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A Review of Occurrence of Fungal Pathogens on Significant *Brassicaceous* Vegetable Crops and their Control Measures

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Abstract: *Brassica* vegetables are subjected to viral, bacterial as well as fungal attack, which causes a high yield loss. Temperature and moisture conditions, which promote the growth of fungus, are needed to be studied in order for an effective control of the disease to be estimated. The present review gives a brief account of the fungal diseases which have been considered responsible for major economic loss to the *Brassica* crops. The epidemiological conditions necessary for the occurrence and prevalence of the different types of fungal diseases studied by different workers have been reviewed and it has been found that an optimum temperature and high moisture conditions are required for the growth of fungi. The different available control measures that have been considered effective against the pathogens were investigated and breeding practices was considered most effective owing to the lack of field trials in the genetic engineering of plants.

Key words: *Brassica* disease, control measures, disease resistance, epidemiology, fungal attack, mycopathogens

INTRODUCTION

Vegetable growing is one of the most important branch of agriculture and consuming plant rich-diets will provide us a milieu of phytochemicals, non-nutritive substances in plants that possess health-protective benefits (Craig, 1997). Moreover, previous epidemiological studies have consistently shown that consumption of fruits and vegetables have been associated with reduced risk of chronic diseases, such as cardiovascular diseases and cancers (Gerber *et al*., 2002; Kris-Etherton *et al.* 2002; Serafini *et al*., 2002) and neurodegenerative diseases, including Parkinson's and Alzheimer's diseases (Di Matteo *et al*., 2003) as well as inflammation and problems caused by cell and cutaneous aging (Ames *et al*., 1993). *Brassica* is the most economically important genus in the *Brassicaceae* family (Srivastava *et al*., 2010). *Brassica* vegetables include different genus of cabbage, broccoli, cauliflower, Brussels sprouts, and kale, which are consumed all over the world (Podsedek, 2007). In addition, these vegetables possess both antioxidant and anticarcinogenic properties (Cohen *et al*., 2000; Chu *et al*., 2002). *Brassica* crops are heavily challenged by various fungal pathogens and insects, whereas bacterial and viral diseases have little effect on their yield (Abdel-Farida *et al*., 2009). Various workers have reported different fungal pathogens found on *Brassica* vegetables, which include the *Alternaria* sps. causing leaf blight or dark spot, the *Leptoshaeria maculans* causing black leg or Phoma stem canker, the clubroot disease caused by *Plasmodiophora brassicae*, and various others, thus culminating into heavy loss to the *Brassica* crop yield.

In this review, we present a brief account of the occurrence of the fungal pathogens in *Brassica* vegetables; the temperature and moisture conditions responsible for their prevalence, the advances in the various control measures adopted for these fungi and ultimately provide an outlook for future research.

The various fungal diseases affecting the *Brassica* vegetables include the followings:

Alternaria blight: The different species of *Alternaria* are members of the deuteromycetes and they caused black spot or leaf spot disease on *Brassica* vegetables. For example, *A. brassicae* can infect virtually any part of the plant with visible symptoms of infection, which includes chlorotic and necrotic lesions on the leaf, petiole, stem, inflorescence, silique and seed (Verma and Saharan, 1994). In addition, the infection can occur in cotyledons at the seedling stage and on leaves, leaf petiole, stem, inflorescence, siliquae and seeds in adult stage (Kolte *et al*., 1988). Thus, the damaged seeds usually show both internal and external presence of

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fungus. However, the estimates of yield losses due to this disease vary between 35 and 70% as seen in different species of oilseed brassicas grown in different parts of the world. Moreover, oil yield losses due to infected seeds have been reported to be in the range of 15-36% (Ansari *et al*., 1988).

Epidemiology: Infected seeds with either spores on their coats or mycelium under their coats are likely to be the main source of transport for these pathogens. In addition, the infected crops left on the ground after harvest also serve as a source of infection for *A. brassicae* and *A. brassicicola* (Humpherson-Jones and Maude, 1982). Other workers have also reported the germination of *Alternaria brassicicola* at a minimum temperature of 15ºC, which grows in plants as the temperature rises to 25ºC. However, the seeds are more infected at 30ºC (Chauhan *et al*., 2009). Thus, a high temperature of 15-30ºC is required for the growth and survival of fungus. According to some workers, a high relative humidity of more than 65% is required for spore germination (Sangeetah and Siddaramaiah, 2007). In addition, a fall in relative humidity also promotes the release of spores such that in a daily cycle air spore concentration is minimum in morning and maximum in afternoon (Humpherson-Jones and Maude, 1982). Subsequently more work is needed to check the roles of relative humidity for the germination of fungus. However, it is clear that a wet weather promotes the release of spores. For most of the growing season, spore movement is restricted to within the crop. The massive release of spores and subsequent distribution over a wide area occurred, when the crop is cut and later threshed (Humpherson-Jones and Maude, 1982).

