International Journal of Bio-resource and Stress Management https://ojs.pphouse.org/index.php/IJBSM

Crossref

IJBSM March 2026, 17(3): 01-13

Article AR6273

Review Article

Stress Management

DOI: HTTPS://DOI.ORG/10.23910/1.2026.6273

Host Resistance, Bioagents, Botanicals, Nutrients and Fungitoxicants Approaches for Management of Spot Blotch in Wheat Incited by *Bipolaris sorokiniana*

Durga Prasad, Manisha Kumari, Gajendra Manohariya, Chakshu Panwar and D. V. Pahima

Dept. of Plant Pathology, College of Agriculture, Jodhpur, Agriculture University, Jodhpur, Rajasthan (342 304), India

Open Access

Corresponding dp.aujodhpur@gmail.com

0000-0002-0678-0859

ABSTRACT

Wheat (*Triticum aestivum* L.) is one of the most widely cultivated crops and a staple food for millions worldwide. In India, it ranks as the second most important cereal after rice. However, wheat productivity is significantly impacted by abiotic and biotic stresses, with diseases posing a major challenge. Various pathogens, including nematodes, viruses, bacteria, necrotrophic fungi, and biotrophic fungi, attack wheat, resulting in substantial yield and quality losses. Among fungal diseases, spot blotch, caused by *Bipolaris sorokiniana*, is a major threat to wheat cultivation, particularly in the North Eastern Plain region of India. Most often, the pathogen causes symptoms on the leaf and sheath. Additionally, the spikes may be impacted, resulting in low-weight, shriveled grains with a dark tip at the kernel embryo end. Spot blotch symptoms initiated as small, light brown lesions scattered throughout the leaves. As the disease worsens, these lesions enlarge into huge, oval to oblong spots. This disease, prevalent in warm and humid climates, can reduce wheat yields by 15% to 20% and adversely affect grain quality. Even a slight reduction in spot blotch severity through effective disease management strategies can significantly improve farmers' income. This review comprehensively analyzes the impact of micronutrients, botanicals, bioagents, and fungitoxicants on *Bipolaris sorokiniana* under both in vivo and in vitro conditions. Additionally, it presents detailed insights into host resistance mechanisms against spot blotch, offering valuable information for researchers, agricultural professionals, and farmers.

KEYWORDS: *Bipolaris sorokiniana*, bioagents, micronutrients, fungitoxicants, spot blotch, wheat

***Citation* (VANCOUVER):** Prasad et al., Host Resistance, Bioagents, Botanicals, Nutrients and Fungitoxicants Approaches for Management of Spot Blotch in Wheat Incited by *Bipolaris sorokiniana*. *International Journal of Bio-resource and Stress Management,* 2026; 17(3), 01-13. HTTPS://DOI.ORG/10.23910/1.2026.6273.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, author have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The author has declared that no conflict of interest exists.

RECEIVED on 05th April 2025 RECEIVED in revised form on 10th February 2026 ACCEPTED in final form on 01st March 2026 PUBLISHED on 12th March 2026

1. INTRODUCTION

In India, wheat (*Triticum aestivum* L.) is the second most important cereal crop, playing a vital role in ensuring the nation's food and nutritional security. Globally, approximately 55% of the population derives about 20% of their daily calories from wheat. It serves as a staple food for the people of North India and is one of the country's major food grains. In India, wheat is cultivated on approximately 318.33 lakh hectares, with an average yield of 3,559 kg ha-1 and a total production of 1,132.92 lakh tonnes during the 2023-24 crop season (Anonymous, 2024–25). The wheat crop is subjected to multiple biotic and abiotic stresses that interfere with metabolism at all growth stages. Biotic stresses, including fungal, bacterial, viral, nematode, and mycoplasma diseases, have caused substantial yield losses. Among fungal diseases affecting wheat, foliar blights are particularly concerning. These include Alternaria blight/ leaf spot (*Alternaria triticina*), spot blotch (*Bipolaris sorokiniana*), and rusts such as black rust (*Puccinia graminis* f. sp. *tritici*), brown rust (*Puccinia recondita*), and yellow rust (*Puccinia striiformis*). Spot blotch, associated with devastating losses to the economic yield potential of the wheat, is the most significant wheat disease in NEPZ, which encompasses warm and humid regions of India and South Asia (Kumar et al., 2025a). Spot blotch symptoms start as small, light brown lesions that expand into larger, oval to oblong spots (0.5–10 mm long, 3–5 mm wide) within a week (Chand et al., 2002). Lesions also develop on coleoptiles, crowns, stems, and roots of infected seedlings (Acharya et al., 2011). Yield losses vary based on environmental conditions, cultivar susceptibility, and disease management strategies (Duveiller and Sharma, 2009; Pandey et al., 2005; Vaish et al., 2011). In South Asia, spot blotch causes an estimated 15–20% annual yield loss (Duveiller and Sharma, 2009), with losses in India ranging from 10% to 50%. Under severe conditions in the Eastern Gangetic Plains (EGPs), losses can reach 100% (Pandey et al., 2005). In India's Trans-Himalayan Ladakh region, losses range from 6% to 53% (Vaish et al., 2011). Disease management strategies focus on preventing outbreaks through chemical pesticides and host-plant resistance. However, chemical pesticides are expensive, toxic to non-target organisms, and environmentally harmful. Host resistance has become a key research priority. Crop rotation and seed treatment with eradicant fungicides are effective control measures. Systemic fungicides like propiconazole and tebuconazole are particularly effective against foliar diseases (Dubin and Duveiller, 2000). Botanical fungicides, which can be produced locally, offer a promising alternative (Roy et al., 2005). Biological control methods are also being explored to reduce reliance on chemical pesticides (Xu et al., 2011; Mishra and Singh, 2012). Triazole fungicides, including tebuconazole and propiconazole, have shown efficacy against spot blotch (Singh et al., 2011). Microbial antagonists from the Bacillus, Pseudomonas, and Trichoderma genera are widely studied for biological control (Bettiol and Morandi, 2009). Biocontrol agents can be applied directly (seed dipping, aerial spraying, or soil application) or indirectly through solid-phase inoculants. Micronutrients influence plant physiology and disease resistance (Kumar et al., 2025b). Zinc application has been linked to improved spot blotch resistance by modulating wheat plant metabolism (Yadav et al., 2013). Given these insights, this review compiles detailed information on the management of spot blotch through nutrient application, host resistance, botanicals, bioagents, and fungitoxicants. This information may be beneficial for researchers, professionals, and farmers seeking effective disease control strategies.

2. HISTORY, DISTRIBUTION, AND ECONOMIC IMPORTANCE

Among the various wheat diseases, spot blotch is one of the most common and destructive, affecting wheat-growing regions across India. The causative pathogen, *Helminthosporium sativum* Pammel, King, and Bakke (syn. *Bipolaris sorokiniana* (Sacc. in Borok) Shoem.), is highly variable and has been reported globally as the cause of foot rot, culm rot, seedling blight, spot blotch, and seed infection in various cereals and grasses (Luttrell, 1955). In India, the disease was first observed by Mohy in 1914 in Pusa, Bihar (Joshi et al., 1986). It has since been confirmed that *B. sorokiniana* is responsible for leaf blight in wheat across India's North Eastern Plains Zone. (Joshi and Chand, 2002; Joshi et al., 2004). The disease is particularly prevalent in this zone, characterized by high humidity around and after the heading stage (Duveiller et al., 1998). In warm regions worldwide, spot blotch, caused by B. sorokiniana, is a major concern, particularly in India and other South Asian countries. The disease is widespread and has been increasingly severe in areas with high humidity and temperatures above 17.5°C (Duveiller et al., 2005). It affects a range of crops, including wheat, barley, oats, rice, and maize, as well as various grasses and vegetables (Dickson, 1958). In tropical and subtropical regions, such as parts of Brazil, Argentina, Paraguay, Tanzania, Zambia, and Madagascar, spot blotch has also been reported (Hetzler et al., 1991). In India, it is notably prevalent in Punjab, Haryana, Uttar Pradesh, and Delhi (Dharmvir et al., 1968; Joshi et al., 1974). Spot blotch is a common occurrence in warm, humid climates and has spread across Southeast Asia (Saari, 1998). The disease is estimated to affect around 25 million hectares of wheat globally, significantly impacting India's Indo-Gangetic Plains, primarily used for rice-wheat cultivation (Shamim et al., 2010). Recent studies indicate that in 2009, four diseases, including spot blotch, were widespread in Punjab, Pakistan, with no wheat variety immune to the pathogen (Rattu et al., 2011). Spot blotch continues to pose a serious threat to wheat production in Southeast Asia, particularly in India, Nepal, and Bangladesh (Acharya et al., 2011; Chowdhary et al., 2013; Bahadar et al., 2016). The pathogen *B. sorokiniana* can severely affect grain yield. Studies show that inoculation of wheat at the flowering stage significantly reduces both grain yield and 1000-grain weight (Dostaler et al., 1980). Losses under various agro-climatic conditions have ranged from 2.72% to 36.24% (Singh et al., 1995). In specific cultivars, yield losses as high as 21.72% and 9.80% were reported (Singh et al., 1997). In China, average yield losses have reached 20% to 30%, with some cases exceeding 75% in farmers' fields (Cheng and Yousan, 1998). The disease's impact on 1000-grain weight has been further demonstrated, with losses ranging from 17% to 32% depending on disease severity (Pandey and Tewari, 2001; Jayasena et al., 2002). In Nepal, grain losses due to *B. sorokiniana* and *Pyrenophora tritici-repentis* in highly susceptible cultivars have ranged from 24% to 27% (Bhandari et al., 2003), and in some years, grain infections can reach as high as 70% under favorable conditions for the disease. Recent studies have highlighted the severity of yield loss in Nepal's wheat cultivars, with reductions in grain yield ranging from 4% to 43% depending on the severity of spot blotch in 2004 and 2005 (Sharma and Duveiller, 2006). In India, losses due to spot blotch in the Eastern Gangetic Plains (EGPs) can range from 10% to 50%, with weather conditions and cultivar resistance playing key roles in determining the extent of damage (Singh et al., 2007). Additionally, significant yield losses occur when the infection affects the flag leaf and the leaf below it before ear emergence (Krishnendu et al., 2011).

