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Review on spot blotch of wheat: An emerging threat to wheat basket in changing climate

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Abstract
Wheat is one of the most nutritious, proteinaceous and basic stable food crop is attacked by several factors. Among the biotic factors, the most notorious disease of wheat is spot blotch caused by *Bipolaris sorokiniana* (teleomorph *Cochliobolus sativus*). The disease mainly occurs in warm, humid wheat-growing regions, and the Eastern Gangetic Plains (EGP) of South Asia is a hotspot. It is most important disease of wheat in north eastern plains zone (NEPZ) representing warm and humid climate in India as well as in other South Asian countries. The incidence of spot blotch of wheat that were thought earlier as minor diseases, are increasing tremendously now a days due to global climate change. It is also increasing in North western plains zone (NWPZ) due to climatic change and causing losses in susceptible varieties. It is a soil and seed borne pathogen of wheat, barley and other small cereal grains and grasses that causes head blight, foliar blight/ spot blotch, seedling blight, common root rot, black point diseases and yield losses. The yield loss due to the disease is very significant especially in North Eastern Plains Zone (NEPZ) of India, Nepal Tarai and North Western Bangladesh. Estimates of yield losses due to spot blotch were reported to vary from 15.5 to 19.6% and up to 100% under severe infection conditions. Ideal conditions for spot blotch development on the leaves are relative humidity of near 95 per cent with an average temperature in the coolest month above 17 °C and long periods (more than 12 to 18 hours) of leafs wetness caused by rainfall, irrigation, fog or dew. Recently a number of genotypes have been identified as donors for improving host resistance. The best way to control spot blotch is through an integrated approach including varietal replacement, agronomic management and need based application of fungicides.

Keywords: *Triticum aestivum*, *Bipolaris sorokiniana*, yield loss, disease management, spot blotch

Introduction
Wheat (*Triticum aestivum* L.) is one of the oldest and most important cereal crops. The cultivation of wheat dates back to more than 5000 years back during the era of Indus valley civilization where the original species was *Triticum Sphaerococcum* popularly known as Indian wheat has now disappeared and replaced by present day species *Triticum aestivum* or the common Bread Wheat, *Triticum durum* or the Macaroni wheat and the *Triticum dicoccum* or the Emmer Wheat with share of production in percent 95%, 4% and 1% respectively, are being cultivated in the country. It is the second important staple cereal food in India after rice and has played vital role in stabilizing the food grain production in the country. Wheat is believed to have originated in south west part of Asia. Some of the earliest remains of the crop have been found in Syria, Jordan and Turkey (Feldman, 2001) [37].

It provides edible grain which forms staple food for a large number of people across the world. Wheat, the versatile cereal crop is also described as “the shuffle of life” or “king of cereals”. Even today, it occupies primary position among all the cereal crops due to its feeding the mankind. It supplies more nutrients particularly essential amino acids than any other cereal crop. It has attained a premier position in the world for its unique consumable protein i.e., gluten, which is vital for bread making properties of wheat flour, along with the straw which is a major source of nutritious feed for large population of cattle.

In India it is grown mostly in the plains where as in the hills it is cultivated in mountainous region of North India & Nilgiris and Palani hills in South India. For convenience of testing & finding out the correct adaptability the country is divided into six different wheat growing zones namely Northern Hill Zone (NHZ), North Western Plains Zone (NWPZ), North Eastern Plains Zone (NEPZ), Central Zone (CZ), Peninsular Zone (PZ), and Southern Hill Zone (SHZ). The zone -wise total percentage of Acreages of wheat crop are 2.9%, 40.1%. 33.2%, 18.1%, 5.4% and 0.4% respectively. Wheat is used by human beings in form of flour for making Chapaties, Semolina and Pasta products. It is also used for preparation of bread, biscuits, cookies, cracks, noodles, dalia, maida, vermicelli etc. Wheat straw is also used for the animal feed as fodder and for packaging materials.

The Wheat contains nearly carbohydrates 70%, protein 12%, fat 1.7%, minerals 2.7%, fiber 2% and moisture 12%.

Globally, total area under wheat production is 214.29 million hectare with production 734.04 million tons and productivity 3425 kg/ha. India is second largest producer of wheat after China with an area of 29.58 million hectare with production of 99.71 million tons and productivity of 3370 kg/ha covering 12 per-cent of world production (FAO Statistics Division 2018). Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar and Maharashtra are the major (80%) wheat growing states in the country from the point of both area and production. Now, India is surplus and in a position to export Wheat in the International Market and can earn foreign exchange.

The major Wheat producing States are Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar, Maharashtra, Gujarat, Karnataka, West Bengal, Uttarakhand, Himachal Pradesh and Jammu & Kashmir. These States contribute about 99.5% of total Wheat production in the country. Remaining States, namely, Jharkhand, Assam, Chhattisgarh, Delhi and other North Eastern States contribute only about 0.5% of the total Wheat production in the country.

In India, during 2018-19 Rabi season, wheat was cultivated in 29.55 mha, Indian wheat production in 2018-19 has made a landmark achievement by producing 101.20 mt by registering another record in average national productivity i.e., 3424 kg/ha.

As usual, Uttar Pradesh holds the top slot in wheat acreage (9.85 mha: 33%), followed by Madhya Pradesh (5.52 mha: 19%), Punjab (3.50 mha: 12%), Rajasthan (2.88 mha: 10%), Haryana (2.51 mha: 8%) and Bihar (2.26 mha: 8%). The above mentioned states altogether comprise 90 per cent of the total area and produce 93 per cent of the total wheat. The crop yield varied across regions and it ranged from as high as 5077 kg/ha in Punjab to 1275 kg/ha in Maharashtra. Only Punjab and Haryana have registered yield levels much higher than the national average productivity of 3424 kg/ha. The Production of wheat in India has improved tremendously with the expansion of high yielding varieties and efficient use of inputs that changes microclimate congenial for the buildup of spot blotch and leaf blight (Devi *et al*. 2012) [27]. In recent years, spot blotch has caused serious damage on wheat crop in India particularly in Eastern and central India. The Problem of spot blotch is more prominent in the north eastern region and is being addressed through national programme. The disease is known to cause yield losses up to 50% as well as deterioration in seed quality (Malik *et al*. 2008) [66].

Due to continuous rise in temperature during the wheat growing season and high humidity coupled with winter rains, spot blotch caused by *Bipolaris sorokiniana* is getting favourable conditions to develop aggressively and cause damage to wheat crop at larger scale by affecting significant yield loss up to 18-50 per cent under favourable conditions (Duvellier *et al*. 2005) [29].

Wheat is the second most important cereal crop in India after rice and main staple food of South Asian countries and climate change such as decreasing rainfall impacts rice and wheat production which is mainly irrigated crops (Abeysingha *et al.* 2016) [1].

In changing climatic scenario diferent diseases are also major threat to wheat production (Chowdhury *et al*. 2014) [26].

Among these, spot blotch caused by *Bipolaris sorokiniana* Sacc. (Syn. *Helminthosporium sativum* Pamm, King and Bakke) is one of the most important diseases in warm and humid regions of India and other South Asian countries (Joshi *et al*. 2007; Savary *et al*. 2011) [44, 48, 95]

Yield losses caused by *B. sorokiniana* were reported to be 18–22% in India (Villareal *et al*. 1995) [111, 112].

