.	University of New England, Armidale	Australia
4.	The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009	Australia
5.	Charles Sturt University, Wagga Wagga, NSW 2678	Australia
6.	ISK Biosciences Europe N.V., Diegem	Belgium
7.	Universidade Federal de Viçosa, 36570-000, Viçosa, MG	Brazil
8.	Universidade Federal da Grande Dourados, UFGD, Dourados, MS	Brazil
9.	Universidade Federal de Goiás-UFG, Goiânia, GO	Brazil
10.	Universidade Estadual de Ponta Grossa	Brazil
11.	Agriculture and Agri-Food Canada, 107 Science Place, Saskatoon, SK S7N 0X2	Canada
12.	Agriculture and Agri-Food Canada, Lethbridge Research Centre, 5403-1st Ave. S, PO Box 3000, Lethbridge, Alberta T1J 4B1	Canada
13.	University of Alberta, Edmonton, AB T6G 2P5	Canada
14.	University of Saskatchewan, 110 Science Place, Saskatoon, SK S7N 5C9	Canada
15.	University of Manitoba, Winnipeg, MB R3T 2N2	Canada
16.	Agriculture and Agri-Food Canada, P.O. Box 1240, Melfort, Saskatchewan, S0E 1A0	Canada
17.	University of Guelph, Guelph, ON N1G 2W1	Canada
18.	Nanjing Agricultural University, Nanjing 210095	China
19.	Southwest University, Chongqing 400716	China
20.	Huazhong Agricultural University, Wuhan 430070	China
21.	Nanjing Agricultural University, Nanjing 210095	China
22.	The Oil Crops Institute/National Oil Crops Improvement Center, Changsha, Hunan, 410128	China

23. Oil Crops Research Institute, Chinese Academy of Agricultural Sciences, Wuhan 430062 China
24. Guizhou Institute of Oil Crops, Guiyang, Guizhou 550006 China
25. Anhui Agricultural University, Hefei 230036 China
26. South China Normal University, Guangzhou 510631 China
27. Northwest A & F University, Yangling, Shaanxi 712100 China
28. Longyan University, Longyan 364000 China
29. Jiangsu University, Zhenjiang 212013 China
30. Yangzhou University, Yangzhou 225009 China
31. Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian 116023 China
32. Yangtze University, Jingzhou, Hubei Province 434025 China
33. Zhenjiang Institute of Agricultural Science in Hilly Area of Jiangsu Province, Jurong 212400 China
34. Longyan University, Longyan, Fujian 364000 China
35. Zhejiang University, Hangzhou 310058 China
36. Shanghai Normal University, Shanghai 200234 China
37. Crops Research Institute, Jiangxi Academy of Agricultural Sciences, Nanchang 330200 China
38. Zhejiang University of Technology, 18# Chaowang Road, Hangzhou 310032 China
39. National Research Center of Rapeseed Engineering and Technology, Huazhong Agricultural University, Wuhan 430070 China
40. Zhengzhou University, Zhengzhou 450001 China
41. Industrial Crops Research Institute, Henan Academy of Agricultural Sciences, Zhengzhou 450002 China
42. Hunan Agricultural University, Changsha 410128 China
43. Agricultural Sciences Research Institute of Yichun City, Jiangxi Province, Yichun 336000 China
44. Institute of Crop Sciences, Chinese Academy of Agricultural Sciences, Beijing 100081 China
45. Sichuan University, Chengdu 610064 China
46. Poljoprivredni fakultet u Osijeku, Kralja Petra Svaëić'a 1d, 31000 Osijek Croatia
47. Department of Phytopathology, Svetošimunska 25, 10000 Zagreb Croatia
48. Academy of Sciences of the Czech Republic, Rozvojová 313, 165 02 Prague Czech Republic
49. Agrotest fyto, Ltd. s.r.o., Havlíèkova 2787/121, 767 01 Kromeríz Czech Republic
50. Svaz pestitelu a zpracovatelu olejnin, Na Fabiánce 146, 182 00 Praha 8 Czech Republic
51. Afd. for Plantepatologi Planteværnscentret, Lottenborgvej 2, 2800 Lyngby Denmark
52. CETIOM, Direction Technique - Pathologie végétale, Campus de Grignon, Av. L. Brétignières, FR - 78850 Thiverval-Grignon France
53. DuPont Solutions, Défense Plaza, 23/25 rue Delarivière Lefoullon, F-92800 Puteaux France
54. DRAAF-SRAL Midi-Pyrénées, Bd Armand Duportal, 31074 Toulouse Cedex France
55. Unité de Phytotechnologie, Sanofi Recherche, Centre de Labège, F-31676 Labège Cedex France
56. BASF Agro SAS, 21 Chemin de la Sauvegarde, F-69134 Ecully Cedex France
57. INRA, UMR 211 INRA AgroParisTech, 78850 Thiverval-Grignon France
58. Georg-August-University of Göttingen, Grisebachstr 6, D-37077 Göttingen Germany
59. Dienstleistungszentrum Ländlicher Raum, Westerwald-Osteifel, Montabaur Germany
60. Prophyta GmbH, Inselstrasse 12, 23999 Malchow Germany
61. Feinchemie Schwebda GmbH, Eschwege Germany
62. Du Pont de Nemours (Deutschland) GmbH, Neu-Isenburg Germany
63. Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, Freiberg Germany

