Review Article

Brown Leaf Spot: An Exacerbated Embryonic Disease of Rice: A Review

Muhammad Imran[1,2*], Shahbaz Talib Sahi[1], Muhammad Atiq[1] and Amer Rasul[3]

[1]Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan; [2]Pest Warning and Quality Control of Pesticides, Punjab, Lahore, Pakistan; [3]Department of Entomology, University of Agriculture, Faisalabad, Pakistan.

Abstract | Brown leaf spot (*Bipolaris oryzae*) (BLS) is the serious emerging threat to rice crop. It causes heavy yield losses upto 6 to 90% depending upon the disease triangle. It has become a great concern for the rice-growing areas to find better management strategies under the fluctuation of the climate conditions. Different management practices (cultural, biological, chemical, induce resistance, nutrient management, natural byproducts, and resistant cultivars) are used by farmers in different field areas of the world. The use of the resistant source is the simple, reliable, operative and cost-effective strategy to control the diseases and maximize the yield in limited time. Due to changing the environmental conditions and appearance of the disease epidemic, the use of fungicides judiciously is the alternate significant method for quick and efficient control of diseases and improving the yield of rice. While, the use of phytoextracts and antagonist are considered to be safe, eco-friendly, cost-effective economically and biodegradable. The use of plant activators as another new strategy that activates the defense system of plants and reduces the disease. The plants which are scarce nutrients are more prone to disease as compared to nutrient deficient. The pathogen damage is compensating by a specific nutrient that reduces the disease through tolerance. Good management practices are those which include all possible combinations of cultural, biological, chemical, induce resistance, nutrient management, natural byproducts, and resistant cultivars. The best control of this disease in current climate scenario is the use of the integrated different management approaches to cope the emerging threat of this disease for food security in future.

Received | September 26, 2020; **Accepted** | November 5, 2020; **Published** | November 21, 2020
***Correspondence** | Muhammad Imran, Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan; **Email:** agripp.uaf.pk@gmail.com
Citation | Imran, M., Sahi, S.T., Atiq, M. and Rasul, A., 2020. Brown leaf spot: An exacerbated embryonic disease of rice: A review. *Journal of Innovative Sciences*, 6(2): 108-125.
DOI | http://dx.doi.org/10.17582/journal.jis/2020/6.2.108.125
Keywords | *Bipolaris oryzae*, Epidemic, Ecofriendly, Phytoextracts, Managemen

1. Introduction

Rice (*Oryzae sativa* L.) crop (family Poaceae) is known as staple food in world (FAO, 2004) and its production have a direct impact on the poor's life (Seck *et al*., 2012). Its production is exaggerated with many factors (abiotic and biotic). Mostly biotic causing agents (pathogens) like fungus, nematodes, bacteria and virus are dominant in reducing the production in a qualitative and quantitative way by causing different diseases of rice crops in the world. (John and Fielding, 2014).

Diseases are reported to cause the losses of about $5 billion annually by destroying the rice crop (Asgher *et al*., 2007). Nearly seventy-four diseases have been reported in the world (Wubneh and Bayu, 2016) in which fifteen are present in Pakistan (Mustafa *et al*.,

Links Researchers

2013). Brown leaf spot (BLS) appeared as destructive diseases with diversified nature, has severed distribution and existence in different physiological races (Arshad *et al*., 2008). BLS disease has a great concern in the rice cultivated areas (Quintana *et al*., 2017). In 1900, Breda de Haan first reported the BLS pathogen as *Helminthosporium oryzae* Breda de Haan. Subramanian and Jain in 1966 reassigned the name as *Drechslera oryzae* (Breda de Haan. Subram, and Jain) belong to the genus Drechslera genus. While in 1959, Shoemaker proposed the named *B. oryzae* (Breda de Haan) Shoemaker, which is recently used now a days. Its perfect stage is *Ophiobolus miyabeanus* that was reported in 1927 by Ito and Kuribayashi. In 1934, it was reported that this pathogen belongs to *Cochliobolus* genus. Then Dasture transfer the pathogen into *Cochliobolus* in 1942 and now it is known as *Cochliobolus miyabeanus* (Ito and Kuribayashi) Drechsler ex Dastur. (Breda de Haan) Shoemaker (Palla, 2012). This disease caused 50-90% yield losses. In 1942, it became the source of Bengal Famine with death of two million people. This pathogen attacked on plants at seedling and mature stages, mostly reported in poor soil has fewer nutrients (Agarwal *et al*., 1989; Mia and Safeeulla, 1998; Zadoks, 2002). *B. oryzea* attacked on all parts of the rice plant and symptoms mainly appeared on coleoptile, leaf sheet, leaves, glumes and spikelet's leading to 6-90% decrease rice yield (Webster and Gunnell, 1992; Padmanabhan, 1973; Estrada, 1984; Mew and Gonzales, 2002). Choudhury *et al*. (2019) reported its high incidence in district Sargodha and less in Okara (Pakistan). Maximum disease incidence has been reported on Basmati super variety (51.43%) and less on Basmati-38 (6.57%) Choudhury *et al*. (2019).