The rapid evolution in the pathogen population and change in the environmental conditions are important reasons. On the other hand, spot blotch is one of the prominent diseases, causing significant yield loss in warmer and humid regions of the world such as Eastern India, Bangladesh, the Terai of Nepal, Latin America, China and Africa (Gupta *et al*. 2018) [38].

It affects nearly 9 mha area of the North-Eastern Plains Zone (NEPZ) of India (Joshi *et al*. 2007) [44-48].

Bipolaris sorokiniana [Cochliobolus sativus (Ito & Kurib.) Drechsl. Ex Dast.] [Anamorph: *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem] is the causative organism for this destructive disease.

Saari (1998) [86] reported up to 16% yield loss in Nepal and 15% in Bangladesh, while Mehta (1994) [74] reported up to 100% yield loss in Latin America under the most severe conditions.

Spot blotch or *Helminthosporium* leaf blight is caused by *Bipolaris sorokiniana* (Sacc.) Shoem. It is most important disease of wheat in north eastern plains zone (NEPZ) representing warm and humid climate in India as well as in other South Asian countries. It is also increasing in North western plains zone (NWPZ) due to climatic change and causing losses in susceptible varieties.

The disease appeared at flag leaf visible stage (ZS 37) on lower leaves and moved upward in NEPZ whereas it appeared relatively late at boot swollen stage (ZS 45) in NWPZ. Spot blotch causes small, dark-brown, round to oblong lesions ranging 1 to 2 mm long without chlorotic margin on leaves of wheat plants. In susceptible genotypes, these lesions extend very quickly in oval to elongated blotches, light brown to dark brown in color and may reach several centimeters before coalescing and inducing the death of the leaf. The disease is also emerging in North Western Plain Zone (NWPZ) due to climatic changes. In India, yield loss may range from 10-50% which can be devastating for farmers in the Eastern Gangetic Plains depending on the level of resistance in a cultivar and weather conditions (Chowdhury *et al.* 2013) [25].

B. sorokiniana survive in moderate to warm temperatures (18 ˚C to 32 ˚C) and its infection is more rapid and severe at 28 °C than at lower temperatures.

Early symptoms are characterized by small, dark brown lesions ranging 1 to 2 millimeter long without chlorotic margin. In susceptible varieties, these lesions can extend very quickly in oval to elongated blotches, light brown to dark brown in colour. They may reach several centimeters before coalescing and inducing the death of the leaf. The pathogen has morphological and molecular variations among the isolates

Wheat crop is affected by many fungal diseases. Spot blotch disease of wheat caused by *Bipolaris sorokiniana*, a hemibiotrophic, phytopathogenic fungus is one of them and prevalent in warmer and humid wheat growing regions of the world (Joshi *et al.* 2007) [44-48].

B. sorokiniana usually induce symptoms on the leaf, sheath and stem (Chand and Joshi, 2004) [44, 45].

Severe infection may also reach the spikes, resulting in low weight shrivelled grains (Kiesling, 1985) [52] with black point at the embryo end of kernels (Chand and Joshi, 2004) [44, 45].

The symptoms of spot blotch appear as small, light brown lesions which are scattered throughout the leaves and increase

in size with stage advancement. Later, these lesions coalesce and change to large spots (oval to oblong and measuring 0.5 to 10mm long and 3 to 5 mm wide) after a week of infection (Chand *et al*. 2002) [19].

Annual yield loss of wheat due to this disease in South Asia is estimated to 15-20% (Duveiller and Sharma, 2009) [31].

In eastern India, the yield losses can reach up to 100% under severe conditions (Pandey *et al*. 2005) [77].

In the Trans-Himalayan Ladakh region of India yield loss of 6% to 53% have been estimated (Vaish *et al.* 2011) [113].

The area under North Eastern Plains of India is extremely affected by spot blotch disease (Chand *et al*. 2002) [19].

The productivity of region is not at par with national and international level due to biotic stress. In changed climatic scenario, hot and humid condition favours spot blotch disease. Due to the increasing food demand from limited agricultural land, an effective control of spot blotch needs to be achieved. The warmer parts of the world are mainly affected by many diseases and among these diseases, spot blotch or foliar blight is one of the most concerning disease in warm and humid regions of India and other South Asian countries due to its wide spread prevalence and increasing severity (Joshi *et al*., 2002) [19].

It is an important disease in that mega environment which is characterized by high humid conditions around and after heading stage. According to Duveiller and Sharma (2009) [31] the wide spread use of conservation tillage practices may be favorable for spot blotch incidence in the South East Asia.

It is the major biotic constraint in wheat in the gangetic plains, especially in the rice-wheat cropping system and is the main limiting factor to growing wheat in South-East Asia (Duveiller *et al.* 1998) [7].

Thus, over the last four decades, spot blotch has been seen as a serious constraint in wheat production, not only in the Eastern Gangetic Plains (EGP) of north India, but also in Bangladesh, Nepal, Brazil and other countries. The infection is most severe when the crop's late post-anthesis phase coincides with a period of high relative humidity and high temperature.

Globally, an estimated 25 million ha of wheat area is affected by spot blotch (van Ginkel & Rajaram, 1998) [114], about 40% of which is grown in the Indian subcontinent (Joshi *et al*., 2007a) [49], where the crop losses due to spot blotch have been estimated to be in the range of 15–25% (Dubin & van Ginkel, 1991) [33].

The yield loss in individual fields is sometimes much higher. The disease also affects end-use quality of harvested wheat grains (Mehta, 1998).

Bipolaris sorokiniana first colonizes the older leaves at the base of the wheat plant and then progresses to the upper part of the canopy (Joshi *et al.*, 2002) [19].

Disease severity is affected by crop management, soil fertility, planting density, the developmental stage of the plant and the weather conditions experienced by the host during later parts of the life cycle (Joshi *et al*., 2007b) [50].

High relative humidity, which allows the canopy to remain wet for a prolonged period, is particularly favourable for infection and pathogen growth (Acharya *et al*., 2011) [2]

On the Indian subcontinent, the disease spreads when the temperature stays at >26 °C (Chaurasia *et al*., 2000) [24], which explains why late-sown wheat is particularly vulnerable to the disease (Duveiller *et al*., 2005) [29].

In the Indian EGP, Nepal and Bangladesh, where wheat is typically raised after the harvest of the preceding rice crop, loss in productivity is often due to a combination of spot blotch and terminal heat stress (Joshi *et al.*, 2007c) [51].

In recent years, spot blotch has caused serious damage on wheat crop in India particularly in Eastern and central India. At present spot blotch of wheat is a major pathogen at national level in India and its frequency is highest in north eastern plains zone amongst six agro climatic zones due to prevalence of hot and humid weather conditions. This disease is emerging as a problem in the north western India.

Nomenclature and taxonomy of *B. sorokiniana* and *C. sativus*

Bipolaris and *Cochliobolus* represent two of the three genera (the third genus being *Curvularia*) which form a complex causing several diseases on a number of species from the family *Poaceae*. The taxonomy of this complex has been a subject of discussion, such that frequent nomenclatural changes have been made and opinions continue to differ. A detailed description of *Bipolaris sorokiniana* is available elsewhere (Sivanesan & Holliday, 1981; Sivanesan, 1990) [106-105].