64. Christian-Albrechts-Universität of Kiel, Hermann, Rodewald Str. 9, D-24118 Kiel Germany
65. Julius Kühn-Institut, Braunschweig Germany
66. Inst. Pflanzenbau Pflanzenzucht, Giessen Germany
67. Universität-GH-Paderborn, Labor für Biotechnologie und Qualitätssicherung, Lübecker Ring 2, D-59494 Soest Germany
68. National Institute for Agricultural Quality Control, Budapest Hungary
69. ICAR-Directorate of Rapeseed-Mustard Research (ICAR),Sewar, Bharatpur 321 303 India
70. ICAR-Indian Agricultural Research Institute, Pusa, New Delhi 110 012 India
71. CCS Haryana Agricultural University, Hisar - 125 004 India
72. Sardar Vallabhbhai Patel University of Agriculture & Technology, Modipuram, Meerut 250 110 India
73. GB Pant University of Agriculture and Technology, Pantnagar 263 145 India
74. ICAR-National Centre for Integrated Pest Management, Pusa Campus, New Delhi 110 012 India
75. Gurukul Kangri University, Haridwar, 249 404 India
76. SK Rajasthan Agricultural University, Sriganganagar 335 001 India
77. CSA University of Agriculture and Technology, Kanpur 208 002 India
78. Rajendra Agricultural University Dholi, Muzaffarpur 848125 India
79. SKN Agriculture University,Jobner, Jaipur 302 029 India
80. ND University of Agri. & Tech., Kumarganj, Faizabad 224 229 India
81. Assam Agricultural University, Shillongani, Assam 782 001 India
82. Banaras Hindu University, Varanasi 221 005 India
83. CSK Himachal Pradesh krishi Vishwavidyalaya, Kangra, Palampur 176 001 India
84. Indira Gandhi Agricultural University, Jagdalpur 494 005 India
85. Pulses and oilseeds Research Station, Berhampore 742 101 India
86. RVRS Agricultural University, Morena 476 001 India
87. University of Delhi, South campus, New Delhi 110 021 India
88. Uttar Banga Krishi Viswavidyalaya Majhian, Patiram, Dakshin Dinajpur733 133 India
89. Punjab Agricultural University, Ludhiana 141 004 India
90. Urmia University, Urmia Iran
91. Islamic Azad University, Tehran Iran
92. University of Tehran, Karaj, Tehran Iran
93. Agricultural and Natural Resources University of Sari, Mazandaran Iran
94. University of Zanjan, Zanjan Iran
95. Gorgan Univ. of Agricultural Sciences and Natural Resources, Gorgan Iran
96. Iranian Research Institute of Plant Protection, Tehran Iran
97. National Institute of Genetic Engineering and Biotechnology, P.O. Box 14965/161, Tehran Iran
98. Tarbiat Modares University, Tehran Iran
99. University of Mazandaran, Babolsar, 47416-95447 Iran
100. University College, Cork, Irish Republic
101. Hebrew University, Jerusalem, Rehovot 76100, Israel
102. CRA CAT, Unità di ricerca per le Colture Alternative al Tabacco, via Vitiello 108, Scafati (SA) Italy
103. ENEA, Divisione Biotechnologie e Agricoltura, Centro Ricerche Trisaia, Rotondella (MT) Italy
104. Hirosaki University Japan
105. Tottori Daisen Agricultural Extension Service Station, 541-8 Daisen-cho, Saihaku-gun, Tottori 689-3303 Japan