3. CAUSAL ORGANISM

Pamel King and Bake (1910) proposed the name *Helminthosporium sativum* as the pathogen responsible for spot blotch. Later, Shoemaker (1959) reclassified this species under the genus *Bipolaris*, referring to its fusoid, straight, or curved conidia that exhibit "bipolar germination"—a process where a single germ tube emerges from both polar ends. Currently, the spot blotch pathogen is recognized as *Bipolaris sorokiniana*. Its synonyms include *Helminthosporium californicum*, *Helminthosporium acrothecioides*, and *Drechslera sorokiniana*. The teleomorphic (sexual) stage of the fungus is *Cochliobolus sativus*. The pathogen has been described under various names, including *Bipolaris sorokiniana* (Sacc.) Shoem., *Drechslera sorokiniana* (Sacc.) Subram. & Jain, and *Helminthosporium sativum*. Hawksworth (1986) suggested that the systematics of the segregate genera *Drechslera* and *Bipolaris* were not well understood, leading to inconsistencies in naming conventions. The genus *Helminthosporium* was first established by Link in 1809 and validated by Greys in 1821. *Helminthosporium sativum* was originally reported by Sorokin in 1890 from infected wheat and rye spikes in Ussuria, Russia. Earlier, *Bipolaris sorokiniana* was classified under: Division: *Eumycota,* Subdivision: *Deuteromycotina,* Class: *Hyphomycetes,* Subclass: *Sporomycetidae,* Order: *Moniliales,* Family: *Dematiaceae* (Shoemaker, 1962). However, after the discovery of its perfect stage (Raemaekers et al., 1988), the classification was revised: Subdivision: *Ascomycotina,* Class: *Loculoascomycetes,* Order: *Pleosporales,* and Family: *Pleosporaceae*. Ahmed et al. (1997) described *Bipolaris sorokiniana* colonies as ash-brown, olive-green, light green, or dark green, with regular or wavy margins, fluffy, spreading, or velvety textures, and with or without sectors. Conidia size ranged from 3 to 10 cells wide and 35 to 270 μm long, depending on the isolate. Barnett and Hunter (1999) characterized *Bipolaris sorokiniana* conidia as brown, multicellular, elliptical, straight or curved, and germinating via a single germ tube at each end. Mathur and Kongsdal (2000) further described the conidia as ellipsoid, dark brown to black, smooth, thick (but tapering toward the ends), broadest in the middle, with rounded ends, 3–12 septa, and measuring 40–120 μm in length and 17–28 μm in breadth. Aggarwal et al. (2002) used light microscopy to show that conidia are slightly curved or sometimes straight, fusiform to broadly ellipsoidal, dark olivaceous brown, smooth, thick-walled, and typically 3–12 (mostly 6) pseudoseptate. The basal cell has a sub-hyaline terminal portion with a clear scar. Under scanning electron microscopy, conidia appeared smooth-walled with localized thickening at pseudosepta and visible terminal germ pores. Iftikhar et al. (2006) observed colony color variations, reporting that black cultures sporulate profusely and exhibit suppressed growth, whereas greyish-brown to albino (whitish) colonies sporulate less. Similarly, Narayan (2004) described *Bipolaris sorokiniana* conidiophores as brown to olivaceous, septate, geniculate at the tips, straight or slightly curved, measuring 70–192 μm in length and 5–9 μm in breadth, with 2–9 septa. The conidia were fusoid, dark brown to olivaceous, 32–130 μm long, 8–18 μm broad, and had 2–10 septa. Acharya et al. (2011) reported that *Bipolaris sorokiniana* conidiophores were unbranched, brown to dark brown, erect, single or clustered, and septate. Conidia were brown to olivaceous brown, straight or slightly curved, measuring 50–15 μm in length with 3–7 septa. Bashyal et al. (2011) noted that *Bipolaris sorokiniana* colonies initially appear white but turn brown to black with sporulation. Some isolates form white colonies in culture without sporulation. Like other dematiaceous fungi, the dark coloration of *Bipolaris sorokiniana* hyphae and conidia results from the presence of melanin pigment.

4. SYMPTOMATOLOGY

The characteristic symptoms of spot blotch typically appear in the early stages of crop growth, manifesting as elongated blotches with chlorotic margins. These blotches are uniformly dark brown and lack any obvious water-soaked appearance. In some cases, they may appear yellowish, oval, or oblong. Lesions also develop on floral bracts and kernels, leading to head blight (Anderson, 1952). According to Dickson (1956), the fungus initially causes localized dark brown patches on living plant tissues. These patches later merge, forming larger blotches that cover a significant portion of the leaf blade. In severe infections, plants dry out prematurely. The symptoms of *B. sorokiniana* leaf blight typically appear 5–8 weeks after wheat is sown, intensify after heading, and spread rapidly. The earliest signs of the disease include numerous chlorotic patches, especially on the lower leaves during the seedling stage. Mature lesions are elliptical, exhibit profuse sporulation, and can cover more than 22% of the leaf surface (Mehta, 1981a). Initially, the lesions on leaves are circular, linear, or elliptical (Mehta, 1993). The disease affects all growth stages of the crop, from seedlings to spikes, causing various symptoms, including foot and root rot, seedling blight, leaf blight, head blight, and seed discoloration. Affected sub-crown internodes (SCIs)-the underground stem segments between the original seed and the crown-develop brown to black discoloration, along with infected roots. Seed infection by *B. sorokiniana* negatively impacts germination and root system development, leading to pre- and post-emergence damping-off (Mehta, 1993). Under favorable conditions, the entire wheat ear, including awns, may become severely diseased. Seeds can be heavily infected, shriveled, and reduced in size, significantly impacting grain yield. When the fungus attacks the spike, it causes light brown to black discoloration around the germination point of the seed, a condition known as "black point." This reduces the market value of grains due to their shriveled and discolored appearance. Dark brown, boat-shaped necrotic spots may develop on coleoptiles, leaves, crowns, stems, and roots, sometimes surrounded by a yellow halo. A defining symptom of the disease is the darkening of the sub-crown internode. Initially, lesions on leaves are small (a few millimeters in size), but they can extend into elongated dark brown spots, reaching lengths of 1–2 cm. As the disease progresses, these spots merge to form large blotches, which can eventually destroy the entire leaf. In moist conditions, conidia proliferate easily on infected leaves, spreading over a few centimeters before aggregating and causing extensive tissue necrosis. Old lesions, especially under high humidity, exhibit abundant conidial production, and a chlorotic streak may diffuse from the lesion's border due to toxin production (Chand et al., 2002). Chand and Joshi (2004) reported that *B. sorokiniana* primarily induces symptoms on leaves, sheaths, and stems. In severe cases, the infection reaches the spikes, producing shriveled, low-weight grains (Kiesling, 1985) with black-pointed embryo ends (Chand and Joshi, 2004). Spot blotch symptoms initially appear as small, scattered, light brown lesions on leaves. As the crop develops, these lesions expand, coalesce, and transform into larger spots, measuring 0.5–10 mm in length and 3–5 mm in width within a week of infection. Symptoms primarily appear on sub-crown internodes, stems, leaves, awns, glumes, and seeds. The earliest leaf lesions are tiny (1–2 mm), dark brown, and lack a chlorotic border. In susceptible genotypes, these lesions grow rapidly, eventually reaching several centimeters in length. Infected spikelets produce shriveled grains with darkened embryo ends (Acharya et al., 2011).

