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Analysis of White Rust Research Progress Through Bibliography

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Introduction

An obligate biotrophic fungus *Albugo candida* (Pers. ex Hook.) O. Kuntze. causes white rust or white blister rust or staghead disease in more than 400 plant species belonging to 31 families from Brassicas, crucifers, vegetables and numerous weeds (Saharan and Verma, 1992; Saharan *et al*., 2014). The economic importance of the disease can be judged by the estimated losses in oil yielding crops from 1 to 90 per cent (Berkenkamp, 1972; Saharan and Lakra, 1988). According to the published literature, although, the disease is reported only from more than 50 countries, but considering the nature of the pathogen it is probably prevalent all over the world wherever vegetation is possible (Saharan *et al*., 2014). The genus *Albugo* was first reported by Gmelin in 1792, which was later placed in genus *Uredo* by Persoon, in 1801 and in genus *Cystopus* (*Aecidium*) by Leveilla in 1847. More than 50 *Albugo* species and several of their combinations, have been constructed (Wakefield, 1927; Biga, 1955; Choi and Priest, 1955; Thines and Spring, 2005). Recent studies on the aspects including pathogenicity, molecular, genetical, and phyllogeneticrelationship have revealed existence of *Albugo* in four distinct lineages. Accordingly, *Albugo* s.str. is pathogenic to Brassicaceae, *Albugo* s.l. is pathogenic to convolvulaceae, and two amended lineages, with eight new combinations, viz., Pustula and Wilsoniana, are pathogenic to Asteridae and Caryophylidae, respectively (Thines and Spring, 2005; Choi *et al*., 2006; 2007; 2011; Vogalmayr and Riethmuller, 2006; Thines *et al*., 2009).

In the first review on white rust entitled "white rusts: a review of economically important species", Saharan and Verma (Saharan and Verma, 1992; Table 1) cited 281 publications arranged the text in ten major and thirty subheadings, and reviewed all important research areas which had been researched upto that time. Four years after this review, Verma and Saharan also published the first bibliography on *Albugo* species entitled "*Albugo candida* (Pers. ex. Lev.) Kuntz. (white rust) on crucifers: introduction, bibliography, and subject index" with 584 research publications and subject index (Verma and Saharan, 1996; Table 1). Verma et al (Verma *et al*., 2014; Table 1), and Meena et al (Meena *et al*., 2014; Table 1) in their two recent extensive reviews provided detailed, upto date, and historical perspectives of white rust research conducted since the first report of genus *Albugo* in 1792 (Gmelin, 1792). After a gap of 23 years (1992-2014), since the first review on white rust in 1992, it was realized that the extensive research on white rust, reported in more than 1200 publications, need to be put-together in a book, and hence Saharan et al (Saharan *et al*., 2014; Table 1) have recently published a very comprehensive book entitled "white rust (*Albugo* species) in crucifers: biology, ecology and management". In this book, authors have cited 732 publications, arranged the text in 15 chapters with more than 80 sub-research-areas, and provided a very critical analysis of research progress on white rsut during the period of past 223 years (1792-2014).

The present bibliography on genus *Albugo* which includes 1215 scientific publications, we have very carefully and categorically analysed all aspects of research progress in the world during the period of past 223 years (1792- 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

Table 1. List of major reviews (monograph), bibliographies, and book published by the authors

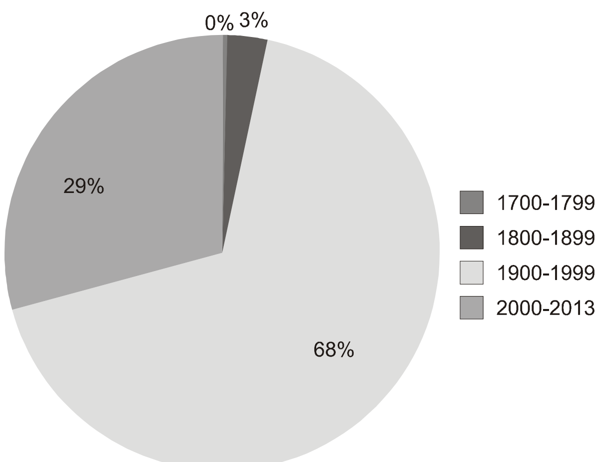
Authors	**Year of**	**Title Publication**	**Name of Journal/ Institutions**	**Vol. and page Number**	**Number of regerences cited**
G.S. Saharan and P.R. Verma	1992	White Rusts : A review of Economically Imported Species	International Developlent Research Centre (IDRC), OTTAWA, CANADA	IDRC-MR315e : 65 pages	281
P.R. Verma and G.S. Saharan	1996	Albugo Candido (Pers. Ex. Lev.) Kuntz. (White Rust) on Crucifers: Introduction, Bibliography and Subject Index	Agriculture and Agri-Food Canada Research Branch, Saskatoon Research Centre	Technical Bulletin 1996-01:69 pages	584
Dhiraj Singh, Ramesh Kumar, R.C. yadav, N.K. Thakral and Amit Singh	2003	Advances in white rsut (*Albugo candida*) resistance in oilseed Brassica	CCSHAU, Hisar	*Brassica* 5 : 12-24	131
P.D. Meena, P.R. Verma, G.S. Saharan and M.Hossein Borhan	2014	Historical Perspectives of White Rust caused by *Albugo candida* in Oilseed Brassicas	*Journal of Oilseed Brassica*	Accepted	313
P.R.Verma, G.S. Saharan and P.D. Meena	2014	*Albugo candida* – A Historical Perspective	Breeding and Management of Brassica Oilseed (eds) Arvind Kumar, S.S. Banga, P.D. Meena and P.R. Kumar. Common wealth Agriculture Bureau International, U.K.	Accepted	153
G.S. Saharan, P.R. Verma, P.D. Meena and Arvind Kumar	2014	White Rust (*Albugo* species) in Crucifers: Biology, cology and Management	Springer	Accepted	732
G.S. Saharan, P.R. Verma, P.D. Meena and M. Hossein Borhan	2014	Analysis of White Rust Research Through Bibliography	*Journal of Oilseed Brassica*	Accepted	1225

identify major research areas and leading research institutions. This, we hope will help both the present and future researchers in identifying important research publications, leading research institutions and researchers related to their choice aspects of research.