The pathogen that causes spot blotch was initially a part of the former genus *Helminthosporium* which has since been divided into three anamorphic genera: *Bipolaris, Drechslera* and *Exserohilum*, with their corresponding teleomorphs named as *Cochliobolus, Pyrenophora* and *Septosphaeria*. Thus, *Bipolaris sorokiniana* is an anamorph representing the asexual state of *Cochliobolus sativus* (teleomorph).

Analysis of gene sequences of rDNA internal transcribed spacer (ITS), the gene encoding glyceraldehyde 3-phosphate dehydrogenase (GPDH) and the gene encoding the large subunit (LSU) of translation elongation factor 1-a (EF1-a) all suggest that *B. sorokiniana* and *C. sativus* represent the two stages of the same taxon (Manamgoda *et al.*, 2012).

It is also known that, in ascomycetes, anamorph and teleomorph of the same taxon develop independently on different substrates so that each phase is often collected in complete ignorance of the occurrence of the other form; this anomalous situation is not uncommon among fungal pathogens, and therefore according to the International Code of Botanical Nomenclature (ICBN), it is not considered to be incorrect to have two separate binomials for two forms of the same pleomorphic fungus. This appears to be a useful option, but creates confusion in the minds of students and users, who would wonder how the same organism can have two names. The use of *B. sorokiniana* is recommended in preference to *C. sativus* for three reasons. First, that the former is more popular in South Asia (where the disease is particularly prevalent) and frequently used; secondly, that this name is informative (bipolar germinations of conidia); and thirdly, the disease-causing conidia are produced on this form. In earlier literature, several synonyms of the anamorph *B. sorokiniana* have been used, which include the following*: Helminthosporium sativum, H. sorokinianum, Drechslera sorokiniana, Drechslera prorokiniana* teleomorph *Cochliobolus sativus* (Maraite *et al.*, 1998) [68].

Initially, Shoemaker (1959) [107] proposed the generic name *Bipolaris* for the *Helminthosporium* species with fusoid, straight, or curved conidia germinating by two germ tubes, one from each of the two ends (bipolar germination). *Bipolaris sorokiniana* is distinguished from other members of the *Bipolaris* genus on the basis of morphological features of conidiophores. A key for distinguishing different species of *Bipolaris* was given by Subramanian (1971) [108], and an

elaborate description of all species of *Bipolaris* has been provided by Manamgoda *et al.* (2012).

Symptoms and diagnosis of the disease

Spot blotch symptoms typically appear on the leaf, sheath, node and glumes as small light brown lesions, mostly oval to oblong to somewhat elliptical in shape, measuring 5–10 mm long and 3–5 mm wide. These lesions have brown margins and are often scattered throughout the leaves and gradually increase in size and coalesce to form larger necrotic patches (reaching several centimetres).

The affected leaves soon become chlorophyll deficient and eventually die. Under the most severe conditions, the spikes are also affected and dark brown to black discolouration appears around the germinating point of the seed, called 'black point'. The level of the disease is modulated by several abiotic factors such as soil fertility, moisture and temperature. The dark brown necrotic spots (boat shaped) occur on the coleoptiles, leaves, crowns, stems, and roots with or without yellow halo around these. Darkening of the sub crown internode is a characteristic symptom. Lesions on the leaves start as a few mm that extend as elongated dark brown spots greater than 1-2 cm (Chand *et al*., 2002) [19].

Later such spots coalesce each other thus result blight on large leaf portion. As the disease progresses the spots join together forming large blotches that cover the leaves and eventually killing it. On leaves, conidia develop readily under humid conditions and spread over several centimeters before coalescing and inducing the death of the leaf tissue. An abundant production of conidia can be observed on old lesions under humid conditions and chlorotic streak is sometimes seen diffusing from the border of the lesion as a result of toxin production (Mercado Vergnes *et al.*, 2006 and Bockus *et al*., 2010) [73, 10]

The symptoms mentioned above may generally be used for diagnosis of the disease, although this may need verification by microscopic identification of the pathogen. Therefore, alternative methods for diagnosis using either antibody or DNA-based probes have also been used (Ward *et al*., 2004) [115]. As an example, a solitary sequence characterized amplified region (SCAR) marker was developed for PCR-based detection of *B. sorokiniana* in plant tissues and soil (Aggarwal *et al.*, 2011) [5].

This marker allowed the detection of the pathogen even when present in the latent form in inoculated wheat leaves, before the visual symptoms appear. This would help in early detection and timely action for disease management. Random amplified polymorphic DNA (RAPD) markers were also used for identification of pathogen isolates belonging to different groups of spot blotch established on the basis of colour and shape of colonies (Pandey *et al*., 2008 [78]; for groups of spot blotch, see later).

In a recent study from China, fungal isolates from volunteer wheat plants were identified to be B. sorokiniana, using DNA markers based on the following three classes of genes: (i) ribosomal DNA genes (ITS), (ii) b-tubulin gene and (iii) EF1-a gene (Sun *et al*., 2015) [109].

Pathogen and host range

Spot blotch is caused by *Bipolaris sorokiniana* (Sacc.) Shoem. Syn. *Drechslera sorokiniana* (Sacc.) [Syn. *Helminthosporium sativum*, teleomorph *Cochliobolus sativus*] Subram., and Jain, *Cochliobolus sativus*, *Drechslera* [anamorph *Bipolaris sorokiniana* (Sacc.) Shoem.] and several synonyms of the anamorph have been used like *Helminthosporium sorokinianum*, *Drechslera sorokiniana* and *Helminthosporium sativum* (Maraite *et al*., 1998) [68].

Bipolaris sorokiniana is characterized by thick-walled, elliptical conidia (60- 120µm ×12-20µm) with 5-9 cells. In axenic culture, the mycelium is composed of hyphae interwoven as a loose cottony mass and appears as white or light to dark grey depending on the isolates (Kumar *et al*., 2002) [53].

B. sorokiniana belongs to the division- Eumycota, subdivision-Deuteromycotina, class-Hyphomycetes, subclass-Sporomycetidae, order-Moniliales and family-Dematiaceae. It is considered as a semi-biotrophic fungus and has worldwide distribution. A key for distinguishing species of *Bipolaris* has been reported (Subramanian, 1971) [108].

Prem Naresh *et al.* (2009) [76] reported that Richard media supported best growth, excellent sporulation occured at pH 6.5 and optimum temperature for growth and sporulation was 28 ºC. The host range study revealed that *Bipolaris sorokiniana* can infect oat barley, maize, rice and wild canary grass and linseed plant indicated that it had wide range hosts.

Acharya *et al*. (2011) [2] reported that conidiophores of *Bipolaris sorokiniana* were unbranched, brown to dark brown, erect, single or clustured, septate and conidia were brown to olivaceous brown color, straight or slightly curved 50-70µ long 15-20µ wide and variation in septation from 3-7.