Control measures: The screening of resistant cultivars in *Brassica rapa* (turnip) against *Alternaria* was done by Doullah *et al.* (2006). Other methods include hot water treatment of the seeds in order to reduce the growth of *Alternaria* (Humpherson-Jones and Maude, 1982). In addition, surface sterilization of seeds infected with *A. raphani* (3 min. in 4% sodium hypochlorite) also help to reduce infection by 30% (Valkonen and Koponen, 1990). However, spores of these fungi can survive on leaf tissue for up to 8 to 12 weeks and that of stem tissue for up to 23 weeks. Hence, fields that are replanted soon after harvest often coincided with a large amount of inoculums, which is likely to affect the crop's emergence and early growth stages (Humpherson-Jones, 1989). Thus, rotation with non-cruciferous crops and eradication of cruciferous weed hosts can help control these pathogens and also fungicide spray in fields should be done at the same time. Dithane M-45 (0.2%) followed by Dithane Z-78 used as foliar spray appeared to be the most effective means for controlling the blight and increasing the yield in the field trials as reported by Nisar *et al.* (1990). In addition, Mancozeb has been shown as a promising fungicide for rapeseed mustard as reported by Meena *et al.* (2004) and Mondal *et al.* (2008). Moreover, for seed dressing, Benlate at 0.1 lb a.i./100 lb seed provided the best control with a mean loss of 4.5 pre-emergence seedlings and 6.5 post-emergence seedlings per pot (25 seeds planted in each pot, 8 pots). In addition, biological control can be done by spraying 1% w/v bulb extract of *Allium sativum* and leaf extract of *Acacia nilotica* causing significant reduction in both the runs compared with control (Meena *et al*., 2004). Preliminary studies with other actinomycete fungus such as *Streptomyces arabicus* indicated its antifungal effect on *A. brassicae* and *A. brassicicola* in both laboratory and field studies (Sharma *et al*., 1984, 1985).

In Finland, surface treatment with powdered *S. griseoviridis* (at 15 mg/g seed) has been shown to provide control against *A. brassicicola,* but does not control *A. raphani,* which infects the inner part of seed (Valkonen and Koponen 1990). In addition, GR isolate of *T. viride* performed the best among the other test isolates of *Trichoderma* causing about 81.1-82.3% reductions in mycelial growth of *A. brassicae* over the control in two separate experimental runs. Meena *et al*. (2004) also identified that 75 days after the sowing of mustard plant to be the most critical stage of disease development. Although, 45 days after sowing was also seen as the next important one, such that fungicide spray at these stages of mustard crops development will be most effective.

Biotechnological approaches have also been used for the development of resistance against the disease. Production of transgenic plant with an over-expression of chitinase inhibited the fungal colony size by 12-56% over the non-transgenic control as reported by Mondal *et al*. (2003). In addition, pathogenesis related protein-osmotin when introgressed in *Brassica juncea* plant gave the plant tolerance to fungal attack. Moreover, osmotin interfered with the p^{53} mediated PCD pathway, which although could not provide adequate resistance but help to delay the appearance of disease symptoms as reported by Taj *et al.* (2004). Resistance in susceptible mustard cv. PR-15 against the highly virulent *A. brassicae* isolates A (AbA) and moderately virulent isolate C (AbC) were also induced using an avirulent *Alternaria brassicae* isolate D (AbD). The induction of resistance due to AbD against AbA or AbC resulted in significant reduction in disease severity as reported by Vishwanath *et al.* (1999). However, further work is needed before these approaches may become practical on field.

Blackleg: Vegetable crop *B. oleracea* and the oilseed rapes *B. rapa* and *B. napus* are the susceptible species to blackleg disease (Srivastava *et al*., 2010). Blackleg caused by *Leptosphaeria maculans* is a very important disease worldwide and also led to large yield loss of significant vegetable crops. This pathogen can infect all parts of the plant, but, the stem canker is the most serious symptom as it causes plant lodging and yield loss (Fernandoa *et al.* 2007).

Epidemiology: The most important source of inoculums of *L. maculans* is previously infected canola stubble, bearing pseudothecia from which ascospores can be released (Guo *et al*., 2005). Timing of maturation of pseudothecia and discharge of ascospores of the Blackleg fungus (*Leptosphaeria maculans*) is critical in relation to infection early in the cropping season of canola. Perres *et al.* (1999) reported that under controlled conditions of a mean temperature of 14ºC and a high frequency of rainfall (2.5 mm every 3 to 4 days) were the best regimes for the first generation of pseudothecia. In addition, similarity in pattern of pseudothecia maturation has been reported regardless of the age of the residues (Khangura *et al*., 2007). However, a marked reduction in the production of new pseudothecia on 18 months old residue also support other previous findings (Gosende *et al*., 2003) and thus, created a reduce threat to the nearby plants in comparison to the 6 months old residues. Hence, the rates of production and maximum number of sporulating pycnidia produced per leaf disk were greater in the light than in the dark and both variables increased with duration of leaf wetness, temperature and light intensity (Vanniasingham and Gilligan, 1989). Thus, the discharge of ascospore at any given day is negatively correlated with accumulated temperature, maximum temperature, evaporation, minimum and maximum soil temperature and solar radiation and also positively correlated with minimum temperature, rain and minimum relative humidity (Vanniasingham and Gilligan, 1989). In some areas the ascospore is discharged from June to August when the plant is in bolting or flowering stage (Khangura *et al*., 2007). However, at this stage the plant is highly susceptible to the disease and fungicide spray is recommended. In addition, the ascospore discharge in the later part of the season is insignificant as the plant has passed the susceptible stages of their growth. The daily variation of ascospore discharge has also been ascribed to the availability of moisture (Petrie, 1986).