5. DISEASE CYCLE

The pathogen *Bipolaris sorokiniana* enters the plant through stomata or by directly penetrating the epidermis of immature leaves. In addition to causing spot blotch, the fungus can also lead to foot and root rot in wheat, though to a lesser extent (Mitra, 1930). According to Mehta (1993), *B. sorokiniana* survives in soil, plant debris, and on seeds, with seed-borne inoculum being a major source of primary infection (Mehta, 1993; Pandey et al., 2005). In soil, the fungus persists by colonizing diseased straw and sporulating on crop residues (Burgers and Griffin, 1968; Reis and Wunsche, 1984). Several studies have documented the seed transmission of *Cochliobolus sativus* in wheat (Neergard, 1977; Reis, 1983; Sati et al., 1993; Goulart, 1996). Bakonyi et al. (1997) reported that *B. sorokiniana* affects a wide range of host plants, including barley, oat, rye, *Phalaris*, *Agropyron*, *Lolium*, *Polac*, *Setaria*, *Bromus*, and *Festuca*. While spot blotch is commonly a seed-borne disease, primary infections can also arise from inoculum present on crop residues, collateral hosts (such as rice, barley, and other grasses), or conidia in the soil. The fungus can persist on straw or in soil for several months before its viability declines (Chand et al., 2002; Pandey et al., 2005). Conidia on wheat straw tend to aggregate into clumps after five months of storage (Chand et al., 2002). Although the sexual stage of *B. sorokiniana* (*C. sativus*) is known, it is not a major source of infection; instead, conidia serve as the primary means of dispersal and survival (Reis and Wunsche, 1984). Malakar et al. (2007) investigated the off-season survival of *B. sorokiniana* in sterilized and unsterilized soils, as well as in wheat straw residues left on the soil surface. Using a dilution plate technique, they tracked the population of viable fungal propagules in soil and crop residues at monthly intervals. The study found that the fungal population initially increased for two months in both soil and crop residues before declining sharply over the next two months. After four months, the decline became more gradual. In free residue, a continuous decline was observed from the beginning of the study. The pathogen survived in sterilized soil for up to 8–10 months, but could not be recovered from unsterilized or sterilized soil residues after 7–8 months. However, in free residue stored at room temperature, *B. sorokiniana* remained viable for up to 12 months. Acharya et al. (2011) described the infection process of *B. sorokiniana*, noting that conidial spores adhere to the surface of leaves, where they germinate and form germ tubes. Within eight hours, the germ tubes swell and develop an appressorium, from which infecting hyphae emerge (Jansson and Akesson, 2003). The hyphae penetrate the host's cuticle within 12 hours (Sahu et al., 2016) and rapidly multiply, spreading into the intercellular spaces of the mesophyll tissue (Acharya et al., 2011). A new generation of conidia is produced within 48 hours on conidiophores, allowing multiple infection cycles to occur during the cropping season. These conidia disperse through dew and rain, leading to secondary infections (Acharya et al., 2011). Airborne conidia serve as the primary cause of secondary infections in spot blotch.

6. HOST RESISTANCE AGAINST SPOT BLOTCH DISEASE

Extensive efforts have been made to identify wheat genotypes resistant to spot blotch (*Bipolaris sorokiniana*), with numerous studies evaluating different germplasm and cultivars. Molan et al. (2001) tested 18 wheat genotypes and two cultivars (Yecora Rojo and West Bred) against *B. sorokiniana*. The study found that four genotypes were resistant, while nine genotypes and both cultivars showed moderate resistance; the remaining genotypes were susceptible. Similarly, Ragiba et al. (2001) screened 567 wheat entries against *Helminthosporium* leaf blight in Pusa, Bihar, identifying 57 resistant (R), 123 moderately resistant (MR), 291 moderately susceptible (MS), 88 susceptible (S), and 8 highly susceptible entries. Among the resistant lines, Mayoor and Chirya-3 from CIMMYT, Mexico, demonstrated a high degree of resistance under field conditions. Bhandari et al. (2002) estimated grain losses due to spot blotch at 24–27% in highly susceptible cultivars. Singh et al. (2002) evaluated 325 wheat genotypes and found three (NW-2043, MACS-2942, and HUWL-99003) resistant, while 75 exhibited moderate resistance. Saadi et al. (2002) tested wheat cultivars (K65, Cooley, Shawarir, and Missani) using a detached leaf method and found that K65 and Cooley were resistant. Akram and Singh (2003) evaluated 24 genotypes, of which 11-including VL 738, C 306, BW 11259, and PBW 343-showed longer incubation periods, fewer spots, lower disease severity, and reduced sporulation, making them resistant in field conditions. Further studies confirmed resistance in select genotypes. Singh et al. (2003) analyzed 500 wheat genotypes, identifying HPW 93 and HPW 184 as resistant and 32 as moderately resistant. Singh et al. (2005) tested 291 wheat genotypes, finding 25 resistant but none immune. Ibeagha et al. (2005) examined interactions of resistant genotypes with *B. sorokiniana*, reporting that Yangmai 6, M3 (W7976), Shanghai 4, and Chirya-7 showed higher resistance compared to the susceptible cultivar Sonalika. Ahmed (2007) screened 385 wheat genotypes under natural conditions in Bangladesh, identifying 50 as resistant to moderately susceptible. Further screening under artificial inoculation revealed 13 resistant genotypes, 28 moderately resistant, seven moderately susceptible, and 2 susceptible. The control variety Kanchan was highly susceptible, with over 60% leaf area infection. Singh et al. (2007) evaluated 78 genotypes under artificial inoculation, identifying 15 as moderately resistant. Malik et al. (2007) tested 19 wheat varieties and found that WH 542, PBW 342, PBW 373, and C 306 developed only 1–3 necrotic spots per leaf and maintained low terminal disease scores under different sowing conditions. Khan and Chowdhary (2011) evaluated 422 spring wheat germplasm lines and found that while none were immune, 52 were resistant, 180 were moderately susceptible, 171 susceptible, and 19 highly susceptible. CIMMYT lines Chirya-3, Chirya-7, and Mayoor exhibited high resistance in both field and polyhouse conditions. Iftikhar et al. (2012) screened 56 commercial wheat varieties under controlled and field conditions, identifying 12 with moderate resistance in both conditions, while nine varieties-including Faisalabad-83, Inqilab-91, and Rohtas-90-were moderately resistant across all conditions. Kumar et al. (2013) tested seven wheat genotypes at different growth stages and found that while none were immune, Chirya-3, Chirya-7, and Chirya-1 were resistant at both seedling and adult stages. Shanghai-7 and Shanghai-4 showed moderate resistance, while HD2932 and Sonalika were moderately susceptible. Kumar et al. (2013) also analyzed spring wheat germplasm, reporting that 15 genotypes were resistant, while 47% were moderately resistant, 43% moderately susceptible, and 6% susceptible. They noted that resistant lines had dwarf stature and early maturity. Kumar et al. (2015) further studied resistance variability across plant heights and maturity groups in 147 wheat genotypes, finding that most lines were moderately susceptible. The area under the disease progress curve (AUDPC) values ranged from 92.6 to 123.5, with PBW 640 showing the highest and K0810 the lowest among resistant lines. Ojha et al. (2016) evaluated 100 wheat entries and identified 20 as highly resistant or immune, 28 as resistant, 22 as moderately resistant, 15 as moderately susceptible, and 15 as susceptible. Indian germplasm tended to be more susceptible than lines from CIMMYT and China. Singh et al. (2016) tested 250 genotypes under artificial conditions, finding one immune, 20 resistant, 146 moderately resistant, 75 moderately susceptible, and eight susceptible. A follow-up study by Singh et al. (2017) on 176 genotypes found one immune, 31 resistant, 75 moderately resistant, 52 moderately susceptible, and 17 susceptible.