Bipolaris sorokiniana has a broad range of hosts. In addition to bread wheat (*Triticum aestivum*), it is able to infect the following crops: durum wheat (*T. dicoccum*), barley (*Hordeum vulgare*), triticale (9Triticosecale), rye (*Secale cereale*), maize (*Zea mays*), pearl millet (*Pennisetum typhoides*), foxtail millet (*Setaria italica*), tufted airplant (*Guzmania* species, Tillandsioideae), *Panicum* sp., *Phleum pratense* and *Phalaris minor*, along with a number of other wild grasses (Hobbs & Morris, 1996; Manamgoda *et al.*, 2011; Singh *et al.*, 2016) [41, 69, 94].

In a study involving northeast China, *B. sorokiniana* was found to be able to infect 29 crop species including several grasses (Acharya *et al.*, 2011) [2].

In another study from China, at least 65 grass species from the Yellow and Huai River plain region were shown to support *B. sorokiniana* (Ma & He, 1987) [35]. Some known collateral hosts are *Agropyron pectinatum* and *Agropyron repen* Bakonyi *et al*., 1998) [11].

Pathogen reproduction and the infection process

As mentioned earlier, *B. sorokiniana* represents the asexual state of the spot blotch pathogen, its sexual stage teleomorph being *C. sativus*. Therefore, it is obvious that the pathogen reproduces through asexual means mainly through conidia, although occurrence of sexuality and a parasexual cycle have been reported in *C. sativus* and in several species of *Helminthosporium* (Nelson, 1960; Tinline, 1962; Chand *et al.*, 2003) [75, 110, 21]. In one of these studies, nine of the 13 interspecific crosses involving eight different species of *Helminthosporium* gave viable ascospore progenies.

Abundant perithecia were also observed in four crosses, suggesting that sexuality does occur in related forms, and that there are pathogenicity genes, which segregate in these crosses. However, no isolates from wheat were involved in this study and no sexuality has been reported within or between *B. sorokiniana* isolates derived from wheat. The existence of two distinct mating types (A, a) was suggested in an analysis of a large number of isolates of *B. sorokiniana* collected from diverse locations (Wen & Lu, 1991) [116].

The pathogen is generally heterothallic, and heterokaryons with a multinucleate condition do occur, which is attributed either to the occurrence of mutations or to anastomoses that have been observed between strains (Bashyal *et al*., 2015) [14]. However, the occurrence of two mating types is insufficient evidence for sexual reproduction, unless actual mating or recombination is demonstrated, because if other requirements for mating are not available (e.g. compatibility between mating types and proper cultural conditions), no mating or recombination through a sexual or parasexual cycle will be possible.

As a corollary, neither the geographic distribution nor the host preference of two different mating types can be used to explain the lack of detection of the sexual stage (Wen & Lu, 1991) [116]. However, crosses have been made between isolates derived from barley and recombination has been studied, leading to the development of 27 linkage groups belonging to 15 chromosomes of *B. sorokiniana = C. sativus* (Zhong & Steffenson, 2001) [120].

Survival of the pathogen and the sources of inoculum

As mentioned earlier, the spot blotch is often seedborne (Pandey *et al*., 2005) [77]. However, the survival of the pathogen on the host and its availability as a source of inoculum depends on several factors.

First, melanin content of *B. sorokiniana* has a direct correlation with conidiogenesis and with aggressiveness, suggesting that melanin produced by the pathogen neutralizes antimicrobial activity of the host cells, thus contributing to propagule durability (Henson *et al.*, 1999; Bashyal *et al.*, 2010) [40, 10]. Secondly, a large number of hydrolytic enzymes are produced by the pathogen when it shifts from biotrophic to necrotrophic mode during infection. Thirdly, a fairly large number of species work as collateral hosts for the pathogen.

Pandey *et al.* (2005) [77] screened 22 grass species and observed that each of a number of species could work as a collateral host for *B. sorokiniana*. When used for artificial inoculation, the isolates recovered from these species proved to be pathogenic on wheat. However, because their ability to infect wheat under natural conditions could not be confirmed, these collateral hosts may or may not be the likely source of natural inoculum in the Indian EGP.

Fourthly, the pathogen can also survive on crop debris (Chand *et al*., 2002) [19], although the high rainfall associated with the monsoon season in India (June–September in the EGP) tends to induce waterlogging in the rice crop. The resulting anaerobic conditions in the soil are inimical to conidial survival, so that the conidia isolated from soil after monsoon are not pathogenic (Pandey *et al*., 2005) [77].

Disease cycle

Infection, multiplication and transmission Although spot blotch is often a seedborne disease, primary infections can also be initiated from inoculum surviving on crop residues, collateral hosts (e.g. rice, barley and other grasses) or conidia in the soil.

The fungus can survive on straw or in the soil for several months, after which its viability begins to decline (Chand *et al.*, 2002; Pandey *et al.*, 2005) [19, 77].

It has been shown that the conidia found on wheat straw tend to aggregate into clumps after storage for 5 months (Chand *et al*., 2002) [19].

Although the sexual state of this fungus (*C. sativus*) is known (see later), it is not a source for infection, leaving conidia as the major vehicle for dispersal and survival of the pathogen (Reis & Wunsche, 1984) [83].

The infection for spot blotch is initiated by adhesion of the conidial spores to the leaf surface, followed by their germination and formation of germ tubes (Acharya *et al.*, 2011) [2]. Within 8 h, the germ tubes swell sufficiently to produce an appressorium, from which infecting hyphae are developed (Jansson & Akesson, 2003) [43].

The hyphae penetrate the host's cuticle within 12 h (Sahu *et al.*, 2016) [84] and multiply rapidly, spreading into the intercellular space within the mesophyll tissue of the leaf (Acharya *et al*., 2011) [2].

A new generation of conidia is produced within 48 h, which are carried on conidiophores that are 100–150 9 6–8 lm long. These conidia are olive-brown, oblong, tapered towards the ends and have a prominent basal scar. They measure 60– 120 9 15–20 lm in size and have three to nine thickwalled septa.

Several cycles of conidia production are possible during the cropping season, which cause secondary infections involving dispersal of conidia through dew and rain (Acharya *et al.*, 2011) [2].

The secondary infection of spot blotch is thus typically caused by the airborne conidia (Duveiller *et al.*, 2005) [29]. *Bipolaris sorokiniana* is a hemi biotrophic fungus, with the initial biotrophic growth phase confined to individual epidermal cells, and the subsequent necrotrophic growth causing apoptosis of the host cells. Once the host's epidermal defence has been overcome, the pathogen spreads within the mesophyll tissue. In the case of seedborne infection, the pathogen is able to respond rapidly to the germination of the host seed, and grows readily to reach the plumule and the tip of the coleoptile (Reis & Forcelini, 1993) [82].

The subsequent systemic development of the pathogen within the host results in accelerated leaf senescence (Dehne & Oerke, 1985) [28]; however, symptoms such as leaf spotting generally do not appear until the flag leaf has emerged (Duveiller *et al.*, 2007) [30].

Cultural and morphological variability of the pathogen

The hyphae and conidia of this fungus are dark coloured due to presence of melanin pigment like other dematiaceous fungi (Bashyal *et al*. 2010) [10].

Asad *et al.* (2009) [9] have noticed that on artifcial media the average size of conidia ranged from 38.3–65.8 µm × 12.3–25 µm, brown to olivaceous brown slightly curved, with 2–13 septa.