Control measures: A lot of control measures have been developed and these include the followings:

- Screening of resistance in different *Brassica* varieties against *Leptosphaeria maculans*.
- Numerous workers have shown crop rotations to have different effect on canola. For example, Petrie (1986) showed that a three year rotation between canola crops reduced the severity of Blackleg disease. Morrall *et al*. (1999) found that when canola was rotated with non-host crops for more than five years, blackleg disease showed a decreasing trend. Though, these differential outcomes may be ascribed to different environmental factors in the study area; however, they suggest that rotation with non-host crops and tillage could significantly reduce the prevalence of the blackleg disease.
- Biotechnological advancements: Brassinin, a crucial plant defense produced by crucifers and is detoxified by the phytopathogenic fungus *Leptosphaeria maculans* (*Phoma lingam*) to indole-3-carboxaldehyde using a putative brassinin oxidase. However, potential inhibitors of brassinin detoxification were designed by replacement of its dithiocarbamate group (toxophore) with carbamate, dithiocarbonate, urea, thiourea, sulfamide, sulfonamide, dithiocarbazate, amide, and ester functional groups. In addition, the indolyl moiety was substituted for naphthalenyl and phenyl. Furthermore, the synthesis and chemical characterization of these potential detoxification inhibitors, alongside with their antifungal and cytotoxic activity, as well as screening using cultures of *L. maculans* have been well reported (Soledade *et al*., 2006).

Clubroot: The disease is caused by the obligate biotroph *Plasmodiophora brassicae* Woron and is one of the most serious and damaging diseases of *Brassica* crops with associated large economic losses (Ando *et al*., 2005). In addition, the life cycle of this organism is in two phases. Examination of the infected plant roots revealed swollen, club-shaped roots instead of the normal fine network of roots. The first phase of the disease is restricted to root hairs of infected plants and the second occurred in the cortex and stele of the hypocotyls and roots (Ingram and Tommerup, 1972). However, during this second phase, the plasmodia incite the host cells and neighboring cells to grow and divide, resulting in hypertrophy of the host tissue (Braselton, 1995; Ludwig-Müller, 1999).

Epidemiology: Evidence of successful infection of *Plasmodiophora brassicae* depends on a number of factors. The disease can occur in both acid and alkaline soils. In acid soils, the very favourable conditions for incidence of the disease are a moisture content equal to about 70% of the maximum water-holding capacity and a mean air temperature of 18-23ºC. Nonetheless, the level of spore load (within the limits of 10^3 to 2.5×10^7 spores per g. of soil) does not influence the number of diseased plants in the acid soils despite the fact that favourable conditions for attack and good growth of the host are provided. Therefore, under less favourable conditions, spore load does exercise an effect (Colhouna, 1953). On the other hand, in alkaline soils, infection is favoured by high moisture content, high temperature and high spore load. Thus, it was suggested that the optimum temperature for infection is higher than 23ºC. However, in alkaline soils at moisture contents and temperatures favourable for infection, a heavy attack can only develop in the presence of a high spore load (Colhouna, 1953). It was found that clubroot severity was influenced mostly by the light level in the second and third weeks. The percentage of diseased plants was found to be most influenced by temperature and probably, the second week being most important period. However, the optimum light value in the second and third weeks for expression of maximum clubroot severity was c. 600 WH/m^2day and a mean daily temperature of not less than c. 19-5ºC was required to give close to 100% infection (Jensen *et al*., 1999).

Control measures:

Many control measures have been developed and these include the followings:

- Resistant cultivars planting, liming of the soil, crop-rotation and fungicides are strategies to combat this disease.
- Yearly application of lime to maintain high soil pH have also been effective in some cases where brassica is cropped regularly (Hildebrand and McRae, 1998).
- Numerous fungicides have been evaluated, but only calomel (mercurous chloride) has worked consistently. This fungicide is not used now due to its environmental concerns. However, another fungicide fluzinam have shown some promises for clubroot control. Clubroot was reduced by non-ionic surfactants under conditions that are highly conductive to the disease as seen in the green house and field trials (Bochow, 1989).
- Biological control of the disease can be done through Isolation, multiplication and application of anti-phytopathogenic soil microorganisms, which enriches the plant rhizosphere and plant substrates with ultimate reduction effects on pathogens and root infections (Coelho and Monterio, 2003). Thus, the practical value of such biological means to control soil-borne phytopathogens is at present restricted by ecological depending factors with large variations of its effectiveness (Niu *et al*., 1983; Piao *et al*., 2009). Hence studies of ecological variations are necessary to make this approach practical and effective on the field.
- Piao *et al*. (2009) have identified resistance genes against clubroot in *Brassica rapa*, *Brassica napus* and *Brassica oleracea* (Jensen *et al*., 1999).

Downy mildew: Downy Mildew (DM) induced by *Hyaloperonospora parasitica* (formerly *Peronospora parasitica*) is a destructive worldwide disease of Broccoli and other *brassica* vegetables. Plants can be attacked from the cotyledon stage, during seedling production and to the mature stage in the field (Koefet and Fink, 2007). The development of sporulating lesions of *H. parasitica* in adult plant induces defoliation and early leaf senescence including reduced yield and head quality of both broccoli and cauliflower as the case may be (Achar, 1998; Gisi and Sierotzki, 2008).

Epidemiology: Numerous workers have suggested different temperature conditions and humidity for the occurrence of infection and germination of spores. It was found that after incubation periods of 12 to 24 h at 20-25ºC, the proportion of infection were approximately 60% in radish. In addition, prolonged incubation periods of about 48 h increased proportions of infection from 50-90% at 15ºC and 60 to 100% at 25ºC. Sporulation can also occur overnight in a temperature range of 20-24ºC. However, maximum sporulation intensities were found between 12 and 16ºC and generally sporulation intensity increased with a prolonged duration of favourable moist conditions (Koefet and Fink, 2007). The temperature range for maximum infection of seedlings of a highly susceptible cabbage cultivar and subsequent disease development invitro was 15-25ºC and 90-100% infection was achieved after 48 h of incubation (Pajot *et al*., 2000).