7. BIOLOGICAL CONTROL OF SPOT BLOTCH IN WHEAT

Trichoderma species have been widely developed as biocontrol agents against fungal plant diseases. Their effectiveness is attributed to their ability to colonize plant roots, promote plant growth, and enhance disease resistance. Bioagents *Trichoderma harzianum* and *Pseudomonas fluorescens* in talc- and oil-based formulations were effective against *Helminthosporium oryzae* under field conditions in India. Three weekly sprays of *P. fluorescens* (talc-based) at 10 g/liter significantly reduced disease severity and improved yields (Joshi et al., 2007). Harish et al. (2008) assessed eight antagonistic organisms against *Bipolaris oryzae* in both laboratory and field conditions. In vitro, *T. viride* (Tv2) was the most effective, inhibiting 62.92% of mycelial growth and 77.03% of spore germination, followed by *T. harzianum* (Th5) and *T. reesei* (Tr3). Glasshouse studies demonstrated that post-infection spraying of rice plants with *T. viride* (Tv2) reduced disease incidence by 45%, while two field sprays reduced pathogen incidence by 48% and increased yield by 14%. Hasan (2013) examined *T. harzianum*'s efficacy in controlling wheat spot blotch, revealing that isolate RUT-103 reduced *B. sorokiniana*'s radial growth by 45.45% after eight days. Seed treatment followed by foliar application resulted in increased plant height (106.6 cm), longer ears (20.0 cm), more grains per ear (46.33), and higher 1000-seed weight (40.0 g), ultimately boosting grain yield by 10.91% (3.76 t/ha). Yadav et al. (2015) studied two bio-agents against wheat spot blotch under field conditions, finding that *P. fluorescens* followed by *T. harzianum* provided the highest disease reduction. However, both were less effective than chemical fungicides. Among four tested plant extracts, two applications of aqueous *Eucalyptus* leaf extract at the tillering and boot leaf stages resulted in the highest wheat yield. Khan et al. (2021) tested *T. viride-1*, *T. viride-2*, *T. harzianum-1*, *T. harzianum-2*, and *P. fluorescens* against *B. sorokiniana*, reporting that *T. harzianum-1* was most effective, inhibiting mycelial growth by 77.90%, followed by *T. harzianum-2* (74.80%) and *T. viride-1* (74.41%). *P. fluorescens* was the least effective, reducing mycelial growth by 47.22%.

8. EFFECT OF BOTANICALS ON SPOT BLOTCH OF WHEAT

Narayan (2004) observed that garlic clove extract effectively inhibited the mycelial growth of *Helminthosporium sativum*, achieving 65.03%, 72.55%, and 83.63% inhibition at 2%, 5%, and 10% concentrations, respectively. Neem leaf extract exhibited 62.42% inhibition at a 10% concentration. Under field conditions during the Rabi seasons of 2000–01 and 2001–02 at Pusa (Bihar), neem leaf, mentha leaf, tulsi leaf, bael leaf, onion bulb, and garlic clove extracts significantly reduced disease severity. Two sprays of 5% garlic clove extract resulted in 47% disease control, whereas neem leaf extract provided 35–36% control. Akhter et al. (2006) tested the inhibition of *B. sorokiniana* conidial germination using eight ethanolic plant extracts and ten aqueous extracts, both alone and in combination with cow dung and cow urine. *Adhatoda vasica* (leaf) and *Zingiber officinale* (rhizome) ethanolic extracts at 2.5% concentration achieved 100% inhibition of conidial germination. Additionally, *Vinca rosea*, *Piper betle*, and *Azadirachta indica* extracts combined with cow dung suspension also showed complete inhibition. Conversely, *Ocimum sanctum* extract exhibited minimal inhibitory effects against *B. sorokiniana*. Hasan et al. (2012) evaluated the effects of five botanical extracts-garlic, onion, ginger, neem, and black cumin-at 5%, 10%, and 15% concentrations on *B. sorokiniana* mycelial growth. The highest inhibition (67.50%) was recorded with 15% garlic extract, while lower concentrations showed reduced efficacy. Hasan (2013) reported that among ten plant extracts tested, garlic bulb, margosa (neem) leaf, and ginger rhizome extracts significantly reduced seed-borne fungal infections, particularly *B. sorokiniana*, *Fusarium graminearum*, *Aspergillus flavus*, and *Alternaria alternata*. Similarly, Perello et al. (2013) demonstrated that allicin in garlic juice inhibited the radial colony growth of *Drechslera tritici-repentis*, *B. sorokiniana*, and *Septoria tritici* on agar plates, as well as spore germination. Prashanth et al. (2014) evaluated six plant extracts-garlic clove, ginger rhizome, neem leaves, onion bulb, tulsi, and marigold-against the foliar blight pathogen of wheat. Garlic clove extract at 5% was significantly more effective than the other plant extracts. Katooli et al. (2011) found that eucalyptus essential oil completely inhibited the mycelial growth of *Pythium ultimum* and *Rhizoctonia solani*. However, for *B. sorokiniana*, complete inhibition lasted only five days, after which mycelial growth resumed. Yadav et al. (2015) examined four plant extracts against wheat spot blotch under field conditions. Two applications of aqueous eucalyptus leaf extract at the tillering and boot leaf stages resulted in the highest wheat yield compared to other botanical extracts. Jatoi et al. (2019) tested five plant extracts-

Azadirachta indica, *Calotropis procera*, *Allium sativum*, *Datura stramonium*, and *Zingiber officinale*-at three concentrations (5%, 10%, and 15%). *Z. officinale* and *A. sativum* were most effective at higher doses, showing complete (0.00 mm) and nearly complete (2.00 mm) mycelial growth inhibition, respectively. *D. stramonium* (4.62 mm), *A. indica* (18.00 mm), and *C. procera* (12.00 mm) also performed better than the control (40.00 mm). Magar et al. (2020) studied five botanicals-neem, garlic, eucalyptus, and bojho-at three concentrations (5%, 10%, and 15%). Garlic clove extract at 15% exhibited the highest mycelial growth inhibition (52.85%), followed closely by bojho (52.48%) at 15%. The lowest inhibition (9.59%) was observed in the neem extract at 15%. Debsharma et al. (2021) tested five botanical oils-ginger, eucalyptus, clove, til (sesame), and neem-against *B. sorokiniana* at five concentrations (1000, 1500, 2000, 2500, and 3000 ppm). Clove oil exhibited the highest inhibition (46.49%), whereas neem oil showed the lowest (17.92%). The fungistatic effect increased with extract concentration.

9. EFFECT OF MICRONUTRIENT APPLICATION ON SPOT BLOTCH OF WHEAT

Kostas et al. (2005) studied the effects of foliar application of boron, manganese, and zinc on tan spot disease in winter durum wheat, caused by *Drechslera tritici-repentis* (Died.) Shoem. In both years, sprayed plots showed significantly fewer flag leaf lesions than untreated ones from the booting to milk stages. Among the treatments, boron application significantly reduced the number of lesions per leaf compared to manganese and zinc at the booting stage in both years. In the first year, no significant differences were observed between manganese and zinc treatments. However, in the second year, zinc treatment resulted in the lowest number of lesions at the booting and heading stages, whereas manganese was most effective at the milk stage. Zinc treatment also significantly influenced flag leaf area, potentially reducing disease severity, whereas boron and manganese had no significant effect. Despite these effects, no significant differences in yield components were observed. These findings suggest that foliar micronutrient application can mitigate tan spot severity in wheat, although the physiological mechanisms remain unclear. Sharma et al. (2006) reported that the application of KCl and CaCl reduced spot blotch severity. Lower disease severity and higher grain yield were observed with KCl compared to CaCl, suggesting that KCl is more suitable for K-deficient soils in the warm wheat-growing regions of South Asia, where spot blotch is a major concern in intensive rice-wheat cropping systems. Rahman et al. (2009) observed that disease severity was significantly higher with both excessive (150 kg N ha^{-1}) and deficient (0 kg N ha^{-1}) nitrogen levels compared to the recommended dose of 100 kg N ha^{-1}. A significant reduction in disease severity was noted under the recommended fertilizer regimen (N-100 kg ha^{-1}, K-50 kg ha^{-1}, S-20 kg ha^{-1}, B-1 kg ha^{-1}). Yadav et al. (2013) evaluated the effects of micronutrients (zinc, iron, manganese, boron, molybdenum, and sulfur) and fungicides (carbendazim and mancozeb) on spot blotch incidence, severity, and crop yield. Spraying at the tillering and boot leaf stages showed that molybdenum, boron, and manganese were the most effective micronutrients in minimizing disease incidence. Devi et al. (2019) reported that chemical inducers at different concentrations significantly reduced leaf infection compared to untreated controls. The lowest disease leaf area percentage was recorded in plants treated with salicylic acid (10 ha^{-4} M) at 12.76%, followed by $CuSO_4$ (10^{-4} M) at 14.81%, which was statistically similar but significantly lower than $CuSO_4$ (10^{-5} M) at 16.87%. In contrast, the highest disease leaf area percentages were observed in plants treated with $ZnSO_4$ (10^{-4} M) at 41.28%, followed by $ZnSO_4$ (10^{-5} M) at 38.89% and 2,4-D (10^{-6} M) at 38.68%. Jaiganesh et al. (2019) investigated the effects of various macro- and micronutrients-calcium sulfate, copper sulfate, ferrous sulfate, magnesium sulfate, manganese sulfate, potassium sulfate, and zinc sulfate-on *Helminthosporium oryzae* growth at concentrations of 1000, 2000, and 3000 ppm. Among these, $ZnSO_4$ at 3000 ppm exhibited the highest inhibition of mycelial growth (83.30%), mycelial dry weight, and spore germination. The lowest inhibition was recorded for manganese sulfate (61.10%) at the same concentration. Naga et al. (2022) found that all tested macronutrients significantly inhibited fungal growth at different concentrations, with increased inhibition observed at higher nutrient concentrations. Four macronutrients (ammonium sulfate, potassium sulfate, calcium sulfate, and magnesium sulfate) and four micronutrients (ferrous sulfate, manganese sulfate, copper sulfate, and zinc sulfate) were tested. Among the micronutrients, $ZnSO_4$ at 0.3% showed the highest mycelial growth inhibition (58.89%), while among macronutrients, K_2SO_4 at 0.3% exhibited the highest inhibition (56.67%).