Singh *et al.* (2013) [54], who reported that the average length and width of conidia of Kalyani, West Bengal isolates was 20.35–90.30 and 11.95–23.43 µm. The average number of septa and spore size in control was 7 and 57 × 17.5 µm (l × b) respectively (Ansari 2015) [8].

Acharya *et al.* (2011) [2] also concluded that the conidium size of *B. sorokiniana* ranging 40–120 and 15–28 µm.

According to Bandyopadhyay *et al.* (2016) [13] the highest average length of the conidia was 72.43 ± 23.70 µm in WB10 isolate, which was followed by WB 7 (65.01 ± 12.55 µm) and the highest average breadth was 23.68 ± 1.53 µm found in WB 6 followed by WB 8 (22.81 ± 1.85 µm). The most important factor, temperature plays a key role coupled with high humidity and Moderate to warm temperature range (18–32 °C) favours the growth of B. sorokiniana (Chowdhury *et al.* 2013) [25].

According to Hodges (1975) [42] revealed that conidia germinated in large numbers, at a faster rate and produced more and longer germ tubes as temperature was increased

from 10–22 °C and above 22 °C, percent germination and growth rate of germ tubes declined.

However, Singh *et al.* (1998) [101] reported that for rapidly infection favourable temperature is 28 °C. It is consequently quite close to real field environment prevailing in north eastern plains zone which is a spot blotch prone area having temperature range of 12–30 °C in the month of February and 16–35 °C in the month of March.

The similar observation reported by Aggarwal *et al.* (2009) [4] and Bashyal *et al.* (2010) [10]. For that reason, the temperature prevailing in this zone during February and March is quite favourable for the development of spot blotch. Fungi exhibit varying response to light, depending on the light intensity and duration of exposure and temperature.

Exposure to light is needed by some fungi for sporulation, whereas other fungi sporulate better in dark and with the decrease in germination of conidia as the period of darkness increase (Rewal and Grwal 1989) [81].

Patsa *et al.* (2018) [79] were observed that maximum length of unipolar germ tube (26.28 µm) was recorded at 15 °C which was statistically superior to other treatments followed by 20, 25 and 30 °C in descending order. Whereas, maximum width of germ tube (4.49 µm) was observed at 25 °C temperature followed by 15 °C temperature. The length and width of germ tube of bipolar germinated *Bipolaris* spores at diferent incubation temperatures showed that, maximum length of germ tube of the two poles spores were 19.74 µm, 22.61 µm respectively was observed at 15 °C temperature followed by 20, 25, and 30 °C temperature. Whereas, maximum width of germ tube 3.92 and 4.11 µm was observed at 15 °C followed by 25 °C temperature.

Effect of physical parameters on the pathogen growth

Patsa *et al.* (2018) [79] were tested the behaviour of the *Bipolaris sorokiniana* with diferent combinations of weather regimes were studied in-vitro, in the dark at diferent temperatures and found that Maximum conidial germination (92.04%) was observed at 30 °C followed by 91.69% at 25 °C temperature after 4 h of incubation. Lowest germination was recorded at 10 °C. Maximum length of unipolar germ tube (26.28 µm) was recorded at 15 °C which was statistically superior to other treatments. Whereas, maximum width of unipolar germinated germ tube (4.49 µm) was observed at 25 °C followed by 15 °C. The length and width of germ tubes of the two poles of bipolar germinated *B. sorokiniana* spores were 19.74, 22.61 and 3.92, 4.11 µm, respectively at 15 °C followed by 20 °C temperature. Signifcantly lowest time required for secondary conidiophore formation (25 h) and conidia formation (39 h) was recorded at 25 °C. Highest time required for formation of secondary conidiophore (35 h) at 20 °C, conidia at 30 °C (80 h) but at 10 and 35 °C temperature secondary conidiophore and conidia formation was not observed within 80 h of incubation. Higher mycelial growth and no sporulation were observed under continuous light condition.

The conidial germination percentage increases with the increases of temperature from 10 to 30 °C and decline in germination percentage was recorded beyond 30 °C. Such variation of conidial germination was also reported by Hodges (1975) [42] in species of *Bipolaris sorokiniana*.

Patsa *et al.* (2018) [79] were tested the effect of diferent temperature on secondary conidia and conidiophore formation of *Bipolaris sorokiniana* and the microscopic studies revealed that the secondary conidia of *Bipolaris sorokiniana* produced at various temperature regimes on water agar were 60–77 × 20–27 µm in size, tapered at both ends, dark brown to olivaceous, distoseptate and irregular margin. The maximum length of secondary conidia was observed 76.97 µm under 15 °C temperatures followed by 72.49 µm at 20 °C temperatures. Whereas, maximum width (21.46 µm) of conidia was recorded at 20 °C followed by 21.29 µm under 15 °C temperatures. The length and width of conidia recorded at 25 °C was 71.48 and 21.11 µm respectively.

Singh *et al.* (2013) [54] were reported that the average length and width of conidia of Kalyani, West Bengal isolates was 20.35–90.30 and 11.95–23.43 µm. Asad *et al.* (2009) [9] concluded that, the length and width of conidia vary from 38.3–65.8 and 12–25 µm respectively. Acharya *et al.* (2011) [2] also concluded that the conidium size of *B. sorokiniana* ranging 40–120 and 15–28 µm. In addition to the Conidia, morphology of secondary conidiophores also studied and dark greyish olivaceous colour was recorded and had solitary emergence. The microscopic studies revealed that the average length and width of conidiophores was 83.36–172.60 and 5.52–6.76 µm.

Such variations of characters in conidiophore were also reported by Bashyal *et al.* (2010) [10] in species of *Helminthosporium.* However, highest length and width of secondary conidiophores was observed 172.60 and 6.76 µm respectively at 30 °C temperature followed by 25 °C, where length of conidiophores 94.81 and width 6.29 µm was observed. Whereas, lowest length and width of the secondary conidiophores was 80.52 and 5.52 µm respectively at 15 °C temperature.

Patsa *et al.* (2018) [79] were tested effect of light and dark condition on colony growth of *Bipolaris sorokiniana* at 25 °C and showed diferences between light and dark condition in respect of colony growth. Colonies of the studied pathogen grew faster in light condition than dark condition at 25 °C temperature on Potato Dextrose Agar media. tion at 25 °C temperature on Potato Dextrose Agar media. Under dark condition, on PDA media the Bipolaris pathogen formed wavy with scanty aerial mycelium, olivaceous brown colour and irregular margin and becoming dark brown to black colour, irregular shaped mycelia growth.

Phenotyping the disease

Spot blotch infection data in wheat crops can be recorded on a continuous scale using one of two available methods (Duveiller *et al.*, 1998; Bashyal *et al.*, 2010) [7, 10] a single digit scale with scores ranging from 0 (immune) to 9 (highly susceptible; Saari & Prescott, 1975) [85], or a double digit scale (00–99), where the first digit indicates the extent of the disease progression from ground level to the top of the canopy, while the second digit refers to the extent of leaf area showing disease symptoms (Eyal *et al.*, 1987) [35] the double-digit scale has been widely adopted. In a recent study, where 4925 wheat accessions from the National Bureau of Plant Genetic Resources (NBPGR) Genebank in India were screened for spot blotch (Kumar *et al.*, 2016a) [55], the following classification was used, based on the double digit scale: (i) I, immune (00); (ii) R, resistant (susceptible (35–56); (v) S, susceptible (57–78); (vi) HS, highly susceptible (>78). More recently, a sensor-based evaluation approach, involving a hand-held green seeker normalized difference vegetation index (NDVI), has been suggested to screen a large number of lines (Kumar *et al.*, 2016b) [56]. NDVI is a simple graphical indicator that can be used to analyses remote sensing measurements and to assess whether the target contains live green vegetation.