Control measures: The control measures which have been developed include the followings:

- Different fungicides have been screened for their efficacy. A mixture of cymoxanil and mancozeb was consistently found to be most effective against crucifer downy mildew. Site specific fungicides as phenylamides, Quinone outside Inhibitors, Corboxylic Acid Amides have also been found effective against downy mildew (Monot *et al*., 2002).
- Apart from fungicides, other various formulations have been found effective against downy mildew. Phytogard containing 58% potassium phosphonate (K_2HPO_3) and 42% water at a concentration of 7.0 ml/L for seedlings and 10 ml/l for young plants were also found effective. However, the resistance was not systemic and lasted for 15 days after treatment (Monot *et al*., 2002).
- Systemic resistance was induced in Broccoli by avirulent isolates and disease incidence was reduced from 40-70% (Sousa *et al*., 1997; Coelho and Monterio, 2003).
- Resistant and susceptible varieties have been identified by many other workers (Farnham *et al*., 2002).
- Inheritance of resistance against downy mildew was studied, which suggested a dominant character controlled by a single locus (Farinho *et al*., 2007; Chan, 1999). Pp523 locus that includes single

dominant gene conferring resistance to downy mildew was identified and mapped. AFLP marker and five DNA markers encompassing the Pp523 genes were cloned and sequenced. These markers can be used in marker assisted selection in breeding programmes aimed at the introgression of the Pp523 resistance locus (Yang *et al*., 2007).

Damping-off: *Rhizoctonia solani* is an important seed and soil borne pathogens associated with seed rot and seedling decay in vegetables (Pitt, 1964), thus, reducing germination and causing pre and post-emergence damping-off in seedlings resulting in a poor plant stand (Van Bruggen *et al*., 1986). The population of *R. solani* that infects oilseed rape and canola is mainly composed of anastomosis groups AG2-1 and AG4, which cause pre- and post-emergence seedling damping-off, seedling root rot and basal stem or foot rot (brown girdling root rot) of adult plants.

Epidemiology: There are discrepancies in the literature concerning the different response of R. solani isolates to moisture and temperature conditions as this may relate to a change in the taxonomy of this fungus. Pitt (1964) and Van Bruggen *et al.* (1986), who worked on cereal and beans, respectively showed that disease was greater in dry soil than in wet soil (Bateman, 1961; Roth and Riker, 1943). Other workers in a similar studies showed that disease incidence and severity increased from dry to moist soil; then decreased from moist to wet soil, probably due to lack of aeration (Roth and Riker, 1943; Wright, 1957; Bateman, 1961), However, Shehata *et al.* (1984) showed that AG4 isolates of *R. solani* were favoured by relatively abundant soil moisture. In addition, high temperature also favoured the development of *R. Solani* (Walker, 1928; Abdel-Salam, 1933; Smith, 1946; Sumner, 1974). However, Pitt has shown that *R. solani* grows well in low temperature. The temperature and moisture conditions suitable for the disease vary due to the infection by different anastomosis groups. Hence more specific identification of the anastomosis group of *Rhizoctonia* occurring on *brassica* vegetables is required.

Control measures: A lot of control measures have been developed and these include the followings:

- Daghman *et al.* (2006) evaluated *Trichoderma herzianum* (UPM40) with compost (OPTCD) as the food base carrier for the control of *Rhizoctonia* damping-off in leaf mustard (*Brassica rapa* L.). It was also found that the loss in emergence were only 2.83 and 3.71%, respectively as compared with 21.9% in the untreated soil (Nath *et al*., 2000).
- Screening of genotypes for resistance to pre-emergence damping-off and post-emergence seedling root rot caused by *Rhizoctonia solani* AG-2-1 was also done by various workers (Verma and Saharan 1994; Yang *et al*., 2007). They did not find immune varieties, but, susceptibilities to the disease varied in different cultivars. However, significant correlations were obtained between percentage pre-emergence damping-off and percentage disease ratings of 3-week-old (r = 0.75) and 5-week-old (r = 0.76) plants. In addition, the plants became less susceptible with age and progenies from the disease-free plants of *B. napus* cv. Midas showed a higher level of resistance than the original parental strains, indicating that resistance could be improved through selection (Nath *et al*., 2000).
- Hiroyoshi Shiraishi *et al*. (2003) also evaluated the usefulness of Collembola species, Folsomia hidakana Uchida et Tamura for preventing damping-off in cabbage (*B. oleracea capitata*) and Chinese cabbage (*Brassica rape var. pekinensis*) in a green house. However, the severity of the disease was reduced to 82-87% (Liu and Rimmer, 1990).

White rust: White rust caused by *Albugo candida* is an important disease of rapeseed (*Brassica campestris L.*) and mustard (*Brassica juncea Coss.)* in India (Shiraishi *et al*., 2003). Symptoms of white rust begin as chlorotic lesions on the upper leaf surface and as the lesions develop small white pustules (sori) containing sporangia are produced on the underside of the leaf and occasionally on the upper leaf surface.

Epidemiology: Primary infection is thought to occur from soil borne oospores that are splashed on plants by rainfall or overhead irrigation or by airborne sporangia. While, secondary infection results from airborne sporangia discharged from pustules. These sporangia are produced in pustules and once liberated are dispersed by wind, rain, or insects to neighbouring plants. In addition, each germinating sporangium gives rise to five to seven zoospores. Moreover, a higher day/night temperature was found to be more favourable to white rust development than the lower ones. Temperatures should be between 16 and 25ºC with the optimum being at 20ºC for zoospores to produce germ tubes and penetrate plant tissue. This is in agreement with Verma and Saharan (1994) who reported that optimum temperature for white rust development on *Brassica rapa* was 18-21ºC (Liu and Rimmer, 1990).