10. EFFECT OF FUNGITOXICANTS ON SPOT BLOTCH OF WHEAT

Malik et al. (2008) examined the effects of foliar application of Propiconazole (Tilt 25% EC) at different growth stages on spot blotch severity in the susceptible wheat variety HD-2329. Yield losses were estimated under varying disease levels, with significant yield increases observed in protected plots. The yield improvements due to fungicidal spraying over unprotected plots were 29.6%, 50.2%, 61.2%, and 63.4%, while the 1000-grain weight increased by 2.8%, 9.2%, 16.6%, and 18.3% with one, two, three, and four applications, respectively. Singh et al. (2008) reported that three foliar applications of Propiconazole (0.1%) after disease onset significantly reduced severity and increased yield across multiple locations in India. Malaker and Mian (2009) found that foliar application of Tilt 25 EC (0.05%) significantly minimized disease severity in all spray schedules except those at 70 and 90 DAS. Singh et al. (2011) demonstrated that Propiconazole and Tebuconazole effectively controlled spot blotch in HD-2329 wheat. These treatments significantly increased grain yield, with Propiconazole (5.24 t ha^{-1}) and Tebuconazole (5.08 t ha^{-1}) at 0.1%. During the 2001–02 season, similar increases were observed with Propiconazole (5.36 t ha^{-1}) and Tebuconazole (5.26 t ha^{-1}) compared to untreated plots. Hasan et al. (2012) evaluated five fungicides-Hexaconazole, Carbendazim, Mancozeb, Difenoconazole+Propiconazole, and Propiconazole-at concentrations ranging from 100 to 500 ppm. Complete mycelial growth inhibition of *B. sorokiniana* was observed with Propiconazole, Hexaconazole, and Difenoconazole+Propiconazole at all concentrations. Mahapatra and Das (2013) tested ten different fungicidal combinations, including Captan 50% WP, Propiconazole 25% EC, Tebuconazole 25% EC, Mancozeb 75% WP, and Carboxin 37.5%+Thiram 37.5%. The most effective treatment was seed treatment with Carboxin + Thiram (2.5 g kg^{-1}) combined with two foliar sprays of Propiconazole (0.1%) at the boot leaf stage and 20 days later. Singh et al. (2014) reported that spot blotch appeared at the flag leaf stage (ZS37) in NEPZ and at the boot swollen stage (ZS45) in NWPZ. The first foliar spray at the boot leaf stage and the second 15 days later resulted in the lowest spot blotch scores (35) with Vitavax (2.5 g kg^{-1}) and two Propiconazole sprays (0.1%). Singh et al. (2015) observed a minimum disease intensity (37.28%) with seed treatment using Vitavax (3 g kg^{-1}) followed by Tilt (0.1%) spray at boot leaf or disease initiation on flag-1 leaf. Yadav et al. (2015) studied the effects of Propiconazole, Carbendazim, and Hexaconazole, noting that two Carbendazim (0.1%) sprays at tillering and boot leaf stages maximally reduced disease incidence and severity. Propiconazole was also highly effective. Samia et al. (2015) evaluated four fungicides-Mancozeb, Carbendazim, Propiconazole, and Copper oxychloride-against *B. sorokiniana* isolates from Bangladesh. Propiconazole completely inhibited mycelial growth at all concentrations, while Copper oxychloride, Carbendazim, and Mancozeb showed increasing inhibition with higher concentrations. Singh et al. (2016) found that seed treatment with Vitavax (3 g kg^{-1}) followed by two foliar sprays of Propiconazole (0.1%) at flag-1 leaf and soft dough stage provided the best disease control (39.03% disease intensity). This treatment also yielded the highest 1000-grain weight (51.74 g) and grain yield (42.81 q ha^{-1}). Magar et al. (2020) tested eight fungicides, finding Tilt (Propiconazole) completely inhibited mycelial growth at all concentrations, while Carbendazim was the least effective (23.56% inhibition at 25 ppm). Khan et al. (2021) evaluated six fungicides, with Propiconazole, Tebuconazole, Azoxystrobin, and Azoxystrobin + Difenoconazole completely inhibiting mycelial growth. Difenoconazole provided 96.27% inhibition at 200 ppm, while Mancozeb was the least effective (89.18% at 200 ppm). Tiwari et al. (2022) reported complete mycelial growth inhibition with Propiconazole, Hexaconazole, and Difenoconazole + Propiconazole at 250 ppm. Carbendazim and Copper oxychloride achieved complete inhibition at 500 and 1000 ppm, respectively, while Mancozeb remained ineffective at 1000 ppm.

11. CONCLUSION

Wheat, a vital cereal crop in India, faces significant yield and quality losses due to various diseases, among which spot blotch, caused by *Bipolaris sorokiniana*, is most destructive in the North Eastern Plain Zone of India. Characterized by lesions on leaves, sheaths, and spikes, the disease thrives in warm, humid climates, reducing yields by 15–20%. This review highlights the roles of micronutrients, botanicals, bioagents, fungitoxicants, and host resistance in managing spot blotch, supporting sustainable wheat cultivation and farmer livelihoods.

12. REFERENCES

Acharya, K., Dutta, A.K., Pradhan, P., 2011. *Bipolaris sorokiniana* (Sacc.) Shoem. The most destructive wheat fungal pathogen in the warmer areas. Molecular and Applied Mycology and Plant Pathology Laboratory, Department of Botany, University of Calcutta, Kolkata, WB, India. Australian Journal of Crop Science 5(9), 1064–1071.

Aggarwal, R., Soma, D., Singh, D.V., Srivastava, K.D., 2002. SEM studies on spore morphology and infection process of spot blotch pathogen in wheat. Indian Phytopathology 55(2), 197–199.

Ahmed, A.U., Rahman, M.Z., Bhuiyan, K.A., Mian, I.H., 1997. Variation in isolates of *Bipolaris sorokiniana* from wheat. Bangladesh Journal of Plant Pathology 13(1&2), 29–36.

Ahmed, F., 2007. Reaction of wheat genotypes to leaf blight caused by *Bipolaris sorokiniana*. Bangladesh Journal of Plant Pathology 23(1/2), 75–78.

Akhter, N., Begum, M.F., Alam, S., Alam, M.S., 2006. Inhibitory effect of different plant extracts, cow dung, and cow urine on conidial germination of *Bipolaris sorokiniana*. Journal of Bio-Science 14, 87–92.