The pathogen mycelium enters through epidermal cells or stomata of the leaf. (Ou, 1985) after 18 hours, the entry regions are observed on leaves (Dallagnol *et al*., 2009). When fungal mycelium enters next to the invaded cell, brownish appearance occurred. (Tullis, 1935). These spots merged and bigger chlorotic lesions developed having a halo around them and rice leaf blades totally destroyed (Dallagnol *et al*., 2009). Pathogen after infection produced toxins that produced dead browning parenchyma cells (Tullis, 1935). Xiao *et al*. (1991) reported two main toxins named ophiobolin A and ophioboloin B from the conidia of pathogen and leaves, which causing chlorosis. These toxins cause the enhancement of electrolyte leakage in root cells (Tipton *et al*., 1977), electrical potential in transmembrane and permeability variation in plasma membrane due to Potassium and electrolyte leakage efflux (Cocucci *et al*., 1983). The infection of pathogen and production of lesions reduced the photosynthetic area of leaves leading to less tillering nodes (Lee, 1992), grains weight and numbers in panicles (Aluko, 1975). Pathogen infection also decrease green pigment in leaves which are involved in photosynthesis (Abdel-Fattha *et al*., 2007; Shabana *et al*., 2008).

The infection occurred at seedling, leaf, culm and on the kernel, which causes huge loss of yield. The symptoms appeared as minute spots of brown to reddish brown, circular to oval, older spots are light reddish brown or grey center along dark to reddish-brown margins (Quintana *et al*., 2017). Similarly, Ou (1985) and Mew and Gonzales (2002) described symptoms of this disease in the form of small dark brown spots or purple-brown oval to a circular shape having a gray center. Mycelium grey to dark grey, having septation, solitary or in a group, straight or flexuous with conidia on the sides and ends. Conidia are curved, club or cylindrical shape, light to a golden brown and have 6-13 cell walls transversely. Dallagnol *et al*. (2009) reported the lesions in the form of light reddish color along dark or reddish brown margin on glumes and leaves.

Dasgupta and Chattopadhyay (1977) reported that two environmental factors like temperature and relative humidity have a significant role in disease development. High humidity more than 90% with a high temperature of 24-30 °C favors the development of this disease. Other factors like wind speed and rainfall also support the spread of inoculum from infected to healthy areas. If the condition becomes favorable, then severe losses occur and disease can prevail whole growth period. Pathogenic symptoms are present on the leaves in early-stage and observed on the panicles in a later stage (Liu *et al*., 2008). Long time exposure to saturated condition during pre and after inoculation decreases the disease development and don't observe usual rainfall years (Singh *et al*., 2005). Whereas limited rains along with heavy dew favour the epidemic (Sherf *et al*., 1947). Similarly, Pannu *et al*. (2005) describe the disease severity of BLS observed lower in the years with heavy rains as compared to fewer rains. Generally during extended periods of leaf wetness support enhance the density of lesions in the canopy area of rice (Percich *et al.*, 1997). More than 89% relative humidity and 25°C temperature along free water on surfaces of leaves are required by conidia to establish successfully. Dry, intermediate and less wet soil favors the increase in disease frequency (Ou, 1985). Similarly, higher disease severity and yield losses were observed by the researchers in water shortage and rained conditions (Kulkarni *et al.*, 1979, 1981; Kauraw and Samantaray, 1982; Hegde *et al.*, 1999).