The progress of white rust (WR) research has been measured after scanning more than 1215 publications reported from 1792 to 2014. The results can be categorized as follows :

Century-wise research progress: Since its discovery in 1792, research on WR disease and its pathogen has a life span of four centuries. Obviously, only 8 years period was left in the 18th century and since there were many host-pathogen interactions were to be observed by the mycologists and pathologists, there were only a few reports published on this disease during this century. In the 19th century, 3 percent publications were recorded on WR (Fig. 1). Twenteeth centuary can be considered as a boom period for WR research since 68% papers were published during this centuary (Fig. 1). Within the first decade of the 21st centuary, 29 per cent publications were recorded on WR (Fig 1). Probable reseasons for rapid progress of WR research during 20th and 21st centuries seems 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 intrest, interaction of scientists, and development of new fields of biological sciences.

Figure 1 : Percentage of research papers published in different centuries



Decade-wise research progress: The numbers of research papers published WR during different decades in four centuries are presented in figure 2. Obviously, there was a very slow progress of WR research during the last decade of the 18th century. However, a steady progress was observed during the 19th century. During the 20th century, rapid progress was made in WR research from 6th to 10th decade. A total of 54 publications were published in the 6th decade which increased to 63 in 7th, 110 in 8th, 204 in 9th, and 275 in 10th decade. During the 21st century, 293 publications were recorded in the first decade. During the present century more progress is expected because more than 70 papers had already been published from 2010-2014 (Table 2). The reason for very slow research progress from 2nd to the 6th decade in all four centuries, however, is not clear; less than 55 papers were published during this period (Fig. 2).

Table 2. Decade-wise research progress during 20th and 21st centuary

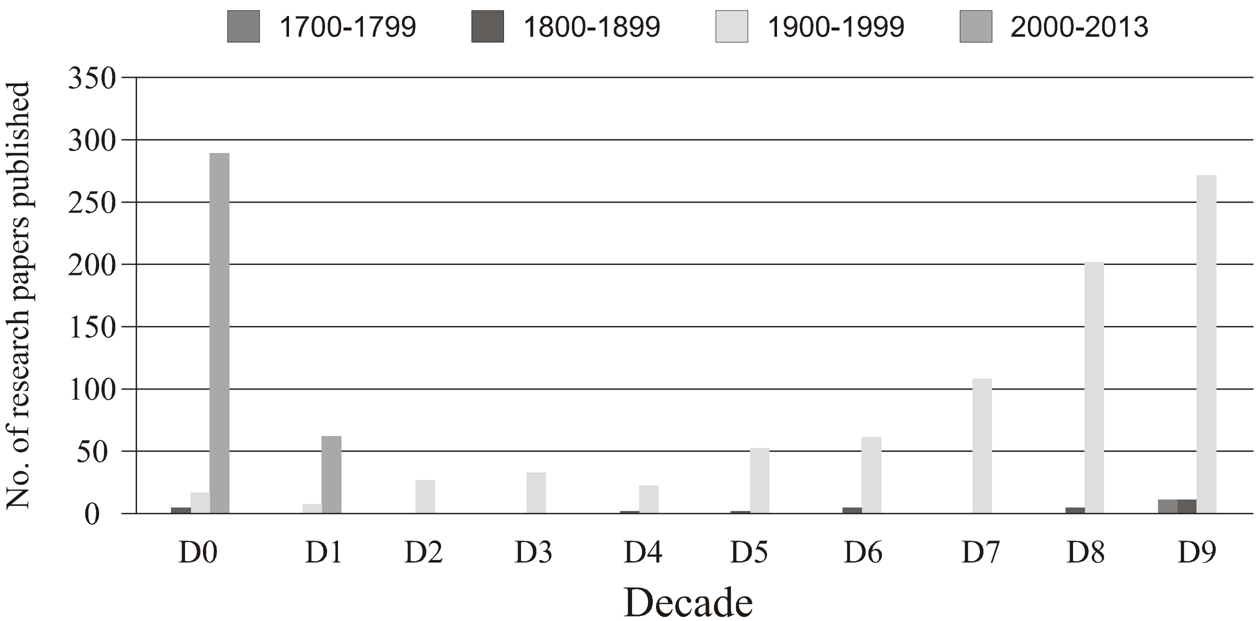
Decade	No. of publication	% publication
1900-1909	17	1.5
1910-1919	9	0.8
1920-1929	28	2.4
1930-1939	34	2.9
1940-1949	24	2.1
1950-1959	54	4.6
1960-1969	63	5.4
1970-1979	110	9.4
1980-1989	204	17.2
1990-1999	275	23.5
2000-2009	293	24.9
2010-2013	63	5.3
Total	**1182**	**100.0**

Decade-wise research progress during 20th and 21st centuary: In the 20th century, the 6th decade can be considered as take-off time for WR research, since more than 50 research papers were published during this 10 year period which increased to 275 papers in the 10th decade. 21st century is the boom period for WR research with 293 publications amounting to 25 per cent of the total publications. During the 20th century, the research progress from 2nd to the 6th decade was slow, but after the 7th decade the rate of progress increased consistently (Table 2).

