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Invited Review Article

Bipolaris sorokiniana (Sacc.) Shoem.: The most destructive wheat fungal pathogen in the warmer areas

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Abstract

In recent years, spot blotch disease, caused by *Bipolaris sorokiniana* (Sacc.) Shoem. syn. *Drechslera sorokiniana* (Sacc.) Subrm and Jain (syn. *Helminthosporium sativum*, teleomorph *Cochliobolus sativus*) have emerged as serious concern for cultivation of wheat in warmer and humid regions of the world. During past two decades, substantial economic loss in wheat production has occurred due to the severity of spot blotch, affecting the livelihood of millions of small-scale farmers. Besides spot blotch, this fungus is also the causal agent of other diseases like common root rot, foot rot, seedling blight and seed rot of wheat. In this review, we have focused on the details of the pathogen and its management approaches. The disease severity is directly related to the humidity, temperature and soil nutrient condition. The greatest yield losses occur when the flag leaf and the leaf below the flag leaf become infected before the emergence of head. Crop rotation and burying wheat stubble by tillage can reduce the level of disease early in the season. Seed treatments are effective in eliminating the fungus on the seed. Application of fungicides is another means of disease prevention. Several sources have also been identified for improving resistance among susceptible commercial cultivars. Although a number of attempts have been made to control the disease, still, field results show that spot blotch continues to cause substantial grain yield reductions and underscore the need for further research.

Keywords: *Cochliobolus sativus*, control measures, disease cycle, spot blotch, wheat disease.

Abbreviations: ARS, Agricultural Research Services; AUDPC, area under disease progress curve; CIMMYT, International Maize and Wheat Improvement Centre; HLB, *Helminthosporium* leaf blight; PCNB, pentachloronitrobenzene; USDA, United States Department of Agriculture.

Introduction

The world's population is increasing by one billion in every 11 years and at the present rate, it is expected to be 8.5 billion by the year 2025. Keeping pace with the increasing population and from the point of their future food security, sustained increase of wheat production and productivity is well understood in different corners of the world. Wheat grains are highly nutritive as they are rich in energy, carbohydrates, dietary fibre, fat, protein, thiamine, riboflavin, niacin, pantothenic acid, vitamin B6, folate, calcium, iron, magnesium, phosphorus, potassium, zinc and manganese (USDA-National Nutrient Database for Standard Reference, Release 19 (2006)). Due to the high nutritive value, wheat grains are eaten in various forms across cultures and continents. Recent yield trials conducted by different breeding centres around the world have shown that the production of bread wheat (*Triticum aestivum* L.) is being constrained by several biotic and abiotic stresses (Dubin and van Ginkel 1991; Hobbs and Giri 1997; Dubin and Duveiller 2000; Regmi et al., 2002; Sharma and Duveiller 2003; Duveiller, 2004). The warmer parts of the world (Table. 1, Fig. 1) like Latin America, Africa, Asia, Southern Asia etc., are mainly affected by *Bipolaris sorokiniana* (Sacc.) Shoemaker [teleomorph, *Cochliobolus sativus* (S. Ito & Kurib.) Drechsler ex Dastur] a notorious wheat fungal pathogen (Dubin and van Ginkel 1991). This fungus act as a causal agent for various diseases like head blight, seedling blight, foliar blight/ spot blotch, common root rot and black point of wheat, barley, other small cereal grains and grasses (Zillinsky, 1983; Wiese, 1998). Among the all diseases, caused by this pathogen spot blotch of wheat is considered as one of the most important diseases in those mega environment which is characterised by high temperature (coolest month greater than 17˚C) and high humidity (van Ginkel and Rajaram 1993). However, it is also gradually instigating serious concerns among places with irrigated, low rainfall and temperate growing conditions (van Ginkel and Rajaram 1993; CIMMYT, 1995). Globally, an estimated 25 million hectares of wheat cultivated land is affected by spot blotch disease (van Ginkel and Rajaram 1998). Indian sub-continent has 10 million ha of affected land, out of which India alone has 9 million ha, most of which is in the rice-wheat cropping system (Nagarajan and Kumar 1998). The widely applied rice-wheat cropping system of South Asia provides favourable environment for the survival and multiplication of foliar blight pathogens because rice serves as a host for the spot blotch fungi and rice stubble plays its role as a substrate for the fungi after rice harvest (Saari, 1998).