Epidemiology

Epidemic has been observed in Punjab (NWPZ) with the dominant pathogen B. sorokiniana followed by *Fusarium* spp. ((Mahto *et al.*, 2002; Mahmood *et al.*, 2011, Ansari 2015) [65, 70, 8]

The severity of the disease is directly influenced by tillage option, irrigation scheduling, soil fertility level, sowing density, crop growth stage, occurrence of late rains during crop cycle, heat stress during grain filling, late planting, high temperature and high relative humidity causing more than 12 hours duration of leaf wetness (Sharma and Duveiller, 2003) [90].

In field, infected seeds and soil serve as an important source for primary inoculum of spot blotch pathogen. Spot blotch pathogen may infect wheat right from first leaf stage and susceptibility of plants increases after flowering. Ideal conditions for spot blotch development on the leaves are high relative humidity with high temperature and long periods (more than 12 to 18 hours) of leafs wetness caused by rainfall, irrigation, fog or dew. The most important factor, temperature plays a key role coupled with high humidity. Moderate to warm temperature range (18 ˚C to 32 ˚C) favours the growth of *B. sorokiniana*. There are various cycles of conidia production during the cropping season which lead to secondary infections after spreading through wind and water drops. Many scientists reported that disease was more severe at 28°C than at lower temperatures.

Epidemiological studies have shown that timely sowing avoids the physiological stress that often coincides with the flowering stage which in turn reduces spot blotch (Duveiller *et al*., 2005) [29]. Acharya *et al*. (2011) [2] concluded that spot blotch of wheat emerged as serious concern for wheat cultivation in warmer and humid regions of world. Disease severity was said to be directly related to humidity, temperature and soil nutrient condition. The greatest yield loss occurred when the flag leaf and leaf below the flag leaf becomes infected before emergence of head.

Disease assessment

The most effective system consists of using a double-digit scale (00-99) developed as a modification of Saari and Prescott's severity scale (Saari and Prescott, 1975) [85]. The first digit (D1) indicates disease progress in the canopy height from ground level; the second digit (D2) refers to measured severity based on diseased leaf area. Both D1 and D2 are scored on a scale of 1-9. For each score, the percentage of disease severity is estimated based on the following formula: Severity (%) = (D1/9) × (D2 /9) × 100 Because the disease evolves very rapidly in areas affected by the spot blotch, it is often necessary to record several individual disease scores per plot at 3 to 7 day intervals over a 3 to 4 week period between anthesis and the dough stage, depending upon the seedling date (Duveiller and Sharma, 2009) [31].

Yield losses

Satvinder *et al*. (2002) [88] observed the yield losses ranged from 27% - 56.6% during 1998-99 in north eastern and north western plains of India due to the leaf blight caused by B. sorokiniana.

Due to this pathogen severe losses were estimated up to 15% on several farms over a number of years in Bangladesh (Alam *et al.*, 1994) [6], In Nepal the loss was reported up to 23.8% (Shrestha *et al.*, 1997) [89].

Yield losses due to foliar blights are variable and in last two decades spot blotch has emerged as serious concerns for wheat cultivation in the developing world. In India, losses due to diseases may be 10-50 per cent which can be devastating for farmers in the Eastern Gangetic Plains (EGPs) and depends on the level of resistance in a cultivar against leaf blight and weather conditions.

Spot blotch has been considered as a major constraint to wheat yields in South Asia due to reduction in 1000-grain weight and grain yield (Singh *et al*., 2007) [30]. Diseased wheat plots in Mexico without fungicides yielded 43 per cent less (Villareal *et al*., 1995) [111, 112]. In farmers' fields in Bangladesh, the average losses due to these foliar blights were estimated to be 15 per cent (Alam *et al.*, 1998) [7].

Earlier studies on wheat diseases have reported impressively high yield losses and suggested that sizable area of wheat is at risk to specific diseases or pests. Grain infections by this fungus in years that were favorable for the disease were detected to be as high as 70 per cent (Sharma *et al*. 2005) [29].

In Nepal, it was shown that spot blotch induced grain yield losses of 52 per cent under soil nutrient stress comrade with 26 per cent under optimum fertilization and spot blotch continues to causes substantial grain yield reductions under resource limited farming conditions (Sharma and Duveiller, 2006) [91]. Saari (1998) [86] confirmed through pathogenicity test that *Bipolaris sorokiniana* because very dire disease foliar blight/spot blotch of wheat and was able to reduce yield losses upto 16-23%.

The disease is known to cause yield losses up to 50% as well as deterioration in seed quality (Malik *et al*. 2008) [66]

Disease management

Identification of high yielding and spot blotch resistant genotypes offers opportunity to further increase the yield of the commercial cultivars by improving resistance through selective breeding. Kumar *et al.*, (2013) [54] observed that Chirya 3, Chirya 7 and Chirya 1 were resistant both at seedling and adult plant stage and two genotypes viz., Milan/Shanghai 7 and Shanghai 4 were moderately resistant when tested at different locations of India.

Dubin *et al*., (1998) [7, 11, 34, 68, 86, 101, 114] reported that the leading commercial wheat cultivars of South Asia in early 1990s had much higher spot blotch severity than K 8027, which showed good level of resistance.

In South Asia, moderate success in breeding for spot blotch and foliar blight resistance has been reported (Bhandari *et al*., 2003, Sharma *et al*., 2004, Joshi *et al*., 2004a, Siddique *et al*., 2006, Singh *et al.*, 2007, Kumar *et al*., 2013) [15, 96, 100, 92, 54].

Conventional breeding of wheat for selection of genotypes resistant for spot blotch has made limited progress in the past (Sharma *et al*., 2004 & 2007, Singh *et al*., 2008) [96, 99, 66].

Joshi *et al*. (2007) evaluated Seven hundred twenty-nine lines of diverse wheat germplasm lines in eight locations of three countries (India, Nepal and Bangladesh) of South Asia for 5 years (1999–2000 to 2003–2004) and promising 25 lines have been listed as sources of strong resistance, with 9 lines better yielding than the best resistant check PBW 343 in fewer days to maturity.

Lia Tukas and Ruzgas (2011) [62] studied a total of 99 modern European winter wheat cultivars and breeding lines for resistance to four *Bipolaris sorokiniana* isolates, obtained from wheat straw and grain, under laboratory conditions using a detached leaf technique

Agronomic practices

Information from different countries on managing foliar blight through manipulation of agronomic practices suggests

that different mineral nutrients may reduce foliar blight (Krupinski and Tanaka, 2000, Singh *et al*., 1998) [61, 101].
Although soil moisture and soil nutrient stress occur together in the wheat fields of South Asia, little quantitative information is available on the effect of low soil moisture and poor soil fertility on foliar blight severity.
There are some reports to indicate the role of potash in reducing spot blotch severity (*Regmi et al.,* 2002) [80].
Good crop husbandry and optimum agronomy may also reduce spot blotch disease severity up to certain level (Sharma *et al*., 2006).
Singh *et al.* (1998) [101] reported that late-sown (30 December) wheat fields suffered more from foliar blight than plots sown on the optimal date (30 November).
Duveiller *et al.* (2005) [29] showed that timely sowing avoids the physiological stress that often coincides with the flowering stage which in turn reduces spot blotch.
Sharma *et al*. (2006) [91] found that the balanced application of nitrogen, phosphorous and potassium reduced spot blotch severity by 15 and 22% respectively.