Major research areas identified and emphasized:

After its first report in 1792, more than 80 research area had been identified and emphasized by the WR researchers during four centuries. Results in Table 3 clearly show that maximum attention of Scientists has been drawn on 21 aspects including symptomatology (92), oospores occurance, survival and germination (88), pathogen taxonomy and

Figure 2 : Number of research papers published in different decades in four centuries



morphology (81), host range (75), species of *Albugo* (66), disease assessment (64), biochemistry of host pathogen interaction (62), fungicidal tests (60), fungicidal control (57), inheritance of resistance (55), histopathology (54), yield losses (48), pathogen variability (42), plant defence resistance genes (42), host-pathogen interaction (39), geographical distribution (36), techniques (35), mechanism of resistance (33), sources of resistance (32), disease identification (30), and germplasm screening (30), followed by disease management (27), host diversity (22), mixed infection (22), phylogenetic relationaship (22), genetics of resistance (19), mapping of resistant genes (17), and cultural control methods (12). These aspects had been considered as major subjects in WR reviews (Saharan and Verma, 1992, Verma *et al*., 2014, Meena *et al*., 2014) and in a recently published book Saharan *et al*. (2014). Other research areas mentioned in Table 3 have been described as sub-headings.

Research areas including host diversity, disease forecasting, phylogenetic relationship, genetics of virulence, mapping of R-genes, fine structures, phytoalexins, biological control and *in-vitro* culture have gained seious attention of researchers during the 20th and 21st centuries.

Table 3: Major Research Areas Emphasized

Major Research Areas	No. of Publications	% Publication
Disease identification	30	2.5
Status	61	5.1
Host range	75	6.3
Geographical distribution	36	3.0
Host diversity	25	2.1
Symptomatology	1	0.1
Disease assessment	20	1.7
Yield loss	18	1.5
Association or mixed infection	22	1.8
Pathogenesis	6	0.5

Histopathology	10	0.8
Disease development/ epidemiology	52	4.4
Disease forecasting	5	0.4
Pathogen taxonomy and morphology	81	6.8
Species of *Albugo*	66	5.5
Physiologic specialization/ pathogenic variability	42	3.5
Phylogenetic relationship	22	1.8
Structures and reproduction	7	0.6
Mycelium and haustoria	3	0.3
Sporangiophore and sporangia	3	0.3
Zoospores	6	0.5
Gametogenesis, fertilization and oospore formation	9	0.8
Oospores	10	0.8
Life cycle of pathogen	2	0.2
Disease cycle		0.0
Survival		0.0
Spore germination	12	1.0
Infection	8	0.7
Host-pathogen interaction	14	1.2
Genetics of host-parasite interaction	13	1.1
Molecular mechanism of host pathogen interaction	12	1.0
Nomenclature of races/ pathotypes	13	1.1
Virulence spectrum	4	0.3
Inheritance of resistance	55	4.6
Slow white rusting	1	0.1
Inheritance of partial resistance	4	0.3
Inheritance of virulence	1	0.1
Inheritance of systemic resistance	7	0.6
Plant defence resistant genes	42	3.8
Mapping of resistant genes	17	1.4
Sources of resistance	32	2.9
Genetics of resistance	19	1.6
Fine structures	7	0.6
Haustoria	7	0.6
Sporangia	2	0.2
Oospores		0.0
Biochemistry of host-pathogen interaction	62	5.4
Carbohydrate metabolism and respiration	4	0.3
RNA content	2	0.2
Photosynthesis	10	0.8
Accumulation of metabolites	5	0.4
Growth substances	7	0.6
Fatty acid composition	3	0.3
Phytoalexins and polar metabolites	7	0.6
Phytoalexins and metabolites from zoosporangia		0.0
Enzyme activity changes	7	0.6
Disease management	27	2.4
Fungicidal control	57	4.9

Cultural methods of control	12	1.0
Biological control	7	0.6
Plant extracts	4	0.3
Integrated disease management	10	0.9
Callus culture	9	0.8
Sporangial viability test	2	0.2
Sporangial preservation	2	0.2
Inoculation applicator/ technique	5	0.4
White rusts as a weed control tool	1	0.1
Disease scoring scale	2	0.2
Induction of stagheads	6	0.5
Germplasm screening	30	2.5
Detached leaf culture	4	0.3
Growth chamber and greenhouse screening	1	0.1
Field screening	10	0.8
Detection of white rust pathogen	4	0.3
Total	**1182**	

Publication of historical significance:

Each year number of publications are being published on WR in the form of research papers, reviews, book chapters, scientific popular articles, conference proceedings, abstracts of group meetings, work shops, adhoc research scheme reports, key note address, circulars for farmers etc. However, all have not been considered worth quoting in succeeding publications. In the six major publications published by the authors (Table 1), we have quoted 281 references in the first white rust review (Saharan and Verma, 1992), 584 in the albugo candida bibliography (Verma and Saharan, 1996), 131 in a review by Singh *et al.* (2003), 313 and 153, respectively in the two recent review by Meena *et al*. (2014), and Verma *et al*. (2014), 732 in a book (Saharan *et al*. 2014), and 1225 in the present bibliography (Saharan *et al.*, 2014).

Out of 1225 publications published so far, some are of classical, conceptual, fundamental, applied, and scientific nature which has helped greatly in WR research developments and comprehension through research in the following major areas.

1. The disease, its host range, host diversity, geogaphical distribution, symptomatology, disease incidence, severity, assessment, yield losses, and association or mixed infection (Gmelin, 1792; Persoon, 1801; De Roussel, 1806; de candolle, 1806; Gray, 1821, Leveilla, 1847; de Bary, 1863; Bega, 1955; Wakefield, 1927; Wilson, 1907; Farr *et al*., 2004; Jacobson *et al*., 1998; Chambers, 1959; Mac Nish, 1963, 1967; Shivas, 1989; Koike, 1996; Jorstad, 1964; Mukerji, 1975; Walker, 1957; Waterhouse, 1975; Kenneth, 1968; Vasudeva, 1960; Choi *et al*., 2006, 2007, 2008, 2011; Thines *et al*. 2009; Voglmayr and Riethmuller, 2006; Ploch *et al*., 2010; Choi and Priest, 1995; Thines, 2010; McRitchiel, 1986; CABI, 2001; Pound and William, 1963; Leckie *et al*., 1996; Berkenkamp, 1972; Harper and Pittman, 1974; Barbetti, 1981; Bains and Jooty, 1979; Kolte *et al*., 1981; Saharan *et al*., 1984; Lakra and Saharan, 1989; Meena *et al*., 2002; Verma and Petrie, 1988; Holub *et al*., 1991; Cooper *et al*., 2008; Singh *et al*., 2002; Mehta *et al*., 1995; Mehta and Saharan, 1998; Saharan and Verma, 1992; Saharan *et al*., 2014; Meena *et al*., 2014; Verma *et al*., 2014).