Control measures: The control measures developed by different workers include the following:

- Development and validation of CAPS and AFLP markers for marker assisted selection for fungi -

disease resistance plant has been done by Somers *et al.* (2002) and Varshney *et al.* (2004).

- New sources of resistance to white rust have been explored by workers like Santos *et al.* (2006) amongst others.
- In another investigation of the interaction between two isolates of *Albugo candida* that were compatible (CO) and incompatible (IN) on a *Brassica juncea* accession, the IN isolate induced both local and systemic protection of cotyledons and true leaves against the CO isolate. However, the extent of the protection was proportional to the zoosporangia concentration used in the inducing (IN) inoculation. Protection was greatest locally on cotyledons and least on true leaves (the most remote tissue from the point of the inducing inoculation). In addition, protection also occurred when the two isolates were inoculated together, but, this was greater when the interval between the IN and CO isolate inoculations was longer. The IN isolates induced only slight protection when it was inoculated after the CO isolates (Santos *et al*., 2006). Four accessions of *B. rapa chinensis* presented more than 50% of resistant plants: the *pak choi* (*BRA 117*) was the most resistant accession with 85% of resistant plants, followed by *pak choi* (*BRA227*) with 73%, *pai tsai 'Ex China 1'* (*B00083*) with 60% and *pak choi 'Ai Jiao Huang'* (*BRA 225*) with 53%. On the contrary, *B. rapa pekinensis* accessions were all considered as susceptible, presenting only 0-11% of resistant plants.

DISCUSSION

A lot of workers have reported varying temperature and moisture conditions for the different fungal infection of plants as numerated above amidst controversy over the conditions required for optimized fungi growth. However, optimum temperature and high moisture conditions are generally required for the occurrence and prevalence of the disease (Table 1, Fig. 1 and 2). More work is still needed in this regard for us to know the optimum conditions required for the disease occurrence, so that effective methods can be employed for their control. Moreover, different practices are now being employed

Table 1: Occurrence of disease in different temperature and moisture conditions

Disease	Temperature (ºC)	Moisture (%)
Alternaria blight	15-30	65
BlackLeg	14	100
Clubroot	18-23	70
Downy mildew	15-25	95
Damping off	16-25	90-95

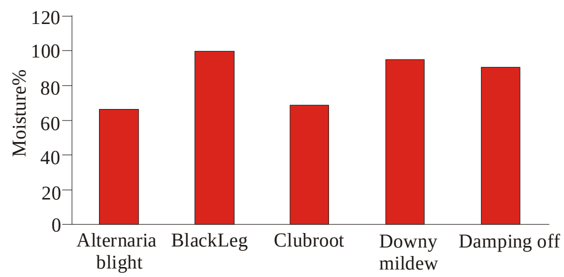

Fig. 1: Moisture conditions required for occurrence of different pathogens

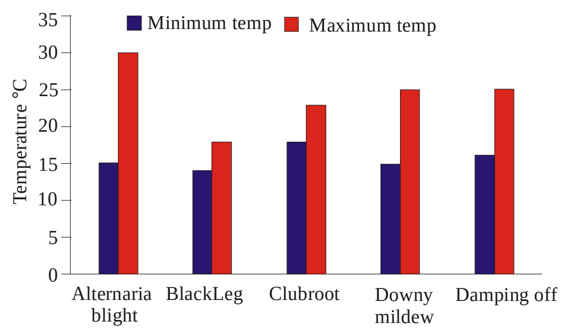

Fig. 2: Temperature range required for occurrence of pathogen

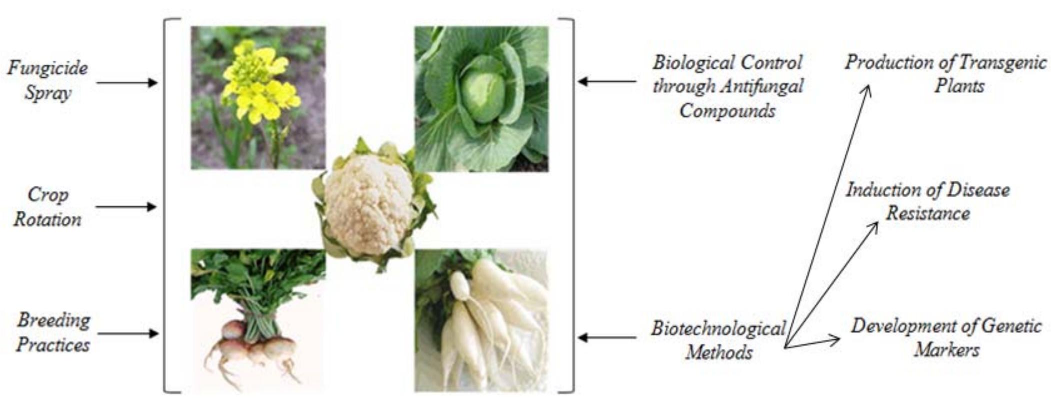

Fig. 3: Different practices for control of fungal disease

to control the disease in plants (Fig. 3). Though transgenic plants with disease resistance genes are being developed; their practical efficiency on the field is still doubted. Therefore, the need for field productivity of any biotechnological approach should be stressed.

In addition, breeding practices by selection of resistant cultivars seem to be the best approach for fungal control as fungicide application has been prohibited due to their environmental impact and concern.