DOI:10.3329/jbs.v14i0.449.
Akram, M., Singh, A., 2003. Screening and host response characterization of wheat against *Bipolaris sorokiniana*. Indian Phytopathology 56(2), 201–204.
Anderson, A.L., 1952. Development of wheat head blight incited by *Helminthosporium sativum*. Phytopathology 42, 451–456.
Anonymous, 2024-25. Annual Report. Department of Agriculture & Farmers Welfare Ministry of Agriculture & Farmers Welfare Government of India Krishi Bhawan, New Delhi-110 001. www.agriwelfare.gov.in.
Bahadar, K., Munir, A., Asad, S., 2016. Management of *Bipolaris Sorokiniana,* the causal pathogen of spot blotch of wheat by eucalyptus extracts. Journal of Plant Pathology & Microbiology 7, 326. DOI: 10.4172/2157-7471.1000326.
Bakonyi, J., Aponyi, I., Fischl, G., 1997. Diseases caused by *Bipolaris sorokiniana* and *Drechslera tritici repentis* in Hungary. In: Duveiller, E., Dubin, H.J., Reeves, J., McNab, A. (Eds), *Helminthosporium* blights of wheat: spot blotch and tan spot. Mexico, D.F., Mexico: CIMMYT, 80–85.
Barnett, H.L., Hunter, B.B., 1999. Illustrated genera of imperfect fungi. *Fourth Edition.* APS press. The American Phytopathological Society, Saint Paul, Minnesota, 126.
Bashyal, B.M., Chand, R., Prasad, L.C., Joshi, A.K., 2011. Partial resistance components for the management of spot blotch pathogen *Bipolaris sorokiniana* of barley (*Hordeum vulgare* L.). Acta Phytopathologica et Entomologica Hungarica 46(1), 49–57.
Bettiol, W., Morandi, M.A.B., 2009. Biocontrol de doenças de plantas: use perspectivas. Embrapa Meio Ambiente, Jaguariúna, 341.
Bhandari, D., Bhatta, M. R., Duveiller, E., Shreshtha, S. M., 2002. Foliar blight of wheat in Nepal: Resistance breeding, epidemiology and disease management. In: Proceedings of Fourth International Wheat Tan Spot Blotch Workshop, QW Bemidji, Minnesota, USA, 34–41.
Bhandari, D., Bhatta, M.R., Duveiller, E., Shrestha, S.M., 2003. Foliar blight of wheat in Nepal: resistance breeding, epidemiology and disease management. Proceedings of Fourth International Wheat Tan Spot and Spot Blotch Workshop, Bemidji, Minnesota, USA, 21–24.
Burgers, L.W., Griffin, D.M., 1968. The relationship between the spore density of Cochliobolus sativus in soil and its activity and parasitism. Australian Journal of Experimental Agriculture and Animal Husbandry 8, 371–373.
Chand, R., Joshi, A.K., 2004. Foliar blight: solved and unsolved problems. In: Joshi, A.K., Chand, R., Arun, B., Singh, G. (Eds.), A compendium of lectures on wheat improvement in eastern and warmer regions of India: conventional and non-conventional approaches. Banaras Hindu University, Varanasi, 221005, India: 58–69.
Chand, R., Singh, H.V., Joshi, A.K., Duveiller, E., 2002. Physiological and morphological aspects of *Bipolaris sorokiniana* conidia surviving on wheat straw. Journal of Plant Pathology 18, 328–332.
Cheng, N., Yousan, W.U., 1998. Incidence and current management of spot blotch of wheat in China. In: Duveiller, E., Dubin, H.J., Reeves, J., Mc Nab, A. (Eds.), Helminthosporium blight of wheat: spot blotch and tan spot. Proceedings of an International Workshop, CIMMYT, Mexico D.F., 119–125.
Chowdhary, A.K., Singh, G., Tyagi, B.S., Ojha, A., Dhar, T., Battacharya, M.P., 2013. Spot blotch disease of wheat-a new thrust area for sustainable productivity. Journal of Wheat Research 5, 1–11.
Debsharma, R., Islam, S., Debnath, D., Chakraborty, S., Mahapatra, S., 2021. Efficacy study of some botanical oils against spot blotch disease (*Bipolaris sorokiniana*) of wheat under *in-vitro* condition. International Journal of Chemistry 9(4), 3022–3028. DOI: 10.22271/chemi.2021.v9.i1ap.11690.
Dharmvir, A., Joshi, L., Pathak, K., 1968. Preliminary note on the occurrence of black point disease of wheat in India. Indian Phytopathology 21, 234.
Dickson, J.G., 1958. Diseases of field Crops (2nd ed.). Mcgraw Hill Book company, New York, USA, pp. 517.
Dickson, J.G., 1956. Diseases of field crops. Tata Mcgraw Hill Publishing Co. Ltd. New Delhi. pp 517.
Dostaler, D., Pelletier, G.J., Couture, L., 1980. Dynamics of *Helminthosporium* blotch of barley inoculum density and frequency of inoculations. Phytoprotection 61, 19–25.
Dubin, H.J., Duveiller, E., 2000. Helminthosporium leaf blights of wheat: integrated control and prospects for the future. In: Proceedings of the International Conference Integrated Plant Disease Management. Sustainable Agriculture, 575–579. Indian Phytopathological Society, New Delhi, India.
Duveiller, E., Garcia, I., Franco, J., Toledo, J., Crossa, J., Lopez, F., 1998. Evaluating spot blotch resistance of wheat: Improving disease assessment under controlled condition and in the field. In: Duveiller, E., Dubin H.J., Reeves, J., McNab, A. (Eds.), *Helminthosporium* blights of wheat: Spot blotch and Tan spot. Mexico. D.F., Mexico: CIMMYT, pp. 63-66.
Duveiller, E., Kandel, Y.R., Sharma, R.C., Shrestha, S.M.,

2005. Epidemiology of foliar blights (Spot blotch and tan spot) of wheat in the plains bordering the Himalayas. The American Phytopathological Society 3(95), 248–256.

Duveiller, E., Sharma, R.C., 2009. Genetic improvement and crop management strategies to minimize yield losses in warm non-traditional wheat growing areas due to spot blotch pathogen *Cochliobolus sativus*. Journal of Phytopathology 157(9), 521–534.

Goulart, A.C.P., 1996. Transmission of *Bipolaris sorokiniana* from seeds to wheat coleoptile. Summa Phytopathologica 22, 5–9.

Grays, S.F., 1821. A natural arrangement of British plants. Baldwin, Cradok and Joy, London 1, 1-824.

Harish, S., Saravanakumar, D., Radjacommare, R., Ebenezar, E.G., Seetharaman, K., 2008. Use of plant extracts and biocontrol agents for the management of brown spot disease in rice. BioControl 53, 555–567.

Hasan, M.M., 2013. Biological control of wheat diseases caused by *Bipolaris sorokiniana, Fusarium graminearum* and *Aspergillus flavus* with antagonists of Trichoderma spp. Persian Gulf Crop Protection 2(3), 1–9.

Hasan, M.M., Ahmed, F., Islam, M.R., Murad, K.F.I., 2012. In vitro effect of botanical extracts and fungicides against *Bipolaris sorokiniana*, causal agent of leaf blotch of barley. Journal of Agroforestry and Environment 6(1), 83–87. https://jagroforenviron.com/wp-content/uploads/2018/09/18.

Hawksworth, D.L., 1986. Fungal genera in urgent need of taxonomic work. Microbial Science 3, 58.

Hetzler, J., Eyal, J., Fehrmann, H., Mehta, Y.R., Kushnir, U., Zekaria-Oren, J., Cohen, L., 1991. Interaction between *Cochliobolus sativus* and wheat cultivars. In: Saunders, D.A. (Ed.), Wheat for the non-traditional warmer areas. Mexico, D.F., Mexico: CIMMYT, pp. 266–283.

Ibeagha, A.E., Huckelhoven, R., Schafer, P., Singh, D.P., Kogel, K.H., 2005. Model wheat genotypes as tool to uncover effective defence mechanism against the hemibiotrophic fungus *Bipolaris sorokiniana*. Phytopathology 95, 528–532.

Iftikhar, S., Shahzad, A., Munir, A., Iftikhar, I., Amir, S., 2006. Prevalence and distribution of foliar blights pathogens of wheat in different agro-ecological zones of Pakistan with special reference to Bipolaris sorokiniana. Pakistan Journal of Botany 38(1), 205–210.

Iftikhar, S., Shahzad, A., Rattu, A.R., Munir, A., Fayyaz, M., 2012. Screening of commercial wheat varieties to spot blotch under controlled and field conditions. Pakistan Journal of Botany 44(1), 361–363.

Jaiganesh, V., Kannan, C., 2019. Effect of certain macro-micro nutrients on *Helminthosporium oryzae* Breda de Haan. Plant Archives 19, 588–592.

Jansson, H.B., Akesson, H., 2003. Extracellular matrix, esterase and phytoalexin prehelimithosporol in infection of barley leaves by *Bipolaris sorokiniana*. European Journal of Plant Pathology 109, 509–605.

Jatoi, G.H., Keerio, A.U., Abdulle, Y.A., Qiu, D., 2019. Effect of selected fungicides and bio-pesticides on the mycelial colony growth of the *Helminthosporium oryzae*. brown spot of rice. Acta Ecologica Sinica 39(6), 456–460.

Jayasenaa, K.W., Loughmanb, R., Majewskib, J., 2002. Evaluation of fungicides in control of spot-type net blotch on barley. Crop Protection 21, 63–69.