2. The pathogen, its taxonomy and morphology, species, key to the genus, pathogenic diversity, phylogenetic relationship, structures and reproduction, life cycle of pathogen and disease (Persoon, 1801; Walker, 1833; Leveille, 1843; Gray, 1821; de Bary, 1863; Wilson, 1907;

wakefield, 1927; Togashi and Shibasaki, 1934; Baker, 1955; Biga,1955; Savulescu, 1964; Waterhouse, 1975; Burdyukova, 1980; Choi and Priest, 1995; Choi *et al.*, 2006, 2007, 2011; Thines and Spring, 2005; Ainsworth *et al*., 1973; Voglmayr and Riethmuller, 2006; Thines, 2010; Berlin and Bowen, 1964; Coffey, 1975; 1983; Davison, 1968; Frymouth, 1956; Wager, 1896; Lakra and Saharan, 1988; Jat, 1999; Goyal *et al*., 1995; Verma, 1989; Verma *et al*., 1975; Verma and Petrie, 1975, Saharan and Verma, 1992; Saharan and Mehta, 2002; Saharan *et al*. 2014; Meena *et al.*, 2014; Verma *et al.*, 2014).

3. Perpetuation and survival of pathogen in the form of mycelium, sporangia and oospores and germination of sporangia and oospores (Endo and Linn, 1960; Kadow and Anderson, 1940; Walker, 1957; Mishra and Chona, 1963; Lakra and Saharan, 1988; Bartaria and Verma, 2001; Butler, 1918; Butler and Jones, 1961; Chupp, 1925; Verma *et al*., 1975; Verma, 2012; Liu and Rimmer, 1993; Meena and Sharma, 2012; Verma and Petrie, 1975; Tewari and Skoropad, 1977; de Bary, 1866; Vanterpool, 1959; Petrie and Verma, 1974; Verma and Bhowmik, 1988; Melhus, 1911; Napper, 1933; Prevost, 1807; Tulasne, 1854; Hoffmann, 1859; Harter and Weimer, 1929; Eberhardt, 1904; Lakra *et al.*, 1989; Holliday, 1980; Saffeefulla and Thirumalachar, 1953; Kajomchaiyakul and Brown, 1976; Whipps and Cooke, 1978; Raabe and Pound, 1952; Saharan and Verma, 1992; Saharan *et al*., 2014; Meena *et al.*, 2014; Verma *et al.*, 2014).

4. Infection, pathogenesis, host-pathogen interaction including molecular mechanism (Butler, 1918; Butler and Jones, 1961; Chupp, 1925; Heald, 1926; Verma *et al*., 1975, 1980; Walker, 1957; Kadow and Anderson, 1940; Verma and Petrie, 1975; Verma, 2012; Raabe and Pound, 1952; Whipps and Cooke, 1978; Liu and Rimmer, 1990; Liu *et al*., 1989; Napper, 1933; Lakra and Saharan, 1988; Coffey, 1975, Bansal *et al*., 2005; Pidskaley and Rimmer, 1985; Maheshwari et al., 1985; Liu *et al.*, 1989; Soylu, 2004; Soylu *et al*., 2003; Kaur *et al*., 2011; Jones and Dangl, 2006; Glazebrook, 2005; Mach *et al*., 2001; Wachter *et al*., 2005; Heeg *et al*., 2008; Strohm *et al*., 1995; Noctor and Foyer, 1998; Kruse *et al*., 2007; El-Zahaby *et al*., 1995; Fodor *et al*., 1997; Vanacker, *et al*., 1998, 1999; Dixon *et al*., 2010; Marrs, 1996; Lamb and Dixon, 1997; Foyer and Noctor, 2000; Gara *et al*., 2003; Loloi *et al*., 2007; Miller *et al*., 2007; Coaker *et al*., 2005; Kromina *et al*., 2008; Dominguez-Golis *et al*., 2008; Motohashi *et al*., 2003; Geliternnikoff, 2001; Richardson *et al*., 1987; Coca *et al*., 2000; Ibeas *et al*., 2000; Roberts and Slitrennikoff, 1990; Trudet *et al*., 1998; Fernandez and Strand, 2008; Belhaj *et al*., 2009; Saharan and Verma, 1992; Saharan *et al*., 2014; Meena *et al.*, 2014; Verma *et al.*, 2014).

5. Epidemirology and forecasting (Raabe and Pound, 1952; Edie and Ho, 1970; Sempio, 1938, 1940; Kajomchaiyakeel and Brown, 1976; Takeshita, 1954; Mishra and Chona, 1963; Lakra and Saharan, 1988; Saharan, 1989; 1992; Kolte, 1985; Saharan *et al*., 1988; Verma and Bhowmik, 1989; Mehta and Saharan, 1998; Kolte *et al*., 1986; Verma *et al*., 1983; Lakra and Saharan, 1990; Biswas *et al*., 2011; Srivastava *et al*., 2005; Sullivan *et al*., 2002; Cattopadhyay *et al*., 2011; Saharan, 1995; Goyal *et al*., 1996; Humpherson-Jones, 1991; Bains and Jhooty, 1979, 1985; Hegde and Anahosur, 1994; Sangeetha and Siddharamaiah, 2007; Mathur, 1993; Meena *et al*., 2002; Tomer *et al*., 1992; Gilles *et al*., 2000; Dooranbos, 1976; Ghadekar, 2002; Draper and Smith, 1981; Agrawal *et al*., 1986; Desai *et al*., 2004; Chattopadhyay *et al*., 2005; West *et al*., 2001; Evans *et al*., 2008; Saharan and Verma, 1992; Saharan *et al*., 2014; Meena *et al.*, 2014; Verma *et al.*, 2014).