CONCLUSION

Fungal diseases are responsible for significant loss of crops. However, understanding the epidemiological conditions can help in the control of disease. From the above discussion it is obvious that optimum temperature and high moisture conditions are required for the occurrence of the fungal disease. High humidity should be avoided for the storage of crops. Above review provides a comprehensive assessment of the different practices being used for the control of the disease however, breeding techniques seem to be the best approach to improve the genetic line of plants as the field efficiency of the genetically engineered plants is questionable. To conclude this review, we suggest that more biological methods should be developed in order to have more effective control of fungal pathogens in plant for the future.

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REFERENCES

Abdel-Farida, I.B., M. Jahangira, C.A.M.J.J. Van den Hondelc, H.K. Kima, Y.H. Choi and R. Verpoorte, 2009. Fungal infection-induced metabolites in *Brassica rapa*. Plant Sci., 176: 608-615.

Abdel-Salem, M.M., 1933. Damping off and other allied disease of lettuce. Promot. Horti. Sci., 11: 259.

Achar, P.N., 1998. Effects of temperature on germination of Peronospora parasitica Conidia and infection of *Brassica oleracea*. J. Phytopathol., 146: 137-141.

Ames, B.N., M.K. Shigenaga and T.M. Hagen, 1993. Oxidants, antioxidants, and the degenerative diseases of aging. Proc. Natl. Acad. Sci., 90: 7915-7922.

Ando, S., T. Asan, S. Tsushima, S. Kamachi, T. Hagio and Y. Tabei, 2005. Changes in gene expression of putative isopentenyltransferase during clubroot development in Chinese cabbage (*Brassica rapa* L.). Physiol. Mol. Plant P., 67: 59-67.

Ansari, A.N., M.W. Khan and A. Muheet, 1988. Effect of Alternaria blight on oilcontent of rapeseed-mustard. Curr. Sci., 57: 1023-1024.

Bateman, D.F., 1961. The effect of soil moisture upon development of poinsettia root rots. Phytopathology, 51: 445-451.

Bochow, H., 1989. Possibilities of protecting plant roots against phytopathogens by biological means (biological control). Dev. Soil Sci., 18: 357-370.

Braselton, J.P., 1995. Current status of the plasmodiophorids. Crit. Rev. Microbiol., 21: 263-275.

Chan, L.L., 1999. Biological seed treatment for the control of rhizoctonia damping off of choysam. B.Sc. Bioindustry Thesis, University Putra Malaysia, Malaysia.

Chauhan, J.S., A. Badoni, N.I. Singh and S. Ali, 2009. Effect of Alternaria on some members of family brassicaceae of garhwal himalaya. New York Sci., 2: 80-85.

Chu, Y.F., J. Sun., X. Wu. and R.H. Liu, 2002. Antioxidant and antiproliferative activities of common vegetables. J. Agr. Food Chem., 50: 6910-6916.

Coelho, P.S. and A.A. Monterio, 2003. Inheritance of downy mildew resistance in mature broccoli plants. Euphytica, 131: 65-69.

Cohen, J., R. Kristal and J. Stanford, 2000. Fruit and vegetable intakes and prostate cancer. J. National Cancer Institute, 9: 61-68.

Colhouna, J., 1953. A Study of the epidemiology of club-root disease of brassiceae. Ann. Appl. Biol., 40: 262-283.

Craig, W.J., 1997. Phytochemicals: Guardians of our Health. J. Am. Dietetic Assoc., 97: 199-204.

Daghman, I.M., M. Sariah, J. Kadir, M.A. Zainal Abidin and A.B. Rosenani, 2006. Dry preparation of Trichoderma harzianum for controlling Rhizoctonia damping-off in *Brassica rapa*. Int. J. Agric. Res., 1: 590-596.

Di Matteo, V. and E. Esposito, 2003. Biochemical and therapeutic effects of antioxidants in the treatment of Alzeimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis. Curr. Drug Target CNS Neurol. Disord., 2: 95-107.

Doullah, M.A.U., M.B. Meah and K. Okazaki, 2006. Development of an effective screening method for partial resistance to Alternaria brassicicola (dark leaf spot) in *Brassica rapa*. Eur. J. Plant Pathol., 116: 33-43.

Farinho, M., P. Coelho, A. Monterio and J. Leitao, 2007. SCAR and CAPS markers flanking the *Brassica oleracea* L. Pp523 downy mildew resistance locus demarcate a genomic region syntenic to the top arm end of Arabidopsis thaliana *L. chromosome* 1. Euphytica, 157: 215-221.

Farnham, M.W., M. Wang and C.E. Thomas, 2002. A single dominant gene for Downy mildew resistance in broccoli. Euphytica, 128: 405-407.

Fernandoa, W.G.D., Y. Chena and K. Ghanbarnia, 2007. Breeding for blackleg resistance: The biology and epidemiology. Adv. Bot. Res., 45: 271-311.

Gerber, M., M.C. Boutron-Ruault, S. Hercberg, A. Riboli Scalbert and M.H. Siess, 2002. Food and cancer: State of the art about the protective effect of fruits and vegetables. Bulletin du Cancer, 89: 293-312.

Gisi, U. and H. Sierotzki, 2008. Fungicide modes of action and resistance in Downy mildews. Eur. J. Plant Pathol., 122: 157-167.

Gosende, S., A. Penaud, J.N. Aubertot, O. Schneider and X. Pinochet, 2003. Evolution of soil surface oil seed rape stubbles and their ability to produce spores of Leptosphareia maculans: Preliminary results. Proceeding 11th International Rapeseed Congress, Copenhagen, Denmark, pp: 1166-1168.

Guo, X.W., W.G.D. Fernandoa and M. Entz, 2005. Effect of crop rotation and tillage on blackleg disease on canola. Can. J. Plant Pathol., 27: 53-57.