Table 1. Worldwide distribution of *Bipolaris sorokiniana*

Continent	Country	Reference
Africa	Kenya, Malawi, Sudan, South Africa, Tanzania, Zimbabwe	
Asia	China, Korea, India, Indonesia, Taiwan, Thailand	USDA ARS Fungal Database
Australia	Australia, New Zealand, Papua New Guinea	
Europe	Austria, Belgium, Czechoslovakia, Denmark, Germany, Greece, Hungary, Italy, Poland, Scotland, United Kingdom, USSR	
North America	Indiana, Kansas, Minnesota, Montana, North Dakota, South Dakota, Utah, Virginia	
South America	Argentina, Brazil	

Fig 1. Distribution of *Bipolaris sorokiniana*: (a) Global and (b) in India

Yield Loss

The destructive capacity of this pathogen is evident from the reports around the world. Grain yield reductions due to spot blotch are variable but are of great significance in warmer areas of South Asia (Saari, 1998; Sharma and Duveiller 2004). On an average, a South Asian country loses 20% of crop yield through leaf blight disease (Saari, 1998). Grain yield loss due to spot blotch in South Asia ranged from 4% to 38% and 25% to 43% in the year 2004 and 2005 respectively and the number of kernels per spike as well as thousand-kernel weight were reduced respectively by 10% and 15% in 2004 and 11% and 18% in 2005 (Sharma et al., 2006). Yield loss was estimated to be 18-22% in India (Singh et al., 1997), which can be devastating for farmers in the Eastern Gangetic Plains, who frequently have small holdings with little land or profitability (Joshi et al., 2007). In Nepal, under rice-wheat cropping system, spot blight severity went up to 100% and 70% in 2004 and 2005 respectively (Sharma and Duveiller 2007). Spot blotch has been reported to cause 15% grain yield reduction in Bangladesh (Alam et al., 1998) and China (Xiao et al., 1998). The pathogen also causes grain yield losses up to 10, 15, and 20% through common root rot and seedling blight in countries like Scotland, Canada, Brazil etc. (Murray et al., 1998).

The Pathogen

Cochliobolus sativus (S. Ito & Kurib.) Drechsler ex Dastur, *Indian Journal of Agricultural Research* 12: 733 (1942)

Synonyms

Bipolaris californica (Mackie & G.E. Paxton) Gornostaĭ [as '*californicum*'], in Azbukina et al. (eds), *Vodorosli, Griby i Mkhi Dal'nego Vostoka* (Vladivostok): 80 (1978)
Bipolaris sorokiniana (Sacc.) Shoemaker, *Can. J. Bot.* 37(5): 884 (1959)
Drechslera sorokiniana (Sacc.) Subram. & B.L. Jain, *Curr. Sci.* 35: 354 (1966)
Helminthosporium acrothecioides Lindf., (1918)
Helminthosporium californicum Mackie & G.E. Paxton (1923)
Helminthosporium sativum Pammel, C.M. King & Bakke, *Bulletin of Iowa State College* 116: (1910)
Helminthosporium sorokinianum Sacc. (1890)
Ophiobolus sativus S. Ito & Kurib., *Trans. Sapporo nat. Hist. Soc.* 10: 138 (1929)
(http://www.indexfungorum.org/Names/SynSpecies.asp?RecordID=285403)

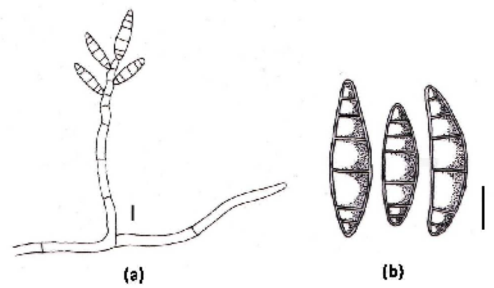

Fig 2. Conidiophore and conidia of *Bipolaris sorokiniana* , bar = 20 µm.