6. Physiologic specialization, pathogenic variability, races, pathotypes, virulence spectrum, phylogenetic relationship of races or pathotypes (Eberhardt, 1904; Melhus, 1911; Pape and Rabbas, 1920; Pfister, 1927; Taubenhaus, 1923; Ciferri, 1928; Savulescu and Rayas, 1930; Savulescu, 1946; Hiura, 1930; Napper, 1933; Ito and Tokunaga, 1935; Biga,

1955; Togashi and Shibasaki, 1934; Endo and Linn, 1960; Pound and Williams, 1963; Petrie, 1994; Verma *et al*., 1975; Delwiche and Williams, 1977; Williams, 1985; Verma *et al*., 1999; Singh and Bhardwaj, 1984; Lakra and Saharan, 1988; Gupta and Saharan, 2002; Jat, 1999; Kaur *et al*., 2008; Saharan, 2010; Kaur *et al*., 2011; Burdyukova, 1980; Pidskalny and Rimmer, 1985; Kolte *et al*., 1991; Mathur *et al*., 1995; Rimmer *et al*., 2000; Wu *et al*., 1995; Saharan and Verma, 1992; Saharan *et al*., 2014; Meena *et al*., 2014; Verma *et al*., 2014).

7. Genetics of host-parasite interaction, inheritance of resistance, partial reistance, slow white rusting and virulence, induction of systemic resistance, plant defence resistant genes and mapping of resistant genes (Hougas *et al*., 1952; Williams and Pound, 1963; Humaydon and Williams, 1976; Bonnet, 1981; Delwiche and Williams, 1974, 1981; Ebrahami *et al*., 1976; Thukral and Singh, 1986, 1996; Fan *et al*., 1983; Liu *et al*., 1996; Bansal *et al*., 2005; Liu and Rimmer, 1992; Sachan *et al*., 1995; Tewari *et al*., 1988; Saharan and Krishnia, 2001; Jat and Saharan, 1999; Subudhi and Raut, 1994; Borhan *et al*., 2008; Liu *et al.*1989; Coffey, 1975; Lakra and Saharan, 1988; Gupta and Saharan, 2002; Saharan, 2010; Bansal *et al*., 1999, 2005; Edwards and Williams, 1987; Kole *et al*.,1996; Adhikari *et al*., 2003; Singh *et al*., 1999; Ellis *et al*., 1999, 2000; Holub, 2001; Hulbert *et al*., 2001; Takkenland Joosten, 2000; Kaur *et al*., 2010; Borhan *et al*., 2004, 2008; Eulgem *et al*., 2004; Holub, 2001,2007; Holub *et al*., 1995; Mc Dowell *et al*., 1998, 2000; Tor *et al*., 2002; Young, 2000; Kobe and Deisenhofer, 1994, 1995; Ellis *et al*., 1999; Wulff *et al*., 2001; Meyers *et al*., 1998, 2003; Dodds *et al*., 2001; Dangle and Jones, 2001; Mackey *et al*., 2002, 2003; Muskett *et al*., 2002; Tornero *et al*., 2002; Gassmann *et al*., 1999; Parker *et al*., 1996; Feys *et al*., 2001; Zhou *et al*., 1998; Somers *et al*., 2002; Cooke *et al*., 2000; Monchlvo *et al*., 1995; Cheung *et al*., 1998; Tanhuanpaa, 2004; Varshney *et al*., 2004; Bansal *et al*., 1999; Kole *et al*., 1996, 2002; Kumar *et al*., 2003; Parken *et al*., 1995; Bartche *et al*., 2006; Choi *et al*., 2006; Rehmany *et al*., 2000; Tan *et al*., 2007; Underwood *et al*., 2007; Melotto *et al*., 2006; Cooper *et al*., 2008; Massand *et al*., 2010; Somers *et al*., 2002; Saharan and Verma, 1992; Saharan *et al*., 2014; Meena *et al*., 2014; Verma *et al*., 2014).

8. Sources of resistance (Williams and Powel,1963; Humaydon and Williams,1976; Bonnet,1981; Fan *et al*., 1983; Bhardwaj and Sud, 1993; Chauhan and Raut, 2002; Somers *et al*., 2002; Saharan, 2010; Li *et al*., 2003, 2008, 2009; Kolte and Tiwari,1980; Lakra and Saharan,1989; Saharan,1988, 2005; Kolte *et al*.,1985; Jahn *et al*.,1998; Gupta *et al*.,1995; Borhan *et al*., 2001, 2008; Santos *et al*.,1996; Saharan and Krishnia, 2001; Bansal *et al*., 1999; Dainello *et al*.,1981; Adhikari *et al*., 2003; Dang *et al*., 2000; Sheikh and Singh, 2001; Wood and Falk, 2001; Krishnia *et al*., 2000; Singh *et al.* (2003); Saharan and Verma,1992; Saharan *et al*., 2014; Meena *et al*., 2014; Verma *et al*., 2014).

9. Fine structures of haustoria, sporangia and oospore (Berlin and Bowen,1964; Davison,1968; Coffey,1975, 1983; Woods and Gay,1983; Koch and Slusarenko,1980; Khan,1976, 1977; Tiwari *et al*., 1980; Hughes,1971; Tiwari and Skoropad, 1977; Soylu, 2003; Soylu *et al*., 2004; Boka, 2008; Voglmayer and Riethmuler, 2006; Saharan and Verma,1992; Saharan *et al*., 2014; Meena *et al*., 2014; Verma *et al*., 2014).