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| 106. | Tokyo Metropolitan Agriculture and Forestry Research Center, Chichijima, Ogasawara-mura, Tokyo 100-2101 | Japan |
| 107. | Latvia University of Agriculture, Liela Street 2, Jelgava, LV 3001 | Latvia |
| 108. | Lithuanian University of Agriculture, Studentu 9, LT-53361 Akademija, Kaunas District | Lithuania |
| 109. | Lincoln University, Lincoln 7647 | New Zealand |
| 110. | Uniwersytet Przyrodniczy we Wroc ³ awiu, Katedra Ochrony Roœlin, Pl. Grunwaldzki 24A, 50-363 Wroc ³ aw | Poland |
| 111. | Instytut Genetyki Roœlin Polskiej Akademii Nauk w Poznaniu, Poznan | Poland |
| 112. | DuPont Poland Sp. z o.o., Postepu 17b, 02-676 Warszawa | Poland |
| 113. | Uniwersytet Warmin'sko-Mazurski w Olsztynie I Katedra Fitopatologii i Entomologii Prawochen'skiego 17, 10-720 Olsztyn | Poland |
| 114. | National Research Institute, Research Division in Poznan', ul. Strzeszyn'ska 36, 60-479 Poznan' | Poland |
| 115. | Stacja Doœwiadczalna Oceny Odmian, Kreczunowicza 13, 62-811 Koœcielna Wieœ | Poland |
| 116. | Instytut Ochrony Roœlin, Pan'stwowy Instytut Badawczy, Wladyslawa Wegorka 20, 60-318 Poznan' | Poland |
| 117. | Technical-Agricultural University, Bydgoszcz | Poland |
| 118. | University of Bucharest, 1-3 Portocalelor Alley, RO-060101 Bucharest 35 | Romania |
| 119. | University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Maras'ti Blvd., District 1, 011464 Bucharest | Romania |
| 120. | University of Agricultural Sciences and Veterinary Medicine of Ias'i, Ias'i | Romania |
| 121. | Banat's University of Agricultural Sciences and Veterinary Medicine, Timisoara, Aradului Street, No. 119, RO-300645 | Romania |
| 122. | Slovak Academy of Sciences, Nádrazná 52, SK-90028 Ivanka pri Dunaji | Slovakia |
| 123. | North-West University, Potchefstroom Campus, Private Bag X6001, Potchefstroom 2520 | South Africa |
| 124. | Stellenbosch University, Stellenbosch | South Africa |
| 125. | Department of Plant Biology, SLU, Box 7080, SE-750 07 Uppsala | Sweden |
| 126. | Agroscope RAC Changins, case postale 254, CH-1260 Nyon 1 | Switzerland |
| 127. | Mustafa Kemal University, 31034 Antakya-Hatay | Turkey |
| 128. | Central Science Laboratory, Sand Hutton, York, YO41 1LZ | UK |
| 129. | ADAS Boxworth, Boxworth, Cambridge, CB23 4NN | UK |
| 130. | NIAB TAG, Winchester, Hampshire S021 3NE | UK |
| 131. | Rothamsted Research, Harpenden, Herts AL5 2JQ | UK |
| 132. | ADAS Drayton, Defra Drayton, Alcester Rd., Stratford on Avon, Warwickshire CV37 9RQ | UK |
| 133. | Washington State University, Pullman, WA 99164 | USA |
| 134. | University of Florida, Quincy, Florida | USA |
| 135. | Monsanto Corporation, Spencer, IA 51301 | USA |
| 136. | North Dakota State University, Fargo, ND 58108 | USA |
| 137. | Texas A&M University, College Station, TX 77843 | USA |
| 138. | University of Georgia, Griffin Campus, Griffin, GA 30223 | USA |
| 139. | University of Alaska Fairbanks, Palmer, AK 99645 | USA |
| 140. | A DuPont Company, 7300 NW 62nd Avenue, P.O. Box 1004, Johnston, IA 50131 | USA |
| 141. | New York State Agricultural Experiment Station, 630 W. North St., Geneva, NY 14456 | USA |
| 142. | FONAIAP Experimental Station El Cuji, Barquisimeto | Venezuela |
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Future Thurst Areas of Research

S. sclerotiorum is a major challenge faced by plant pathologists. Management is difficult, inconsistent and uneconomical due to the presence of wide host range and long-term survival of the resting structures. Biotechnological methods viz., gene transfer, *Agrobacterium tumefaciens*-mediated transformation, protoplast culture, somatic hybridization and microplast techniques should be exploited for developing transgenic plants of crops with superior resistance to *Sclerotinia*. Several strategies including detoxification defense, activation and general inhibition have potential to engineer *Sclerotinia* resistance. It is essential to understand disease epidemic in variable environmental conditions. The integrated disease management strategy including cultural, chemical, biological and host resistance should be refined, retested and revalidated under changing environmental conditions. Most future research should be concentrated on the disease management and development of resistant/tolerant varieties as follows:

- i. Effect of weather on different stages of pathogen/ pathogenesis/ disease cycle.
- ii. Development of precise and quick diagnostic tools.
- iii. Monitoring of occurrence, distribution and severity of disease.
- iv. Analyses of host-pathogen-environment interaction for developing disease forecasting models.
- v. Development of simple and functional disease forecasting models.
- vi. Use of Information Technology (IT) to manage, storage, processing, analysis and presentation of data.
- vii. Dissemination of disease management technology.
- viii. Identification of multiple disease resistant sources.
- ix. Analysis of genetic diversity in populations of host and pathogen.

- x. Induced resistance and systemically acquired resistance (SAR).
- xi. Identification of disease tolerance and partial resistance genes.
- xii. Genetics of virulence and virulence spectrum.
- xiii. Best use of IPM and IDM technology.
- xiv. Coordination/cooperation/interaction with other researchers including plant breeders, statistician, soil scientist and institutions.

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