Singh *et al.*, 2005 observed that BLS disease did not occurred in those years that had continuous rainfall whereas Sherf *et al.* (1947) reported severe epidemic of disease in those seasons which have less rainfall and more dew conditions. Similarly, the seasonal condition was observed by Pannu in five years 2000-2004 and found high disease severity in the 2002 year where less rainfall occurred as compared to other years where the disease occurred in less severity of 8.8-9.2%. (Pannu *et al.*, 2005). Similarly, the quantitative relationship of environmental variables and BLS disease is described by Choudhry *et al.*, 2019 the maximum disease incidence is observed in the month of October ranging as 1.12-14.37% during 2014-2017. The relative humidity also has a strong relationship with disease incidence observed that year having more value.

The primary infection occurred through seed while secondary from the wind. Other inoculums sources are weeds, soil and infested debris. Conidial germination occurred at 25-30°C and hyphal growth at 27-30°C optimum temperature along high relative humidity over 90%. The disease wide spread occurred by continuous rain and cloudy weather with 25-30°C temperature along with leaf wetness of 8-24 (hours) (Percich *et al.*, 1997). It becomes an epidemic where the soil has a poor nutritional profile and low pH (Carvalho *et al.*, 2010).

Therefore, seeing the importance of this emerging disease, the present study is undertaken to explain the brief history of the disease in relation to its management with different suitable approaches which are in practice under the view of disease progress which not only assist to form a good management strategy but, also support the farmers for prediction of time frame for disease control. Management with different suitable approaches (Figure 1) which are in practice under the view of disease progress which not only assist to form a good management strategy but, also support the farmers for prediction of time frame for disease control.

1.2 Management strategies

1.2.1 Resistant source

The selection of resistant sources is the simple, reliable, operative and cost-effective method to control the diseases of rice. It helps to maximize the yield in a limited time (Katasntonis *et al.*, 2007). Several studies are conducted on BLS disease to find out the resistance level. They are reported to be highly infected with BLS at seedling, booting and flowering stages (Chakrabarti, 2001). A native rice variety of Korean (Kutto-urupe) in 1930 are first reported to be more prone to disease as compared to others in the field under natural conditions (Nagai and Hara, 1930) that discussed the resistance level of different varieties against BLS. Then the resistant cultivar Mubo-Aikoku was found resistant to BLS in United States (Adair, 1941). Similarly, Yoshii and Matsumoto used another inoculation method of spray the plants on various life stages i.e. seedling, tillering, booting and flowering to demonstrated the disease levels on rice cultivars as found six moderately resistant (MR) and two cultivars (Tetep and Ginnen) resistant (R) (Yoshii and Matsumoto, 1951). Balal found two cultivars (Pi1 and YNA282) resistant in Egypt (Balal *et al.*, 1979). This disease also related to soil fertility (Barnwal *et al.*, 2013: Ou, 1985). The effect of the nutrient also subjected to soil structure as severe disease reported on the soil having the deficiency of K (Ono, 1953), in sandy loam and peat soil (Ohata, 1989). Another study resistant variety were observed over 11 years in soil having different conditions i.e. peat soil, sandy loam, K deficient field and found two cultivars and twenty breeding lines resistant against BLS (Yasumasa *et al.*, 1962). Similarly, this disease was severely found in the soil having a deficient level of Silicone (Datnoff *et al.*, 1997), and recently BLS resistance was determined through Silicone transporter mutant (Dallagnol *et al.*, 2014).

Deren evaluated different cultivars and lines in the soil which have low Si and found two resistant cultivars (Deren *et al.*, 1994). Eighty rice cultivars in 1974 were screened and found eight cultivars resistant to BLS (Ohata, 1989). The cultivars (Choukakou, Tadukan, Ginnen, Tetep,) were found resistant (Ohata, 1989). Similarly, Tetep cultivar was found in United States