10. Biotechnology of host-pathogen interaction, carbohydrate Metabolism, respiration, RNA content growth substances, fatty acid composition, phytoalexins, metabolites and enzyme activity changes (Scott,1972; Heitefuss and Willams,1976; Cooke,1970; Aldesuquy and Baka,1992; Chou *et al*., 1982; Singh, 2000; Debnath *et al*., 1998; Gupta *et al*., 1997; Kaur *et al*., 2011; Misra and Padhi,1981; Harding *et al*., 1968; Daly,1976; Long *et al*., 1975; Dhingra *et al*., 1982; Dhawan *et al*.,1981; Pruthi *et al*., 2001; Mishra *et al*., 2009; Purohit *et al*., 1980; Singh *et al*., 1980, 2011; Maheshwari and Chaturvedi, 1983; Klermayer, 1958; Hirata, 1954, 1956; Srivastava *et al*.,1962;

Kumari *et al*., 1970; Lal *et al*., 1980; Herman,1985; Spring *et al*., 2005; Rouxel *et al*., 1991; Liang *et al*., 2006; Widarto *et al*., 2006; Pedras *et al*., 2007, 2008; Chou *et al*., 2000; Tan *et al*., 2004; Rollend *et al*., 2006; Voit, 2003; Godika and Pathak, 2005; Saharan and Verma,1992; Saharan *et al*., 2014; Meena *et al.*, 2014; Verma *et al.*, 2014).

11. Disease management through fungicidal, cultural, biological methods, host resistance and integrated approach (Frickhinger, 1932; Naumann, 1955; Vasucleva, 1958, Perwaiz *et al*., 1969; Bains and Jhooty, 1979; Klote, 1982, 1985, 1987; Lakra and Saharan,1988; Saharan *et al*., 1982, 1984, 1990; Singh *et al.*, 1980, 2008; Verma and Petrie, 1979; Dueck and Stone, 1979; Martaria *et al*., 1998; Khangura and Sokhi, 2000; Meena *et al*., 2005; Mukerji *et al*., 1999; Saharan and Mehta, 2002; Saharna and Verma,1992; Saharan *et al*., 2014; Stone *et al*.,1987a, b; Meena *et al.*, 2014; Verma *et al*., 2014).

12. Techniques (Berlin and Bowen, 1964; Coffey, 1975; 1983; Davison, 1968; Frymouth, 1956; Wager, 1896; Heald, 1926; Walker, 1957; Zalewski, 1883; Stivens, 1901; Lahri and Bhowmik, 1993; Nath *et al*., 2000; Singh, 1966; Goyal *et al*., 1995, 1996; Verma and Petrie, 1974, 1975, 1979, 1980; Verma *et al*., 1975; Vyalykh and Lanetsku, 1974; O'Brain and Webb, 1958; Lakra and Saharan, 1988, 1989; Perry and Willams, 1984; Fox and Willams, 1984; Black and Dainello, 1986; Lie *et al*., 1989; Hartmann and Watson, 1980; Liu and Rimmer, 1993; Meena and Sharma, 2012; Verma and Bhomik, 1988; Pound and Willams, 1963; Mayee and Datar, 1986; Meena, 2007; Jenkyn *et al.*, 1973; Kolte *et al*., 1998; Verma and Petrie, 1978; Verma, 2012; Singh and Singh, 1983, 1999; Stringam, 1971; Saharan *et al*., 1988, 2014; Lakra and Saharan, 1989; Li *et al*., 2007; Meena *et al.*, 2011; Jacobson *et al*., 1998; Williams and Hill, 1986; Pedras *et al*., 2008; Francis *et al*., 1996; Lee and Taylor, 1990; White *et al.*, 1990; Hudspeth *et al*., 2000; Saharan and Verma, 1992; Singh *et al*., 2003; Meena *et al.*, 2014; Verma *et al.*, 2014).

Leading Institutions involved in WR Research:

There are more than 110 leading institutions (Table 4) which are engaged in WR research all over the World. Some of these institutes have very active program on WR. Considering the human resources as input, output in the form of quantities and qualities of publications on WR is not appreciable. It appears that most of the research data are limited to the annual reports of the research schemes rather than publishing in the national and international journals.

Table 4: Leading institutions involved in research on white rust in the world

S.No	Institution	Country
1.	Department of Systematic and Evolutionary Botany, University of Vienna, Rennweg 14, 1030 Vienna	Austria
2.	Verlag Ferdinand Berger & Söhne Gesellschaft m.b.H., 3580 Horn	Austria
3.	Institute of Botany, University of Agricultural Sciences Vienna Gregor-Mendel-Str. 33 A1180 Vienna	Austria
4.	Southeastern Oklahoma State University, Durant, Oklahoma	U.S.A.
5.	Department of Plant Science, University of Manitoba, Winnipeg, Manitoba R3T 2N2	Canada
6.	Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, P.O. Box 1000, Agassiz, BC, V0M 1A0	Canada
7.	Saskatoon Research Centre, Agriculture and Agri-Food Canada, 107 Science Place, Saskatoon, SK, S7N 0X2	Canada
8.	Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, T6G 2P5	Canada
9.	Department of Chemistry, University of Saskatchewan, 110 Science Place, Saskatoon, SK, S7N 5C9	Canada