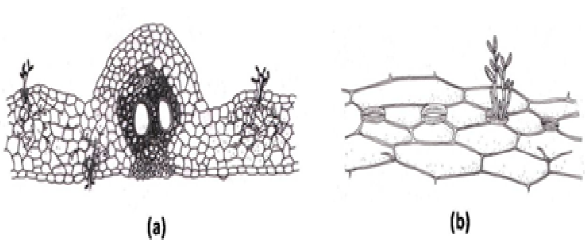

Fig 3. Histology of an infected wheat leaf showing ramifications of *Bipolaris sorokiniana* hyphae along with conidia and conidiophores protruding through stomata. (a) VS through infected leaf; (b) Surface view of the infected leaf.

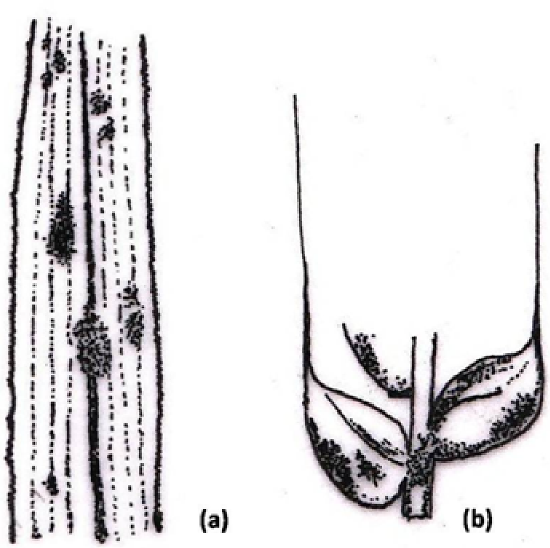

Fig 4. Symptoms of *Bipolaris sorokiniana* : (a) spot blotch lesions on wheat leaf, (b) infection in spikelet.

The fungus *C. sativus* is the telemorph (Sexual stage) of *B. sorokiniana* (anamorph) which is the causal agent of wide variety of diseases. *B. sorokiniana* belongs to the division-Eumycota, subdivision-Deuteromycotina, class-Hyphomycetes, subclass-Sporomycetidae, order-Moniliales and family-Dematiaceae. After the discovery of perfect stage, *C. sativus*, the fungus was transferred under the subdivision-Ascomycotina, class-Loculoascomycetes, order-Pleosporales and family-Pleosporaceae. The genus *Cochliobolus* produces globose ascomata with a long cylindrical neck, obclavate cylindrical asci, and helically coiled filiform ascospores. Mycelium of *B. sorokiniana* is olive-brown and it produces light grey colonies at early stage of growth in potato dextrose agar medium, later turns into black to olivaceous black. Conidiophores are 6-10 × 110-220 µm, brown, erect, unbranched, single or clustered, septate (Fig. 2a). Conidia are 15-28 × 40-120 µm, straight to slightly curved, oblong, fusiform to broadly ellipsoid, olive brown to dark brown, tapered towards the end and have a prominent basal scar, smooth walled and having 3-10 thick walled transverse septa (Jones and Clifford 1983; Mathre, 1987) (Fig. 2b). In the host tissue, it produces septate mycelium, which ramifies both inter- and intra-cellularly. Conidiophores are long, septate, simple, dark brown to olivaceous at the base and somewhat paler at the growing tip. They arise in tufts through stomata, ruptured epidermis or wounds (Fig. 3) and produce conidia successively on new growing points. The points of attachment of successive conidia are marked by scars at the regular intervals on the condiophores. The perfect stage i.e., the ascigenous state was observed in the laboratory on natural media in the presence of opposite mating types, and was first described as *Ophiobolus sativus*. It was later renamed *C. sativus* (Ito & Kuribayashi) Drechsler ex Dastur, 1942 (Dastur, 1942). Under natural conditions, the perfect stage was only found in Zambia (Raemaekers, 1988), and it has not been reported to occur in any other pathogen dominated areas.