(Eruotor, 1986). Mostly BLS was reported until the 20th century in Japan but later it severely appeared in South Asia (Chakrabarti, 2001). The rice line-139 found resistant in Bangladesh (Hossain *et al*., 2004) and twenty cultivars among one eighty-three were found partial resistance to BLS in India in a separate study (Misra, 1985; Shukla *et al*., 1995; Satija *et al*., 2005). Pannu *et al*. (2006) found three susceptible cultivars under field conditions while 4 accessions found resistant of wild rice to BLS (Goel *et al*., 2006). Aryal *et al*. (2016) screened out the different varieties and found Radha-4 Rice variety as a resistant source which is used in a breeding program and found maximum disease severity on Poonam variety as 51.47% against brown leaf spot of rice. He explained that it is a quick and alternative way to manage the disease and enhance production. Fourteen rice varieties evaluated by Magar, 2013 against BLS and did not found any resistant variety. Hj-g1 was found high yielding and tolerant variety as compared to others. Alam *et al*. (2016) also explained the importance of screening of resistant varieties which provides information to the farmer to increase their yield and economy. He evaluated twenty-five varieties against BLS. He selected four highly resistant varieties out of these varieties against this disease. Seven were found resistant and six were moderately resistant. Three were moderately susceptible, two susceptible and three were to be highly susceptible against BLS. While Magar, 2015 found no rice variety resistant against disease among the screened out 14 varieties with disease severity range 21.73-58.07%. Two varieties (HJ-G1 and HJ-G2) observed moderately resistant. The HJ-G1 was observed highly yielding 5.10 ton per hectare along with minimum disease severity 21.73%. Bisen *et al*. (2015) evaluated twelve rice varieties against this disease on the base of total phenolic content and protein. He reported different levels of disease incidence on these varieties ranging from 5 to 38% at different growth stages.

Those varieties having a high level of phenolic and protein content are highly resistant cultivars and had low disease incidence. Irron M2 205 was reported to be highly resistant cultivars having maximum protein and phenolic contents. Yaqoob *et al*. (2011) screened 31 rice cultivars against BLS under the field of low water application in NARC, Islamabad. Four lines i.e. IR84677-34-1-B, HHZB, HHZ11-Y6-Y1-Y1 and IR80416-B-32-3 were reported high resistant. The lines which were late and early sowing had disease response and medium type lines were highly resistant against BLS. Channakeshava and Pankaja (2018) determined the disease severity after 30, 60, 90 days on 51 rice varieties. The severity was more on the mature crop as compared to early crops. No disease severity observed after thirty days while after sixty days' disease severity was found up to 13.55% and up to 21.20% after 90 days. The moderately resistant actions observed on thirty-one genotypes and eleven were found resistant. Mwendol *et al*. (2017) evaluated a hundred lines of rice at NaCRRI (National Crops Resources Research Institute) Namulonge, Uganda against this disease and found three lines susceptible, eighteen were highly resistant, fifty-two resistant, twenty-seven moderately resistant (Table 1).

1.2.2 Management through fungicides

Due to changing the environmental conditions and appearance of the disease epidemic, the use of fungicides judiciously is a significant method for quick and efficient control of diseases and improving the yield of rice. These fungicides manage the diseases as well as increase the production of rice. Different researchers used different fungicides and reported their efficacy against this disease. Such as application of Switch DF 80WG fungicide reduced the disease incidence up to 10% (Qudsia *et al*., 2017). Likewise, Kumar *et al*., 2017 evaluated four different fungicides i.e. Carbendazim 50WP, Carboxin 50 WP, Propiconazole 25 EC and Hexaconazole 25EC. Propiconazole was reported effective fungicides at 500ppm concentration that inhibited the fungus growth of 96.58% in the lab. Seed treatment by carbendazim @ 2g/kg along with the foliar application of Propiconazole @1ml/L under field condition reduces the disease severity significantly 37.26% and increases the yield 55.49%. Sandeep (2015) reported that the use of fungicides is effective for the control of BLS. All the used fungicides controlled the fungus growth significantly *in vitro* experiment as compared to the control condition. Bavistin was the best fungicides among other @1500ppm to inhibit the growth of fungus after the incubation period of 144 hrs. Sunder *et al*. (2005) used seven different fungicides in a laboratory experiment for efficacy against fungus growth and found two fungicides such as Hexaconazole and propiconazole most prominent in result following by iprobenphos and edifenphos. Similarly, infield, these two also have a good result as reduction of disease leaf spot 86.2 and 78.7% and stalk rot 71.5 and 63.5% and enhance the production of

Table 1: List of resistant germplasm source.