10.	DNA Landmarks Incorporated, P.O. Box 6, St.-Jean-sur-Richelieu, QC J3B 6Z1	Canada
11.	International Development Research Centre	Canada
12.	The Natural Sciences and Engineering Research Council	Canada
13.	Canola Council of Canada	Canada
14.	Department of Botany, Faculty of Science, University of Mansoura, Mansoura	Egypt
15.	Department of Botany, Faculty of Science, South Valley University, Aswan	Egypt
16.	Department of Conservation, PO Box 10420, The Terrace, Wellington 6143	New Zealand
17.	Department of Molecular Biology, DLO-Centre for Plant Breeding and Reproduction Research, Postbus 16, 6700 AA Wageningen	The Netherlands
18.	Plant Pathology and Weed Science Department, HorticulturalResearch International-Wellesbourne, Warwickshire CV35 9EF	United Kingdom
19.	Sainsbury Laboratory, John Innes Centre, Colney Lane, Norwich NR4 7UH	United Kingdom
20.	The Sainsbury Laboratory, Norwich Research Park, Norwich NR4 7UH	United Kingdom
21.	Department of Animal and Plant Sciences, University of Sheffield, Sheffield, S10 2TN	United Kingdom
22.	Scottish Crop Research Institute, Invergowrie, Dundee, DD2 5DA	United Kingdom
23.	Rothamsted Research Station, Harpenden, Hertfordshire, AL5 2JQ	United Kingdom
24.	Department of Agriculture Sciences, Imperial College, Wye Campus, Wye, Ashford, Kent, TN 25 5AH	United Kingdom
25.	Aberdeen Oomycete Group, College of Life Sciences and Medicine, Institute of Medical Sciences, University of Aberdeen, Foresterhill, Aberdeen AB25 2ZD, Scotland	United Kingdom
26.	Department of Biology, College of Sciences, King Khalid University, Abha, P.O. Box 9004	Saudi Arabia
27.	Plant Diseases Division, Department of Scientific and Industrial Research, Auckland	New Zealand
28.	School of Biological Sciences, Victoria University of Wellington, PO Box 600, Wellington 6140	New Zealand
29.	School of Plant Biology, Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley, Western Australia 6009	Australia
30.	Melbourne School of Land and Environment, University of Melbourne, Victoria 3010	Australia
31.	Biological & Chemical Research Institute, N.S.W. Agriculture, P.M.B. 10, Rydalmere, N.S.W. 2116	Australia
32.	Cooperative Research Centre for Tropical Plant Pathology, University of Queensland, Brisbane, Queensland	Australia
33.	Department of Plant Pathology, Waite Agricultural Research Institute,University of Adelaide, Glen Osmond, South Australia 5064	Australia
34.	Department of Agriculture and Food, Western Australia, Baron-Hay Court, South Perth, WA 6151	Australia
35.	Indian Council of Agricultural Research	India
36.	Directorate of Rapeseed-Mustard Research, Sewar, Bharatpur, Rajasthan 321 303	India
37.	National Research Centre on Plant Biotechnology, IARI, New Delhi-110 012	India
38.	Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, 141004 Punjab	India
39.	Project Directorate for Farming Systems Research, Modipuram, Meerut, Uttar Pradesh 250 110	India
40.	Department of Botany, University of Rajasthan, Jaipur	India
41.	Rajasthan Agricultural University, Bikaner	India
42.	CCS Haryana Agricultural University, Hisar 125 004	India
43.	Shiwalik Agricultural Research and Extension Centre, CSKHPKV, Kangra, 176001	India
44.	Biotechnolgy Centre, Himachal Pradesh Krishi Vishvavidyalya, Palampur 176062	India
45.	Department of Plant Pathology, G.B. Pant University of Agriculture & Technology, Pantnagar 263145, Uttrakhand	India

46.	Department of Plant Pathology, Gujarat Agricultural University, Sardar Krushinagar - 385 506	India
47.	Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Krishi Vigyan Kendra, Morena	India
48.	The Energy and Resources Institute, Lodhi Rd, New Delhi 110003	India
49.	Department of Plant Pathology, G.K.V.K, University of Agricultural Sciences, Bangalore –560065	India
50.	SKUAST-J, Jammu, J&K	India
51.	N.D. University of Agri. and Technology, Kumarganj, Faizabad - 224 229 (U.P.)	India
52.	Botany Section, Museum of Evolution, Uppsala University, Norbyvägen 16, SE-752 36 Uppsala	Sweden
53.	Real Jardín Botánico, C.S.I.C. Plaza de Murillo 2, E-28014 Madrid	Spain
54.	Estagco Experimental de Lages, EMPASC, Lages, CEP 88502-970	Brazil
55.	Departamento de Fitopatologia, Universidade de Brasília, Brasília, DF	Brasil
56.	EMBRAPA-Cerrados, Planaltina, DF,	Brasil
57.	Department of Plant Pathology, University of Arkansas, Fayetteville 72701	USA
58.	Harvard University, Department of Organismic and Evolutionary Biology, 22 Divinity Ave., Cambridge, MA 02138	USA
59.	Department of Entomology and Plant Pathology, University of Tennessee, Knoxville, TN 37996	USA
60.	Department of Botany and Plant Pathology, Purdue University, 915 W. State Street, West Lafayette, IN 47907	USA
61.	Crop Production and Pest Control Research, U.S. Department of Agriculture-Agricultural Research Service	USA
62.	Department of Plant Biology, Koshland Hall, University of California, Berkeley, CA 94720-3102	USA
63.	Department of Plant Pathology and Microbiology, 1463 Boyce Hall, University of California-Riverside, Riverside, CA 92507	USA
64.	Departments of Horticulture and Plant Pathology, University of Wisconsin, Madison 53706	USA
65.	Department of Plant Pathology and Faculty of Botany, The Ohio State University, Columbus	USA
66.	Deaprtment of Plant Pathology, Washington State University, Puyallup Research and Extension Center, 7612 Pioneer Way East, WA 98371-4998	USA
67.	Department of Botany and Plant Pathology, Michigan State University, East Lansing, MI 48824-1312	USA
68.	Department of Botany, Field Museum of Natural History, 400 S. Lake Shore Dr., Chicago IL 60605-2496	USA
69.	Department of Plant Biology, Carnegie Institution of Washington, Stanford, CA 94305-1297	USA
70.	The Hull Botanical Laboratory	USA
71.	Torrey Botanical Society	USA
72.	Institute of Botany 210, University of Hohenheim, 70593 Stuttgart	Germany
73.	Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt Main	Germany
74.	Institute of Ecology, Evolution and Diversity, Department of Biological Sciences, Johann Wolfgang Goethe University, Siesmayerstr. 70, 60323 Frankfurt Main	Germany
75.	Bayer AG, Business Group Crop Protection, Development/Registration, Agriculture Center Monheim, D-51368 Leverkusen	Germany