Joshi, A.K., Chand, R., 2002. Variation and inheritance of leaf angle and its association with spot blotch (*Bipolaris sorokiniana*) severity in wheat. Euphytica 124, 283–191.

Joshi, A.K., Chand, R., Kumar, S., Singh, R.P., 2004. Leaf tip necrosis-a phenotypic marker for resistance to spot blotch disease caused by *Bipolaris sorokiniana* in wheat (*Triticum aestivum* L.). Crop Science 44, 792–796.

Joshi, L.M., Gera, S.D., Adalakha, K.L., Srivastava, K.D., Ram, B., Palmar, L.T., 1974. Some foliar diseases of wheat during 1967-70 crop seasons. Indian Phytopathology 27, 178–181.

Joshi, L.M., Singh, D.V., Srivastava, K.D., 1986. Wheat and wheat diseases in India. In: Joshi, L.M., Singh, D.V., Srivastava, K.D. (Eds.), Problems and progress of wheat pathology in South Asia, New Delhi: Malhotra Publishing House 401, 1–19.

Joshi, N., Brar, K.S., Pannu, P. P. S., Paramjit, S., 2007. Field efficacy of fungal and bacterial antagonists against brown spot of rice. Journal of Biological Control 21(1), 159–162.

Katooli, N., Maghsodlo, R., Razavi, S.E., 2014. Evaluation of eucalyptus essential oil against some plant pathogenic fungi. International Journal of Agroforestry and Silviculture1(2), 016–017.

Khan, J.B., Katiyar, S., Kanchan, C., Kumar, J., Gupta, P.K., 2021. Comparative evaluation of different fungicides and bio-agents for management of spot blotch of barley caused by *Bipolaris sorokiniana* (Sace. Ex Sorok). Journal of Cereal Research 13, 211–214. http://doi.org/10.25174/2582-2675/2021/114191.

Kiesling, R.L., 1985. The diseases of barley. In: Rasmusson, D.C. (Ed.), Barley. Madison Wisconsin American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 269–312.

Kostas, B.S., Dordas, C., 2005. Effect of foliar applied boron, manganese and zinc on tan spot in winter durum wheat. Laboratory of Agronomy, School of

Agriculture, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece Received 8 June 2005.
Krishnendu, A., Dutta, A.K., Pradhan, P., 2011. *Bipolaris sorokiniana* (Sacc.) Shoem: the most destructive wheat fungal pathogen in the warmer areas. Australian Journal of Crop Science 5, 1064–1071.
Kumar, D., Prasad, D., Singh, R., Tomar, A., 2025a. Evaluation of micronutrients, botanicals, bioagents and fungitoxicants against *Bipolaris sorokiniana* causing spot blotch disease in wheat. International Journal of Bio-resource and Stress Management 16(1), 01–08. HTTPS://DOI. ORG/10.23910/1.2025.5699.
Kumar, D., Prasad, D., Singh, R., Tomar, A., 2025b. Integrated management of spot blotch disease of wheat (*Triticum aestivum* L.) caused by *Bipolaris sorokiniana* (Sacc.) Shoem. 2025b. International Journal of Economic Plants 12(1), 01–08. https://ojs.pphouse.org/index.php/IJEP.
Kumar, M., Mauriya, A.K., Nitish, D., 2013. Evaluation of spot blotch resistance in spring wheat germplasm. Spot blotch resistance in wheat. Lambert Academic Press, pp 56.
Kumar, P., Dhari, R., Kumar, J., Singh, J., 2015. Variability for leaf blight resistance in Indian spring wheat (*Triticum aestivum*) germplasm. An International Journal of Life Sciences 10(1), 491–494.
Link, J.H.F., 1809. Observationes in ordines plantarum naturales. Dissertatio Ima Gesellschaft Naturforschender Freunde zu Berlin, Magazine 3, 3–42.
Luttrell, E.S., 1955. A taxonomic revision of *Helminthosporium sativum* and related species. American Journal of Botany 42(1), 57–68.
Magar, P.B., Baidya, S., Koju, R., Adhikary, S., 2020. *In-vitro* evaluation of botanicals and fungicides against *Bipolaris sorokiniana*, causing spot blotch of wheat. Journal of Agriculture and Natural Resources 3(2), 296–305.
Mahapatra, S., Das, S., 2013. Efficacy of different fungicides against spot blotch of wheat in Terai region of West Bengal. Journal Wheat Research 5 (2), 7–11.
Malakar, P.K., Mian, I.H., Maniruzzaman, M.D., Khandaker, Reza, M.M.A., 2007. Survival of *Bipolaris sorokiniana* (Sacc.) Shoemaker in soil and residue of wheat, Bangladesh Journal of Botany 36(2), 133–137.
Malaker, P.K., Mian, I.H., 2009. Effect of seed treatment and foliar spray with fungicides in controlling black point disease of wheat. Bangladesh Journal of Agricultural Research 34(3), 425–434.
Malik, V.K., Singh, D.P., Panwar, M.S., 2008. Management of spot blotch of wheat (*Triticum aestivum*) caused by *Bipolaris sorokiniana* using foliar spray of botanicals and fungicides. Indian Journal of Agricultural Sciences 78, 646–648.
Malik, V.K., Singh, D.P., Panwar, M.S., 2007. Development of spot blotch caused by *Bipolaris sorokiniana* on wheat varieties sown on different dates. Journal of Mycology and Plant Pathology 37(3), 390–392.
Mathur, S.B., Kongsdal, Q., 2000. Common laboratory seed health testing methods for detecting fungi. Danish Government Institute of Seed Pathology for Developing countries, Denmark, pp.164. Mc Callan (1957). Control Boyce. Thompson Inst. 19, 157–167.
Mehta, Y.R., 1981a. Conidial production, sporulation period and extension of lesion *Helminthosporium sativum* of flag leaves of wheat. Pesquisa Agropecuaria Brasiliera (Brasilia) 16, 79–99.
Mehta, Y.R., 1993. Spot blotch. In: Mathur, S.B., Cunfer, B.M. (Eds.), Seed borne disease and seed health testing of wheat. Copenhagen, Denmark, Jordhurgsforlaget, pp. 105–112.
Meronbala, D. H., Mahapatra, S., Das, S., 2019. Management of spot blotch of wheat using inducer chemicals under field conditions. Journal of Cereal Research 11(2), 152–158 doi.org/10.25174/2249-4065/2019/86740.
Mishra, S., Singh, H.B., 2012. Glimpses of phytopathology for sustainable agriculture. AB Publication Mayur Vihar, New Delhi, India, pp 37–55.
Mitra, M., 1930. A comparative study of species and strains of *Helminthosporium* on certain Indian cultivated crops. Transactions of the British Mycological Society 15, 254–293.
Molan, Y., Al-Doss, A.A., El- Hussieni, S., Mustafa, K.A., 2001. Evaluation of wheat genotypes against *Bipolaris sorokiniana* causing spot blotch. Alexandria Journal of Agricultural Research 46(3), 99–105.
Naga, H.C.K., Karthiba, L., Saraswathi, R., Ramanathan, A., 2022. Isolation, characterization and effect of micro-macronutrients on the growth of *Helminthosporium oryzae*. Biological Forum – An International Journal 14(3), 599–607.
Narayan, U.P., 2004. Foliar blight of wheat and its management. Ph.D. Thesis Department of Plant Pathology, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar.
Neergaard, P., 1977. Seed Pathology. John Wiley & Sons, New York, USA.
Pammel, L.H., King, C.M., Bake, A.L., 1910. Two barley blights with comparison of species *Helminthosporium sativum* P.K. and *B. Alternaria tenuis Ness*. Journal of Research (Ludhiana) 7, 618–621.
Pandey, S., Tewari, A.N., 2001. Losses due to leaf blight in two cultivars of wheat. Plant Disease Research 16(1), 113–115.

Pandey, S.P., Kumar, S., Kumar, U., Chand, R., Joshi, A.K., 2005. Sources of inoculum and reappearance of spot blotch of wheat in rice-wheat cropping system in eastern India. European Journal of Plant Pathology 111, 47–55.

Perelló, A., Noll, U., Slusarenko, A.J., 2013. *In vitro* efficacy of garlic extract to control fungal pathogens of wheat. Journal of Medicinal Plants Research 7(24), 1809–1817. DOI: 10.5897/JMPR12.511.

Prashanth, J., Vaish, S.S., Omprakash, S., 2014. Efficacy of certain plant extracts against control of foliar blight [*Bipolaris sorokiniana* (Sacc.) Shoem] of wheat under field conditions. Environment & Ecology 32(4), 1309–1312.