Symptoms

Symptoms mainly develop on sub-crown internodes, stem, leaves, awns, glumes and seeds. The main symptom caused by the pathogen is spot blotch, which is nothing but the disease of leaves. The early lesions on leaves are 1-2 mm long, small and dark brown in colour. There is no sign of chlorotic margin at the initial stage of infection. In the later stage in case of a susceptible genotype the small lesions extends very rapidly and ultimately reach into several centimetres (Fig. 4a). When the infection occurs into the spikelet (Fig. 4b); it results into shrivelled grain and the embryo end of the seed becomes dark in colour. Diseased seedlings develop dark brown lesion on the coleoptiles, crowns, stems and roots. Death of the seedlings may occur before or soon after emergence. Common root rot is distinguished by dark brown to black necrotic lesion on roots, subcrown, internodes and basal portion of the stem. At severity, multiple lesions often coalesce to form large areas of necrosis (Jones and Clifford 1983; Mathre, 1987). Plants with common root rot produce fewer tillers and fewer kernels per ear.

Epidemiology

Foliar blight development and severity of the disease is directly related to the minimum tillage or surface seeding, irrigation, low soil fertility, sowing density, crop growth

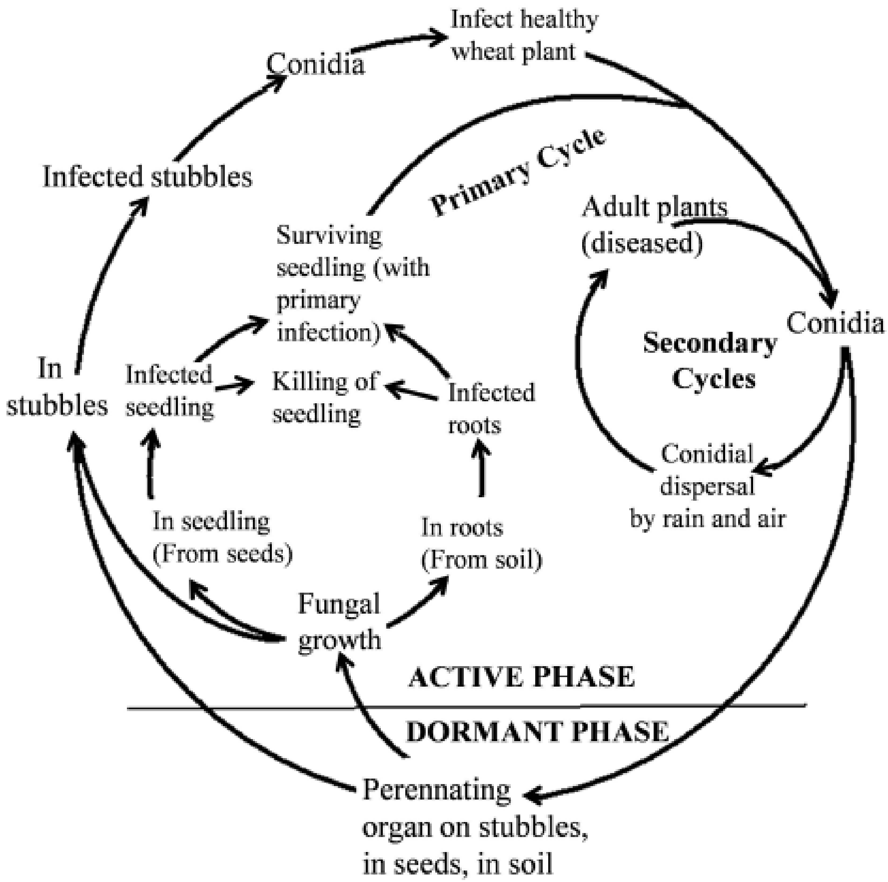

Fig 5. Disease cycle of *Bipolaris sorokiniana*.