76.	Fachbereich 18 Naturwissenschaften, Fachgebiet O¨ kologie, Universita¨t Kassel, Heinrich-Plett-Straβe 40, D-34132 Kassel	Germany
77.	Federal Centre for Breeding Research on Cultivated Plants, Institute of Agricultural Crops, Groß Lu¨ sewitz 18190	Germany
78.	Korean Agricultural Culture Collection, National Institute of Agricultural Biotechnology, Rural Development Administration, Suwon 441-707	Republic of Korea
79.	Division of Environmental Science and Ecological Engineering, College of Life and Environmental Sciences, Korea University, Seoul 136-701	Republic of Korea
80.	W. Szafer Institute of Botany, Polish Academy of Sciences, Department of Mycology, Lubicz 46, PL-31-512 Kraków	Poland
81.	Wageningen University, 6703 HB Wageningen	The Netherlands
82.	Institute of Biology, Leiden University, Einsteinweg 55, P.O. Box 9502, 2300 RA Leiden	The Netherlands
83.	Crops and Biotechnology, Plant Production Research, MTT/Agrifood Research Finland, 31600 Jokioinen	Finland
84.	Biocenter Oulu,University of Oulu, 90220 Oulu	Finland
85.	Escola Superior Agrária de Bragança, Campus de Santa Apolónia; 5301- 855 Bragança	Portugal
86.	CEPTA-IICT, Apartado 3014, Tapada da Ajuda, 1301-901 Lisboa	Portugal
87.	Instituto Superior de Agronomia, Technical University of Lisbon, Tapada da Ajuda, 1349-017 Lisboa	Portugal
88.	Plant Protection Department, Agricultural Faculty, Harran University, 63040 Sanhurfa	Turkey
89.	Plant Protection Department, Agricultural Faculty, Ankara University, 06110 Diskapt, Ankara	Turkey
90.	Department of Plant Protection, Faculty of Agriculture, University of Mustafa Kemal, 31034 Antakya, Hatay	Turkey
91.	Institute of Oil Crops Research, Chinese Academy of Agricultural Sciences, Wuhan 430062	P.R. China
92.	The National Key Laboratory of Crop Genetics and Improvement, Huazhong Agricultural University, Wuhan 430070	P.R. China
93.	College of Bioscience and Biotechnology, Yangzhou University, Yangzhou 225009	China
94.	Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Beijing 100101	China
95.	Department of Plant Pathology, University of Georgia, Athens, Georgia 30602	USA
96.	Agricultural and Natural Resources Research Center of Southern Khorasan, PO Box 413, Birjand	Iran
97.	Iranian Research Institute of Plant Protection, PO Box 19395-1454 Tehran	Iran
98.	Agricultural Research Education and Extension Organisation (AREEO) of the Islamic Republic of Iran, Tehran	Iran
99.	Korea University, Division of Environmental Science and Ecological Engineering, Seoul 136-701	Republic of Korea
100.	Universidad de Los Andes, Instituto de Investigaciones Agropecuarias, Laboratorio de Fitopatología, Santa Rosa, Mérida, Estado Mérida	Venezuela
101.	National Institute of Agrobiological Sciences, Tsukuba, Ibaraki 305-8602	Japan
102.	Oita Prefectural Agriculture, Forestry and Fisheries Research Center, Kita-usa, Usa, Oita 872-0103	Japan
103.	Kanagawa Prefectural Museum of Natural History, Odawara, Kanagawa 250-0031	Japan
104.	Technology Extension Division, Agriculture, Forestry and Fisheries Department, Oita Prefectural Government, Ohte-machi, Oita 870-8501	Japan

Future Thurst Areas of Research

During the past century, mycologists/ plant pathologists/ researchers in the world have endured enormously to excel in the comprehension of white rust disease of crops. However, some priority areas of research pointed below may give quantum jump in the production and productivity of crops suffering from white blister rust. Formation of inter and intra-institutional working groups at national and international level may give boost to get reliable and repeatable research results.

√ Generation of enough data on epidemiological elements of white rust to develop disease forecasting system.

√ Recommendation of a package for integrated disease management.

√ Determination of morphological and histological basis of host resistance alongwith induced resistance mechanism.

√ Identification of genotypes with few numbers of stomata and narrow stomatal aperture to ensure mechanical host barrier.

√ Information regarding presence/ production of oospores inside the seeds, and their possible importance in the survival of the pathogen is lacking.

√ Role of simple or branched germ tubes from germinating oospores need to be studied.

√ Single zoospore cultures from germinating sporangia, and from germinating oospores must be prepared, and their pathogenicity compared.

√ After screening lines for resistance against foliar infections, some select advanced lines must also be screened for production of stagheads using flower-bud inoculation technique.

√ Mycologists and taxonomists may consider the division of *A. candida* complex into different species depending on host specificity.

√ There is a need to standardize the host differentials in each crucifer species internationally, and more so in the form of isogenic lines to get true pictures of *A. candida* races/ pathotypes.

√ Nomenclature of the *A. candida* races should be standardized internationally viz., AC jun 1, 2- for *B. juncea* isolates, AC rap 1,2, -for *B. rapa* isolates, AC nig 1, 2, -for *B. nigra* isolates, A Col 1,2, etc., for *B. oleracea* isolates, respectively.

√ Identification of sources of resistance should be based on broad spectrum effectiveness of a genotype against specific races.

√ Efforts should be made to identify resistance loci in the genotypes along with alleles for resistance in each locus.

√ Genotypes exhibiting attributes of slow white rusting, disease tolerance, and partial resistance may be categorized.

√ Studies on inheritance of virulence may be undertaken along with virulence spectrum.

√ Mapping, cloning, characterization, and identification of marker genes for resistance and virulence at molecular level may be strengthened.

√ Genetics of *Albugo-Hyaloperonospora* association may be determined both at phenotypic and genotypic levels.

√ Strong and weak genes for resistance in the host with their suitable combinations for durable resistance may be looked into.

√ Sources of multiple disease resistance should be explored.

√ Morphological, histological and biochemical basis of host resistance should be identified.

√ Rapid identification of latent infection under field conditions using modern techniques of biotechnology is needed.

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