Raemaekers, R.H., 1988. *Helminthosporium sativum:* Disease complex on wheat and sources of resistance in Zambia. In: Klatt, A.R., (Ed.), Wheat production constraints in tropical environments. Mexico, D.F., Mexico: CIMMTY, pp. 175–185.

Ragiba, M., Prabhu, K.V., Singh, R.V., 2001. Characterization of wheat germplasm against *Helminthosporium* leaf blight. Indian Phytopathology 54, 316–318.

Rahman, G.M.M., Barma, N.C.D., Malaker, P.K., Karim, M.R. Khan, A.A., 2009. Integrated management for the *Bipolaris* leaf blight and foot and root rot diseases of wheat. International Journal of Sustainable Crop Production 4(1), 1–4.

Rattu, A.R., Asad, S., Fayyaz, M., Zakria, M., Shamim Iftikhar, S., Ahmad, Y., 2011. Status of foliar diseases of wheat in Punjab, Pakistan. Mycopath 9(1), 39–42.

Reis, E.M., 1983. Selective medium for isolating *Cochliobolus sativus* from soil. Plant Disease 67, 68–70.

Reis, E.M., Wunsche, W.A., 1984. Sporulation of *Cochliobolus sativus* on residues of winter crops and its relationship to the increase of inoculum density in soil. Plant Disease 68, 411–412.

Reuveni, R., Reuveni, M., 1998. Foliar-fertilizer therapy a concept in integrated pest management. Crop Protection 17, 111–11.

Romheld, V., Marschner, H., 1991. Function of micronutrients in plants. In: Mortvedt, J.J., Cox, F.R., Shuman, L.M., Welch, R.M. (Eds.), Micronutrients in agriculture. Soil Science Society of America, *Inc., Madison*, WI, USA. Pp 297–328.

Roy, B. R., Amin, M. N., Uddin, A.T., Islam, M.J., Halder, B.C., 2005. Leaf extracts of Shiyalmutra (*Blumea lacera*) as botanical pesticides against lesser grain borer and rice weevil. Journal of Biosciences 5(2), 201–204.

Saadi, A.M., Deadman, M.L., Maskari, A.Y., 2002. Screening of wheat and barley varieties for resistance to spot blotch disease. Tests of Agrochemicals and Cultivars 23, 16–17.

Saari, E.E., 1998. Leaf blight disease and associated soil-borne fungal pathogens of wheat in South and Southeast Asia. In: Duveiller, E., Dubin, H.J., Reeves, J., Mc Nab, A. (Eds.), *Helminthosporium* blights of wheat: Spot blotch and tan spot. CIMMYT, Mexico, DF, pp. 37–51.

Sahu, R., Sharaff, M., Pradhan, M., 2016. Elucidation of defense-related signaling responses to spot blotch infection in bread wheat (*Triticum aestivum* L.). The Plant Journal 86, 35–49.

Sati, M.C., Dhyani, A.P., Khulbe, R.D., 1993. Seed-plant transmission of *Drechslera sorokiniana* in bean. Madras Agricultural Journal 80, 33–36.

Shamim, I., Shahzad, A., Anjum, M., 2010. Incidence of *Bipolaris sorokiniana* in Punjab and Khyber Pakhtoon Khawa, Pakistan. Pakistan Journal of Phytopathology 22, 95–97.

Sharma, R.C., Duveiller, E., 2006. Advancement towards new spot blotch resistant wheat in South Asia. Crop Science Society of America 47(3), 961–968.

Sharma, R.C., Dubin, H.J., Devkota, R.N., Bhatta, M.R., 1997. Heritability estimates of field resistance to spot blotch in four spring wheat crosses. Plant Breed 116, 64–68.

Shoemaker, R.A., 1959. Nomenclature of drechslera and bipolaris, grass parasites segregated from *Helminthosporium*. Canadian Journal of Botany 37, 879–887.

Singh, A.K., Singh, R.N., Kumar, S., Singh, B.N., 2002. Bread wheat genotypes resistant to spot blotch of wheat. Indian Phytopathology 55(3), 378.

Singh, C.K., Gupta, S., Tiwari, N.K., Singh, D., 2016. Evaluation of wheat genotypes for resistance against spot blotch. International Journal of Plant Protection 9(1), 272–274.

Singh, C.K., Sarvjeet., Singh, S.P., Singh, R.K., Tiwari, N.K., Singh, P.K., Sharma, P., 2015. Antifungal Efficacy of Fungicides against Foliar Blight of Barley, *Bipolaris sorokiniana*. Annals of Biology 31(2), 245–247.

Singh, C.K., Singh, C., Singh, D., Singh, R.K., Chaudhary, A.K., Kumar, R.R., 2016. Effect of chemicals and bio-agent on spot blotch disease of wheat (*Triticum aestivum* L.). International Journal of Bio-resource and Stress Management 7(4), 712–715.

Singh, D.P., Sharma, A.K., Kumar, P., Chowdhury, A.K., Singh, K.P., Kaur, S., Singh, R.N., Singh, A.K., Kalappanavar, I.K., Tewari, A.N., 2008. Management of leaf blight complex of wheat (*Triticum aestivum*) caused by *Bipolaris sorokiniana* and *Alternaria triticina* in different agroclimatic zones using an integrated approach. The Indian Journal of Agricultural Sciences 78(6), 513–517.

Singh, D., Singh, R.V., Singh, A.K., Singh, R.N., 2005. Sources of resistance against foliar blight of wheat caused by *Helminthosporium sativum*. Indian Phytopathology 58(1), 111–113.

Singh, D.P., Chand, R., Dodan, D.S., Singh, A., Singh, K.D., Tewari, A.N., Singh, K.M.O., Pant, S.K., Chaudhary, S.W., 2003. Evaluation of wheat and triticale genotypes for resistance to leaf blight caused by *Bipolaris sorokiniana* and *Alternaria triticina*. Indian Phytopathology 56(4), 473–475.

Singh, D.P., Kumar, A., Solanki, I.S., Singh, S.P., Verma, J., Mahapatra, S., Vaish, S.S., Mukhopadhyay, S.K., Dutta, S., 2014. Management of spot blotch of wheat caused by *Bipolaris sorokiniana* in wheat using fungicides, Directorate of Wheat Research, Karnal. Indian Phytopathology 67(3), 308–310.

Singh, R.V., Singh, A.K., Singh, S.P., 1995. Progress of work under national centre on foliar diseases during 1994-95. In: 34th All India Wheat Research Worker's Workshop. AICWIP. ICAR. at UAS. Dharwad. August 1985.

Singh, R.V., Singh, A.K., Singh, S.P., 1997. Distribution of pathogens causing foliar blight of wheat In India and neighbouring countries. In: Duveiller, E., Dubin, H.J., Reeves, J., Mc Nab, A. (Eds.), *Helminthosporium* blight of wheat: Spot blotch and Tan Spot. 9-14 February, CIMMYT, Mexico. pp. 59–62.

Singh, S.K., Srivastava, K.D., Aggarwal, R., Singh, V.B., 2011. Control of spot blotch (*Bipolaris sorokiniana*) of wheat using systemic fungicides. Indian Phytopathology 64(1), 82–84.

Singh, V., Singh, A.K., Singh, V., 2007. Source of resistance against Spot blotch of Barley. Presented in National Symposium on "Advancing Frontiers of Plant Disease Management" held at the Department of Plant Pathology, N.D.U.A.T., Kumarganj, Faizabad, 150.

Sorokin, H., 1890. Ueber ciniga krankhieten derkuetur pflanzen in sudussue rischchen Gebeit. Trudy obslich. Estest Imp. Kazam University 22, 1–32.

Tiwari, R., Singh, R., Shukla, D. N., Tiwari, P., 2022. Efficacy of fungicides against *Bipolaris sorokiniana* under *in vitro* and *in vivo* conditions. International Journal of Environment and Climate Change, 31–40.

Vaish, S.S., Bilal, Ahmed, S., Prakash, K., 2011. First documentation on status of barley diseases from the high-altitude cold arid Trans-Himalayan Ladakh region of India. Crop Protection 30, 1129–1137.

Xu, X.M., Jeffries, P., Pautasso, M., Jeger, M.J., 2011. Combined use of biocontrol agents to manage plant diseases in theory and practice. Phytopathology 101(9), 1024–1031.

Yadav, B., Singh, R., Kumar, A., 2013. Effect of micronutrients and fungicides on spot blotch of wheat. International Journal of Plant Research, 26(2), 212–219.

Yadav, B., Singh, R., Kumar, A., 2015. Management of spot blotch of wheat using Fungicides, Bio-agents, and Botanicals. African Journal of Agricultural Research 10(25), 2494–2500. DOI: 10.5897/AJAR2013.8196.