stage, late rain during crop cycle, heat stress during grain filling as a result of late planting, high temperature in the field and relative humidity favouring long duration (>12 hours) of leaf wetness (Nema and Joshi 1973; da Luz and Bergstrom 1986; Saunders, 1988; Reis, 1991; Sentelhas et al., 1993; Sharma and Duveiller 2003; Duveiller, 2004; Duveiller et al., 2005). Even at the end of the monsoon and in absence of rainfall, high relative humidity arising from high levels of soil residual moisture along with foggy days allows long hours of wetness on leaf blades that can last until late January in Indo-Gangetic Plains, creating ideal conditions for the establishment and multiplication of wheat pathogen (White and Rodriguez-Aguilar 2001; de Lespiny, 2004). In Brazil, Reis (1991) suggested that, for foliar blight outbreaks to occur, wheat leaves must remain wet for >18 h at a mean temperature of 18˚C or higher.

Moderate to warm temperatures (18˚C to 32˚C) favours the growth of *B. sorokiniana*. In Asia, Nema and Joshi (1973) and Singh et al., (1998) reported that infection was more rapid and more severe at 28°C than at lower temperatures. Area under disease progress curve values (AUDPC), conducted during 26th November 2002 to 26th December 2003 for calculating the epidemiological study of disease development, increased significantly as a function of sowing time (Duveiller et al., 2005). The higher values of AUDPC/day or AUDPC/degree day under late-sown conditions are most likely caused by heat stress, which enhanced HLB development (Nema and Joshi 1973; Sharma and Duveiller 2003). Delayed seeding for wheat, grown after rice in eastern India and Nepal also results in higher losses of grain yield and total kernel weight due to foliar blight (Hobbs and Giri 1997; Singh et al., 1998; Duveiller et al., 2005).

Disease Cycle

B. sorokiniana is a saprophyte and survives primarily as thick walled conidia. The sexual stage is not important in the disease cycle. The pathogen perennates both externally as conidia and internally as mycelium in the seeds, as well as in infected crop residues, volunteer plants, secondary hosts and free dormant conidia in the soil (Reis, 1991). However, the role of infected seed as a primary source of inoculums appears to be important and according to Shaner (1981), it is the main source of inoculums of leaf blight pathogens. Along the germination of the diseased seeds, the perennating organs of the causal organism become active. This is the starting point of the disease. It germinates completely in four hours, and then appressoria forms at the juncture of epidermal cell wall after eight hours and hyphae from initially infected cells enter adjacent cells in 24 hours, which results in the granularisation of the host cytoplasm (Bisen and Channy 1983). Then fungus is transmitted to the plumules and coleoptiles tips with an efficiency reaching upto 87% (Reis and Forcelini 1993). Maximum development of symptoms appears when the leaves remain wet for more than 18 hours with a mean temperature greater than 18˚C (Couture and Sutton 1978).

Under favourable conditions, hypha produces conidiophores, which emerge out through stomata of the host tissue. The emerging conidiophores produce a succession of conidia, which are transmitted by rain splashes and wind, thus building up polycyclic epidemics. Conidia on germination produce germ tube, which is surrounded by thick mucilaginous substrata. This mucilaginous substratum enables the germinating conidia to remain adhered to the host surface. The germ tube then swells to produce appresorium from which infection hyphae are developed. The infection hyphae then enter the host tissue either through stomata or by rupturing through epidermis. Immediately after the entrance in the host tissue, the infection hypha divides rapidly and ramifies along the intercellular spaces of the mesophyll tissue (Fig. 5).

Control Measures

Disease incidents of wheat caused by *B. sorokiniana* can be controlled in a number of ways. Integrated pest management is by far the best method of controlling the pathogen (Mehta, 1993; Dubin and Duveiller 2000). Such program integrates the use of: (i) cultural practice, (ii) crop rotation, (iii) seed treatment, (iv) biological control, (v) foliar fungicide and (vi) disease resistant varieties.