Sr. No.	Rice varieties evaluated	Finding	Reference
1	Korean (Kutto-urupe)	More prone to disease	Nagai and Hara, 1930
2	Mubo-aikoku	Resistant cultivar	Adair, 1941
3	Tetep and ginnen	High resistant cultivar	Yoshii and Matsumoto, 1951
4	cultivars Pi1 and YNA282	Resistant cultivar	Balal *et al.*, 1979
5	Eighty rice cultivars	Eight cultivars resistant	Ohata and Kubo, 1974
6	Tadukan, tetep, choukakou and ginnen	Resistant cultivar	Yoshii and Matsumoto, 1951
7	Tetep	Resistant cultivar	Eruotor, 1986
8	Line-139	Resistant cultivar	Hossain *et al.*, 2004
9	One eighty-three	Twenty cultivars partial resistance Misra 1985	
10	One eighty-three	Twenty cultivars partial resistance Misra 1986	Shukla *et al.*, 1995
11	One eighty-three	Twenty cultivars partial resistance Misra 1987	Satija *et al.*, 2005
12	150 accessions	4 accessions resistant	Goel *et al.*, 2006
13	Radha-4	Resistant cultivar	Aryal *et al.*, 2016
14	Poonam variety	More susceptible	Aryal *et al.*, 2016
15	Fourteen rice varieties	No resistant variety,	Magar, 2013
16	Twenty-five varieties	Four highly resistant	Alam *et al.*, 2016
17	14 varieties	No resistant variety, HJ-G1, HJ-G2 were found moderately resistant	Magar, 2015
18	Twelve rice varieties	Irron M2 205 highly resistant	Bisen *et al.*, 2015
19	Thirty-one rice cultivars	Lines i.e. HHZB, IR80416-B-32-3, IR84677-34-1-B and HHZ11-Y6-Y1-Y1high resistant	Yaqoob *et al.*, 2011
20	51 rice varieties	Eleven were found resistant	Channakeshava and Pankaja, 2018
21	Hundred lines of rice	Eighteen were highly resistant	Mwendol *et al.*, 2017

14.6 and 14.2% in grain yield, respectively, followed by mancozeb and edifenphos and in 2010, Sunder *et al.*, 2010 used six fungicides against this disease. Among these, two (Propiconazole (1 ml per l): Hexaconazole (2 ml per l) appeared efficient to reduce severity from 22.34% to 5.19 and 7.98%, respectively and increased the grain yield significantly. While Gupta *et al.* (2013) described the efficacy of seven different fungicides at five different concentrations to control the BLS disease. Propiconazole @250 ppm approved to be the best among others in controlling the fungus growth by about 97% in the lab. Infield conditions, Basmati-370, Jaya and PC-19 were tested against these fungicides at 0.1% concentration. Among seven, Propiconazole was effective to decrease the disease severity 69, 73 and 70 and enhanced the production i.e. 19, 12, 21% as compared to control respectively.

Iqbal *et al.* (2015) evaluated the different fungicides (Mencozeb @1250 g/hec, Propineb @ 1250 g/hec, Chlorothelonil +Metalyxal @ 750 g/hec, Difenaconazol @ 313 ml/hec and Copper hydro-oxide @ 1250 g/hec) against BLS. Copper hydroxides significantly decrease disease intensity and improved rice production as compared to others. Mustafa *et al.* (2013) also determined the efficacy of different new fungicides against BLS disease by sowing the susceptible variety Super basmati is filed. After the severe disease prevalence, I applied the fungicides. He reported that the score (250EC) @308.2mlha^{-1} proved to be the most effective treatment in controlling the BLS. Asghar *et al.* (2007) performed the experiments to control the BLS by using the fungicides along with macronutrients NPK in Adaptive Research Farm, Gujranwala, Pakistan. Super Basmati variety was sown under three replications in field conditions. The fungicide difenoconazole along with NPK at rate 315 ml/ha + 500g/ha controls the disease incidence significantly 9.31% and increases yield (3.57 tha-1). Chemical efficacy of Carbendazim 12% + Mancozeb 63% (SAAF), Propiconazole 25 EC (Tilt) and Carbendazim 50% W.P (Bavistin) at different concentration i.e. 1.5, 2 and 2.5 g is determined by Shrestha *et al.*, 2017 on Sabha Mansuli rice cultivars. Propiconazole at 2 ml/lit water have considerably less AUDPC value 373.7 then at Carbendazim + Mancozeb2 gm/lit have 374.9 value and Carbendazimhigh as 2gm/lit (590.1). By application of chemicals SAAF® at 2gm/lit (5.220 t/h), Tilt® at 2ml/lit water (5.210t/ha) and Bavistin® at 1.5gm/lit (3.320t/ha) yield obtained respectively. Jatoi *et al*. (2016) evaluated four fungicides *in vitro* and found Mencozeb and Thiomal reducing the fungus growth completely at 150 and 200 ppm (00. mm) as related to control treatment (36.62 mm) respectively. The fungicide bavistin was observed moderately effective (10.50 mm) and Melody due was found less effective (12.87 mm) as compared to control (36.62 mm). Thind *et al*. (2004) found the excellent inhibitory effect of azoxystrobin, trifloxystrobin and kresoxim-methyl, Pereira *et al*. (2002) used iprodione to control the mycelial growth of *B. oryzae.*