Hildebrand, P.D. and K.B. McRae, 1998. Control of clubroot caused by *Plasmodiophora brassicae* with nonionic surfactants. Can. J. Plant Pathol., 20: 1-136.

Humpherson-Jones, F.M. and R.B. Maude, 1982. Studies on the epidemiology of Alternaria brassicicola in *Brassica oleracea* seed production crops. Ann. Appl. Biol., 100: 61-71.

Humpherson-Jones, F. M., 1989. Survival of *Alternaria brassicae* and *Alternaria brassicicola* on crop debris of oilseed rape and cabbage. Ann. Appl. Biol., 115: 45-50.

Ingram, D.S. and I.C. Tommerup, 1972. The life history of *Plasmodiophora brassicae* Woron. Proc. Roy. Soc. London B., 180: 103-112.

Jensen, B.D., J. Hockenhull and L. Munk, 1999. Seedling and adult plant resistance to downy mildew (Peronospora parasitica) in cauliflower (*Brassica oleracea convar. botrytis var. botrytis*). Plant Pathol., 48: 604-612.

Khangura, R., J. Speijers, M.J. Barbetti, M.U. Salam and A.J. Diggle, 2007. Epidemiology of Blackleg (Leptosphaeria maculans) of Canola (*Brassica napus*) in relation to maturation of pseudothecia and discharge of ascospores in Western Australia. Phytopathology, 97: 1011-1021.

Koefet, A. and M. Fink, 2007. Development of Peronospora parasitica epidemics on radish as modelled by the effects of water vapour and saturation deficit. Eur. J. Plant Pathol., 17: 369-381.

Kolte, S.J., R.P. Awasthi and Viswanath, 1988. Assessment of yield losses due to Alternaria blight in rapeseed-mustard. Indian Phytopath., 40: 209-211.

Kris-Etherton, P.M., K.D. Hecker, A. Bonanome, S.M. Coval, A.E. Binkoski, K.F. Hilpert, A.E. Griel and T.D. Etherton, 2002. Bioactive compounds in foods: their role in the prevention of cardiovascular diseases and cancer. Am. J. Med., 113: 71-88.

Liu, Q. and S.R. Rimmer, 1990. Effects of host genotype, inoculation concentration and incubation temperature on white rust development in oilseed rape. Can. J. Plant Pathol., 12: 389-392.

Ludwig-Müller, J., 1999. *Plasmodiophora brassicae*, the causal agent of clubroot disease: A review on molecular and biochemical events in pathogenesis. J. Plant. Dis. Prot., 106: 109-127.

Meena, P.D., R.L. Meena, C. Chattopadhyay and A. Kumar, 2004. Identification of critical stage of disease development and biocontrol of alternaria blight of Indian mustard (*Brassica juncea*). J. Phytopath., 152: 204-209.

Mondal, K.K., S.C. Chatterjee, N. Viswakarma, R.C. Bhattacharya and A. Grover, 2003. Chitinase-mediated inhibitory activity of *Brassica* transgenic on growth of *Alternaria brassicae*. Curr. Microbiol., 47: 171-173.

Mondal, L., C.K. Bhunia and A. Baswas, 2008. Efficacy of new bio-fungicides *in vivo* against Alternaria blight disease of rapeseed-mustard. Green Farm., 1: 41-44.

Monot, C., E. Pajot, D.L. Corre and D. Silue, 2002. Induction of systemic resistance in broccoli (*Brassica oleracea var. botrytis*) against downy mildew (*Peronospora parasitica*) by avirulent isolates. Biol. Control, 24: 75-81.

Morrall, R.A.A., D.A. Kaminski and L.A. Kaminski, 1999. The 1996-98 Western Canada Disease Survey; do Agronomic Practices affect Disease or Vice Versa? Proceedings of the the 10th International Rapeseed Congress, Canberra, Australia, Retrieved from: http://www.regional.org.au/au/gcirc/3/164.htm.

Nath, M.D., S.L. Sharma and U. Kant, 2000. Growth of Albugo candida infected mustard callus in culture. Mycopathologia, 152: 147-153.

Nisar, A., M. Ansari, W. Khan and A. Muheet, 1990. Evaluation of some fungicides for seed treatment and foliar application in management of damping-off of seedlings and blight of rapeseed caused by *Alternaria brassicae*. Mycopathologia, 110: 163-167.

Niu, X., H. Leung, P.H. Williams, 1983. Sources and nature of resistance to downy mildew and turnip mosaic virus in Chinese cabbage. J. Am. Soc. Hortic. Sci., 108: 775-778.

Pajot, E., D.L. Corre, C. Monot and D. Silue, 2000. Stéphanie Bécot, Phytogard® (K_2HPO_3) induces localized resistance in cauliflower to downy mildew of crucifers. Crop Prot., 19: 417-425.

Perres, A., B. Poisson, A. Penaud, L. Jain and Pillorge, 1999. Leptosphaeria maculans: a summary of three years of epidemiological studies (1997, 1998, 1999). Proceeding 10th International Rapeseed Congress, Canberra, Australia.

Petrie, G.A., 1986. Consequences of survival of *Leptosphaeria maculans* (blackleg) in canola stubble residue through an entire crop rotation sequence. Can. J. Plant Pathol., 8: 353.

Piao, Z., N. Ramchiary and Y.P. Lim, 2009. Genetics of clubroot resistance in *Brassica* species. J. Plant Growth Regul., 28: 252-264.

Pitt, D., 1964. Studies on sharp eye spot disease of cereals I. Disease symptoms and pathogenicity of isolates of Rhizoctonia solani Kuhn and the influence of soil factors and temperature on disease development. Ann. Appl. Biol., 54: 77-89.