Cultural practice

Sanitation is usually reserved for the physical measures that are used to eliminate sources of inoculums. Clearing or plugging the stubble, grass weeds and volunteer cereals reduce inoculums of *B. sorokiniana* (Diehl et al., 1982). Selection of disease free seeds and utilizing proper fertilization technique can also be effectively controlled spot blotch severity. In Brazil, it is recommended not to plant seed lots with more than 30% black point in order to limit spot blotch incidence (Reis, 1991). Macro and micronutrients have long been recognized as being associated with size, quality and yield of crops. Besides increasing grain quality, the main objective of nutrient application is also to protect crops against the pathogen. Macro and micronutrients helps plants to withstand pathogen attack at the time of stressful conditions and also provides advantage of plants and disadvantage to the pathogen (Palti, 1981). Good crop husbandry and optimum agronomy may also reduce spot blotch disease severity up to certain level (Sharma et al., 2006). In this connection limited previous studies were available to indicate the role of potash in reducing spot blotch severity (Krupinsky and Tanaka 2000; Regmi et al., 2002; Duveiller, 2004). Later during the year 2001 and 2002 a field study conducted in Rampur, Nepal, using two wheat varieties (Bhrikuti and Sonalika) to determine the effect of nitrogen, phosphorus, and potassium fertilization on reducing spot blotch severity. Results of this field study showed that the balanced application of nitrogen, phosphorous and potassium reduced disease severity by 15 and 22% respectively (Sharma et al., 2006). Potassium helps to prevent disease development by hindering multiplication, development and survival of pathogen and controlling the internal metabolism of the plant and thus affecting food supply for the pathogen, as well as preventing the establishment of the pathogen and its spread within the plant (Perrenoud, 1990).

Crop rotations

Crop rotation favours beneficial soil organisms as well as promotes better plant nutrition. According to Reis et al., (1998) eradicant fungicide treatment and crop rotation with non-host crops can control spot blotch. As this pathogen has a wide host range, so there are some difficulties to find out the suitable non-host crop. According to the report of Iftikhar et al., (2009) 11 plants including *Avena sativa*, *Brassica campestris*, *Glycine max*, *Hordeum vulgare*, *Lens culinaris*, *Pennisetum amaricanum*, *Sesamum indicum*, *Sorghum bicolour*, *Vigna radiata*, *Vigna mungo* and *Zea mays* has already been reported to be the host of this pathogen. More than 29 species of poaceae and other crops in North-eastern China, 65 species of poaceae in Yellow and hai river region and 17 plant species in Guandong province also serves as the host of *B. sorokiniana* (Chang and Wu 1997). Though some scientists suggests that rotating crops with rape, sorghum and soybean might reduce the carry over population of the pathogen to very low level, selection of suitable non-host crop requires further research.

Seed treatment and the use of fungicide

Seeds are one of the important sources of primary infection. Therefore, seed treatment with a suitable fungicide reduces the carry over inoculums potential, but unless soil inoculums are reduced, seed treatments along offer no benefit. Although various kinds of systemic fungicides are now available for seed treatment, the decision to treat the seed should be carefully considered. As determined by the blotter test, seed treatment should not be applied if the seed infection level is less than 20% and germination is within standards. Seed lots with less than 20% infection should be treated only if percent germination is lower than the standard and there is shortage of seed (Mehta, 1997). In Brazil, seed treatment is recommended based on seed health analysis, soil condition and crop rotation (Reis, 1991). Seed treatment with suitable fungicides such as Captan, Mancozeb, Maneb, Thiram, Pentachloronitrobenzene (PCNB) or Carboxin guazatine plus, Iprodione and Triadimefon are useful in protecting germinating seeds and seedlings from seedling blights (Stack and McMullen 1988; Mehta, 1993). Sharma-Poudyal et al., (2005) has reported that seed treatment with Vitavax 200B and Carbendazine improves early plant establishment in heavy soil predominating areas where wheat is cultivated after rice.