Seed treatment
Seeds are one of the important sources of primary infection. Therefore, seed treatment with a suitable fungicide reduces the carry over inoculum potential, but unless soil inoculums are reduced, seed treatment alone offers no benefit.
Seed lots with less than 20 per cent infection should only be treated if there is a shortage of seed (Mehta, 1993).
Seed treatment with Vitavax 200 B and Bavistin increased seed germination by 43 per cent and reduced seedling infection in Nepal (Sharma *et al.,* 2005) [29].
The seed treatment of a newly developed fungicidal formulation Vitavax 200 WS (Carboxin + Thiram 1:1) @ 2.0, 2.5 and 3.0 g per kg seed gave good results in reducing seedling mortality, incidence of foliar diseases at multi location of India (Singh *et al*., 2007) [92].
Kumar *et al* (2019 a) were tested the efficacy of different fungicides like Raxil 060FS, Trifloxystrobin 500 SC, Trifloxystrobin + Tebeconazole 080 FS, Vitavax, Flint (Trifloxystrobin) 50 WG, Nativo (Trifloxystrobin 25% + Tebeconazole 50%) 75 WG and Tebeconazole 2% DS with different concentrations i.e 0.03, 0.06, 0.12 and, 0.25% and biocides like *Trichoderma viride* @@ 100 ml. spore suspension / 100 g of seed and Neemexcel @ 2.0 ml. / kg. of seeds as seed treatment effect on seed germination and growth of seedling against spot blotch of wheat under Glass house experiment and found that In case of glasshouse condition, the maximum with 99% seed germination was recorded in the treatment of *Trichoderma viride* followed by Raxil 98.50%, Tebuconazole 2% DS 98.30%, vitavax 92.40%. The shoot length of wheat seedling was found maximum better under treatment with *T. viride* (95.23%) representing on against 4.39 cm in control which was followed by 4.05 cm and 3.98 cm in Raxil 060FS and Vitavax treated plant respectively.

Biological and chemical control
Bio-control of spot blotch has been attempted by several scientists with mixed responses. Successful antagonists against seed borne *B. sorokiniana* were *Chaetomium* sp., *Idriella bolleyi*, and *Gliocladium roseum* (Knudsen *et al.,* 1995) [60].
The antagonistic potential of *Chaetomium globosum* against *Drechslera sorokiniana* was first observed by Mandal *et al*., (1999) [63] which was further confirmed (Biswas *et al.,* 2000) [18].
Agarwal *et al.,* (2004) [3] has highlighted the potential antagonism of an antifungal metabolite produced by *Chaetomium globosum* against *C. sativus* both *in vitro* and *in vivo* conditions. Despite the harmful effect of fungicides to human and environment, it has proved useful and economical in the control of spot blotch. Non systemic and systemic foliar fungicides belonging to the dithiocarbamates (viz; Mancozeb) and Triazoles (viz. Propiconazole, Tebuconazole, Flutriazol, Procloraz, and Triadimenol) and dicarboxymides (viz. Iprodione) are known to be effective. Foliar applications especially with systemic fungicides such as Tebuconazole, Epoxiconazole, Flutriazol, Cyproconazole, Flusilazole, Epoxiconazole and Metaconazole applied between heading and grain filing stages, have been proved to be cost effective.
Duveiller *et al.* (2005) [29] observed that Triazole group (e.g.- Tebuconazole and Propinazole) especially have proven to be very effective against spot blotch disease.
Bahadar *et al*. (2016) [17] have evaluated the inhibitory effect of essential oil of flowering buds and potential extracts of *Eucalyptus camaldulensis* Dehn (leaf, Bark and Flowering Buds) on the most aggressive isolate of *Bipolaris sorokiniana*.
Hasan *et al*. (2012) [39] evaluated five botanical extracts namely garlic, onion, ginger, neem and black cumin at different concentrations (5%, 10% and 15%) and five fungicides namely Hexaconazole, Carbendazim, Mancozeb, Difenoconazole + Propiconazole and Propiconazole at different concentrations (100 ppm, 200 ppm, 300 ppm, 400 ppm and 500 ppm) against *Bipolaris sorokiniana* in laboratory. Carbendazim, Propiconazole and Hexaconazole were almost equally effective against spot blotch of wheat and may be used as an alternative to each other for management of disease (Yadav *et al.,* 2015) [118, 119]. Singh *et al*., 2008) proposed that three foliar application of Propiconazole @ 0.1% after appearance of the disease significantly reduce the disease and increase yield tested over several locations of India.
The efficacy of some newly synthesized organotin compounds against B. sorokiniana has also been reported (Sarkar *et al*., 2010) [87].
Yadav *et al.* (2015) [118, 119] were tested the effect of recommended dose of fungicides (Propiconazole, Carbendazim and Hexaconazole) against spot blotch of wheat under field conditions with foliar application at 0.1% on disease incidence and found that two foliar applications of Propiconazole at tillering and boot leaf stage resulted in least incidence 12.06% with 68.35% reduction in the incidence as compare to check plot, disease incidence was 31.11% and of twice foliar application of Carbendazim at tillering and boot leaf stage it resulted in least incidence 4.82% with 61.12% reduction in incidence as compare to check plot, disease incidence was 31.11%.
Yadav *et al.* (2015) [118, 119] were tested the effect of recommended dose of fungicides (Propiconazole, Carbendazim and Hexaconazole) against spot blotch of wheat under field conditions with foliar application at 0.1% on disease Severity and found that twice foliar application of Propiconazole at tillering and boot leaf stage resulted in least severity, that is, 27.58% with 44.42% reduction which was significantly less than the severity (30.32% with 38.90% reduction) due to two application of Hexaconazole at tillering and boot leaf stages of wheat crop, which was at par with severity (32.07% with 33.37% reduction) recorded in the crop which was twice sprayed at tillering and boot leaf stages, with Carbendazim as compare to check plot, disease severity was 49.62% .

Yadav *et al.* (2015) [118, 119] were tested the effect of botanicals (Garlic clove extract, Neem leaf extract, Eucalyptus leaf extract and Neem cake extract) and bio-agents (*Pseudomonas fluorescence* and *Trichoderma harzianum*) with two foliar spray of botanicals @ 5% and bio-agents @ 10 gm. Per liter of water at tillering and boot leaf stage of crop on disease incidence of spot blotch of wheat under field conditions and found in first year that among the botanicals, Eucalyptus leaf extract (27.21% incidence with 28.61% reduction) was superior over the other botanicals and among the bio-agents, *Pseudomonas fluorescence* followed by *Trichoderma harzianum* resulted in the highest reduction in disease incidence and in the second year observed that among the botanicals and bio-agents Eucalyptus leaf extract resulted in 7.96% disease incidence with 16.38% reduction. Effect of Eucalyptus leaf extract on disease incidence of spot blotch was superior among the botanicals and bio-agents but significantly, it was at par with the effect exhibited by other botanicals and bioagents used during the course of investigation.