Podsedek, A., 2007. Natural antioxidants and antioxidant capacity of *Brassica* vegetables: A review. LWT-Food Sci. Technol., 40: 1-11.

Roth, L.F. and A.J. Riker, 1943. Influence of temperature, moisture and soil reaction on the damping off of red pine seedling by pythium and Rhizoctonia. J. Agric. Res., 67: 273-293.

Sangeetah, C.G. and A.L. Siddaramaiah, 2007. Epidemiological studies of white rust, downy mildew and *Alternaria blight* of Indian mustard (*Brassica juncea* (Linn.) Czern and Coss). Afr. J. Agric. Res., 2: 305-308.

Santos, M.R., J.S. Dias., M.J. Silva and M.M Ferreira-Pinto, 2006. Resistance to white rust in pak choi and Chinese cabbage at the cotyledon stage. Commun. Agric. Appl. Biol. Sci., 71: 963-971.

Serafini, M., R. Bellocco, A. Wolk and A.M. Ekstrom, 2002. Total antioxidant potential of fruit and vegetables and risk of gastric cancer. Gastroenterology, 123: 985-999.

Sharma, A.K., J.S. Gupta and R.K. Maheshwari, 1984. The relationship of Streptomyces arabicus to *Alternaria brassicae* (Berk.) Sacc. and *Alternaria brassicicola* (Schew.) Wiltshire on the leaf surface of yellow sarson and taramira. Geobios New Reports, 3: 83-84.

Sharma, A.K., J.S. Gupta and S.P. Singh, 1985. Effect of temperature on the antifungal activity of Streptomyces arabicus against *Alternaria brassicae* (Berk) Sacc. and *A. brassicicola* (Schew.). Wiltshire Geobios, 12: 168-169.

Shehata, M.A., D.W. Davis and N.A. Anderson, 1984. Resistance to Rhizoctonia stem rot in peas as influenced by temperature, watering method and period of disease development. Plant Dis., 68: 22-24.

Shiraishi, H., Y. Enami and S. Okano, 2003. Folsomia hidakana (Collembola) prevents damping-off disease in cabbage and Chinese cabbage by Rhizoctonia solani. Pedobiologia, 47: 33-38.

Smith, O.F., 1946. Effect of soil temperature on the development of Rhizoctonia root canker of alfalfa. Phytopathology, 36: 638-642.

Soledade, M., C. Pedras and M. Jha, 2006. Toward the control of Leptosphaeria maculans: Design, syntheses, biological activity and metabolism of potential detoxification inhibitors of the crucifer phytoalexin brassinin. Bioorg. Med. Chem., 14: 4958-4979.

Somers, D.J., G. Rakow and S.R. Rimmer, 2002. *Brassica napus* DNA markers linked to white rust resistance in *Brassica juncea*. Theor. Appl. Genet., 104: 1121-1124.

Sousa, M.E., J.S. Dias and A.A. Monteiro, 1997. Screening Portuguese cole landraces for resistance to seven indigenous downy mildew isolates. Sci. Hortic., 68: 49-58.

Srivastava, M., B.A. Akhoon, S.K. Gupta and S.K. Gupta, 2010. Development of resistance against Blackleg disease in *Brassica oleracea var. botrytis* through in silico methods. Fungal Genet. Biol., 47: 800-808.

Sumner, D.R., 1974. Ecology and control of seedling diseases of crucifers. Phytopathology, 64: 692-697.

Taj, G., A. Kumar, K.C. Bansal and G.K. Garg, 2004. Introgression of osmotin gene for creation of resistance against Alternaria blight by perturbation of cell cycle machinery. Indian J. Biotechnol., 3: 291-298.

Valkonen, J.P.T. and H. Koponen, 1990. The seed-borne fungi of Chinese cabbage (*Brassica pekinensis*), their pathogenicity and control. Plant Pathol., 39: 510-516.

Van Bruggen, A.H.C., A.H. Walen and P.A. Arneson, 1986. Emergence growth and development of dry bean seedlings in response to temperature, soil, moisture and Rhizoctonia solani. Phytopathology, 76: 568-572.

Vanniasingham, V.M. and C.A. Gilligan, 1989. Effects of host, pathogen and environmental factors on latent period and production of pycnidia of *Leptosphaeria maculans* on oilseed rape leaves in controlled environments. Mycological. Res., 93: 167-174.

Varshney, A., T. Mahapatra and R.P. Sharma, 2004. Development and validation of CAPS and AFLP markers for white rust resistance gene in *Brassica juncea*. Theor. Appl. Genet., 109: 153-159.

Verma, P.R. and G.S. Saharan, 1994. Monograph on Alternaria Diseases of Crucifers. Agriculture and Agri-Food Canada, pp: 162.

Vishwanath, S., J. Kolte, M.P. Singh and R.P. Awasthi, 1999. Induction of resistance in mustard (*Brassica juncea*) against *Alternaria* black spot with an avirulent *Alternaria brassicae* Isolate-D. Eur. J. Plant Pathol., 105: 217-220.

Walker, M.N., 1928. Soil temperature studies with cotton. III Relation of soil temperature and soil moisture to the soreshin disease of cotton. Agric. Expt. Stn., Vol. 197.

Wright, E., 1957. Influence of temperature and moisture on damping-off of American and Siberian elm, black locust, and desert willow. Phytopathology, 47: 658-662.

Yang, B., S. Srivastava, M.K. Deyholos and N.N.V. Kav, 2007. Transcriptional profiling of canola (*Brassica napus* L.) responses to the fungal pathogen *Sclerotinia sclerotiorum*. Plant Sci., 173: 156-171.