Biological control of spot blotch

Natural resistance of wheat towards this pathogen is found to be low (Agarwal et al., 2004). However, there is a possibility of biological control of this disease (Mandal et al., 1999). The saprophytic ascomycete, *Chaetomium globosum* Kunze, is a potential antagonist of several soil and seed borne plant pathogens (Vannacci and Harman 1987; Walther and Gindrat 1988; di Pierto, 1990) and recent studies have emphasized the role of *C. globosum* in controlling spot blotch of wheat caused by *C. sativus*

(Biswas et al., 2000). A thorough study made by Agarwal et al., (2004), has highlighted the potential antagonism of an antifungal metabolite produced by *C. globosum* against *C. sativus* both *in vitro* and *in vivo* conditions.

Foliar fungicides

Use of fungicides has proven useful and economical in the control of spot blotch (Viedma and Kohli 1998). The Triazole group (e.g.-Tebuconazole and Propinazole) especially have proven to be very effective against spot blotch disease. The use of fungicide Opus (Epoxiconazole) reduced disease severity to below 10%, which suggest its value in controlling spot blotch resistant wheat cultivars (Duveiller et al., 2005; Sharma-Poudyal et al., 2005). Later study conducted by Sharma and Duveiller (2006), shows that the fungicide Opus effectively controls spot blotch disease under soil nutrient stressed farmers' field conditions. However, questions have been raised regarding their use and environmental sustainability (Agarwal et al., 2004).

Disease resistant varieties

Cultivation of disease resistant varieties is an economical and effective option for controlling any plant disease. However, conventional breeding of wheat for selection of genotypes resistant for spot blotch has made very limited progress in the past (Sharma et al., 2007). A few studies from South Asia have reported only low to moderate success in breeding for spot blotch and foliar blight resistance (Alam et al., 1994; Devkota, 1994; Bhandari et al., 2003; Sharma et al., 2004a; Siddique et al., 2006). Eventhough, the resistant cultivars of South Asia e.g., "Gautam" have been reported to suffer from substantial grain yield loss under severe epidemic of spot blotch (Duveiller et al., 2005). To date, the best sources of resistance were discovered in the Brazilian and Zambian wheat lines (Rajaram, 1988; Dubin and van Ginkel 1991). A few Chinese wheat genotypes like SW895422, Chirya1, Chirya3, Chirya7, NL781, and NL785 also showed significant resistance levels to spot blotch (Kohli et al., 1991). *Triticum* shows different levels of spot blotch resistance, between species with same and different ploidy and genomes. High frequency of resistance was noted in *T. timopheevii, T. ararticum, T. boeoticum, T. persicum* and *T. urartu* widespread in Transcaucasia as well as in *T. Sphaerococcum* which is native to Indian penninsula (Smurova and Mikhailova 2007). Somaclonal variation is regarded as a supplementary tool to the well-established breeding approaches (Cheng et al., 1992; Karp, 1995; Ivanov et al., 1998). In wheat, somaclonal variants have been reported for various plant traits. Somaclones were regenerated by Arun et al., (2003) from immature embryos of two spring wheat varieties HUW-206 and HUW-234 displayed improved earliness, enhanced resistance to spot blotch disease and increased yield over parents established in regeneration.

Conclusion

Sustainability is an issue governing the production of *Triticum aestivum* L. and global rise in population. For efficient management of *B. sorokiniana*, the use of disease resistant varieties of wheat, use of efficient crop rotation techniques and biological controlling agents needs to be sincerely incorporated during cultivation. Although a number of attempts have been made by several scientists to find out non-host crops for the purpose of crop rotation to reduce the carry-over levels of inoculums and develop resistance of susceptible commercial cultivars against the pathogen, the present study over past decades, reveal that spot blotch remains a disease of serious concern under warmer areas. Therefore, further research is required for finding out suitable non-host crops as well as improving spot blotch resistance in wheat cultivars to control the severity of the pathogen.

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