Yadav *et al.* (2015) [118, 119] were tested the effect of botanicals (Garlic clove extract, Neem leaf extract, Eucalyptus leaf extract and Neem cake extract) and bio-agents (P*seudomonas* f*luorescence* and *Trichoderma harzianum*) with two foliar spray of botanicals @ 5% and bio-agents @ 10 gm. Per liter of water at tillering and boot leaf stage of crop on disease severity of spot blotch of wheat under field conditions and found in first year that two application of 5.0% Garlic clove extract resulted in 35.30% disease severity with 28.66% reduction in severity and it was significantly different than the severity recorded in the crop, which was twice sprayed with 5% Neem leaf extract where 38.65% disease severity and 22.11% reduction in severity was recorded. Two application of 1.0% *P. fluorescence* at tillering and boot leaf stages resulted in 39.05% disease severity with 21.30% reduction in severity, the effect of *P. fluorescence* on disease severity was at par with the effect of Neem leaf extract on spot blotch severity. Application of 5% Neem cake extract at tillering and boot leaf stages resulted in 12.66% disease severity with 37.51% reduction in severity and it was at par with the severity recorded due to two application of 1.0% *T. harzianum* where 12.80% diseases severity with 36.82% reduction in severity was recorded and also with the severity recorded due to two application of 0.1% *P. fluorescence* where 13.86% severity with 31.85% reduction in severity were recorded.

Singh *et al.* (2014) were tested the efficacy of fungicides as seed treatment with Captaf @ 0.25%, carboxin+thiram (1:1) (Vitavax Power) @ 0.1% was given before 24h of sowing and foliar application of propiconazole (Tilt 25 EC) @0.1% and tebuconazole (Folicur25 EC) @ 0.1%, mancozeb (Dithane M 45) @ 0.25% at initiation of spot blotch symptoms on crop and repeated after 15 days of first spray and found that the lowest spot blotch score (35) was in case of Vitavax power @ 2.5 g/kg of seed and two sprays of propiconazole (Tilt) @0.1%, as well as two sprays of propiconazole @ 0.1% as compared to 58 score in case of untreated plots in NEPZ. In case of Karnal (NWPZ), these treatments along with Folicur and mancozeb also reduced the disease score from 13-02.

Bhandari Deepak (2017) [16] evaluated efficacy of frequencies of spray, days of spray after the seeding date and intervals between two sprays of Propiconazole 25% ec @ 1.5 ml/liter water (four frequencies of sprays (single spray, two sprays, three sprays and four sprays) at various dates after seeding (DAS) of crop plants at three different days of interval (10 days, 15 days and 20 days) against spot blotch pathogen and found that among the various treatments best spray schedules for propiconazole was two sprays at 70 and 85 days after seeding (DAS) at 15 days interval were the most effective among the tested treatments against spot blotch disease and two sprays at 70-85 days after seeding had the lowest disease severity.

Biological control of spot blotch involves the use of known antagonists of soil- and seedborne plant pathogens.

Mandal *et al*. (1999) [63] screened 16 fungal species for their antagonistic activity *on B. sorokiniana* (called *Drechslera sorokiniana* in this study). For this purpose, they examined the effect of mycelia and culture filtrates of these fungi on germination of conidia and mycelial growth of *B. sorokiniana*. The culture filtrates were also used for spraying wheat seedlings (3- to 4-leaf stage) already inoculated with a conidial suspension of *B. sorokiniana*. Sixteen species had an inhibitory effect on conidial germination and mycelial growth including the following six: *Trichoderma reesei, Trichoderma pseudokoningii, Trichoderma hamatum, Talaromyces flavus, Chaetomium globosum*, *Trichothecium roseum.* Three of these species (*T. reesei, T. pseudokoningii, C. globosum*) substantially reduced the spot blotch lesions on wheat leaves. *Chaetomium globosum* was also found to be effective in biological control in another study (Aggarwal *et al*., 2004) [3], so that this is one of the most potent antagonists that can be used for biological control. Crop rotation using flax (*Linum usitatissimum*) in rotation with wheat has also been found to reduce the inoculum (Malaker *et al.*, 2008) [67].

Kumar *et al*. (2018) [38] were tested the fungicides like Raxil 060FS, Trifloxystrobin 500 SC, Trifloxystrobin + Tebeconazole 080 FS, Vitavax, Flint (Trifloxystrobin) 50 WG, Nativo (Trifloxystrobin 25% + Tebeconazole 50%) 75 WG and Tebeconazole 2% DS and biocides like *Trichoderma viride*, Neemexcel to standardize its concentrations viz. 0.03, 0.06, 0.12 and, 0.25% against spot blotch of wheat *in vitro* condition by Food Poison Method and found that the maximum mycelial growth inhibitory effect with 73.33% reduction was recorded at 0.25% concentration of Nativo 75 WG fungicides which was statistically at par with 0.12% concentration. It was followed by 0.06% concentration with 68.88% reduction was recorded with Raxil 060 FS.

Kumar *et al*. (2019b) [59] were evaluated comparative efficacy of foliar spray of different fungicide i.e. Raxil 060FS, Trifloxystrobin 500SC, Tebuconazole 2% DS, Trifloxystrobin + Tebuconazole 080 FS, Nativo (Trifloxystrobin 25% + Tebuconazole 50%) 75 WG, Flint (Trifloxystrobin) 75 WG, Vitavax and biocides Neem excel, Bioagent (*T. harzianum*) with three spray at two doses i.e. 0.12% and 0.25% at 45-50 days of sowing with ten days intervals against spot blotch of wheat under glass house condition and revealed that the minimum disease intensity was recorded in foliar spray with Trifloxystrobin + Tebuconazole 080 FS showing, 60.33% disease severity which was followed by foliar spray with Nativo (Trifloxystrobin + Tebuconazole 75 WG) 75 WG (60.53%) and Tebuconazole 2% DS (61.88%) and in field condition, the minimum disease intensity was recorded in foliar spray with Trifloxystrobin + Tebuconazole 080 FS @ 0.12%, 0.25%, showing 60.33% disease severity which was followed by foliar spray with Nativo (Trifloxystrobin + Tebuconazole 75 WG) 75 WG (60.52%) and Tebuconazole 2% DS (61.88%). Foliar spray with trifloxystrobin (flint) 50WG @0.25% was next to superiority in checking foliar disease followed by Vitavax @ 0.25%.The result showed that trifloxystrobin + Tebuconozole 080 FS is the best fungicides

among all chemical for management of spot blotch disease by Nativo 75 WG.

Resistant varieties

Foliar blight is the main problem in humid and warmer areas especially in North Eastern Plains Zone (NEPZ). For effective management of the disease, cultivation of recommended (resistant) varieties, like NHZ: HS 490, VL 829, NWPZ: C 306, HD 3086, WH 1021, WH 1080, WH 1142, NEPZ: DBW 39, HD 2733, HD 2888, K 0307, K 8027, CZ: DBW 110, HD 8627 (d) should be encouraged (IIWBR, 2017).

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