1.2.3 Management through phytoextract

The use of plant extracts against plant pathogen causing diseases is considered to be safe, ecofriendly, cost-effective economically and biodegradable. These are secure plant products in their uses to manage plant diseases (Mariappan, 1995). Botanicals are reported by the different pathologists for the control of plant pathogens. 10% *Azadirachta indica has significantly controlled* the disease (Kumar, 2018). Similarly, neem extract and Nerium oleander are reported to be effective against *B. oryzae* reducing disease incidence 66 % and 52% (Harish., 2008). These extracts have been reported to be efficient in reducing the spore germination and development of mycelium of fungus (Fiori *et al*., 2000). Similarly, Al-Mughrabi (2003) has been describing the efficient efficacy of the extract of *Euphorbia macroclada* to control many fungus species. Likewise, Kumar and Simon (2016) found *Azadirachta indica* best out of the different treatment of plants extracts against this disease. Jatoi *et al*. (2015) used five plant extracts i.e *Azadirachta indica* (Neem), *Calotropi sprocera* (Akk), *Allium sativum* (Garlic), *Datura stramonium* (Datura) and *Zingiber officinale* (ginger) with three concentrations of (5, 10 and 15ml) against *B. oryzae* under CRD design. Three replication of each treatment was used through poisoned food techniques. Ginger and garlic were proved to be most effective by using the dose of 2.75mm for inhibiting the fungus colony growth as compared to other like Dhatura, neem and Akk at a dose of 4.62, 20.00, 13.37 mm respectively as comparing control (38.12mm). The use of phytoextracts against BLS attempted by (Nguefack *et al*., 2005, 2007, 2008; Harish *et al*., 2008; Khoa *et al*., 2011). Nguefack *et al*., 2008 treated the seed by using oil extract of plants (*Thymus vulgaris*, *Cymbopogon citratus*, *Ocimum gratissimum*) against fungus in rice. Similarly, Harish *et al*. (2008) sprayed extract of neem and *Neriumoleander* twice in vivo and found 70% and 53% reduced the severity of BLS respectively and enhance the production 23 %, 18 % respectively. Similarly, Khoa *et al*. (2011) used *Chromolaena odorata* aqueous extract and reduced growth of *B. oryzae* up to 57 % under semi-controlled conditions.

Nguefack *et al*. (2007) applied the extract of ethanol and essential oil of *Callistemon citrinus* and *Ocimum gratissimum* for seed treatment and compared with fungicides carbendazim plus chlorothalonil (100 mg/ml + 550 mg/ml) in field and lab conditions. He found 42-100% decreased disease incidence. In the field, seed treatment with essential oil of *Callistemon citrinus* increased three rice varieties emergence and Farm production than using carbendazim plus chlorothalonil.

Nguefack *et al*. (2013) observed the effects of *Callistemon citrinus* L. and *Cymbopogon citratus* (DC) on *B. oryzae* radial growth. The use of extract *C. citrinus* 4520µg per ml and *C. citratus* 452µg per ml reduced the fungus growth completely and treatment of seed in a lab conditions by using of *C. Citrinus* decreased the incidence of fungi 85-100%. Also, the germination of the rice plants enhanced 10.06%. The use of extract of *C. citrinus* for seed treatment in combined spray with ethanol (2%) and extracts of *C. citrinus* (2% w/v) improved emergence, tillering and yield by 25-55%.

Jyotsna *et al*. (2017) evaluated the leaves extract (aqueous) of different medicinal plants at the concentration of 0.20% and 0.50% in vitro against *Pyricularia oryzae* and *Helminthosporium oryzae* causes diseases in rice to inhibit the mycelium growth of both fungus and found maximum inhibition at 0.50%. Devi and Chhetry (2013) used different plant extracts at 5, 10, 15, 20% *in vitro* and *vivo* condition against BLS disease. The 80% mycelium growth inhibition at 20% conc. of an extract of *Acorus calamus* found as compared to others. Infield trial, 45.29% disease incidence was observed with aqueous extract of *Acorus calamus*. Sunder *et al*. (2010) evaluated ten plant extracts against BLS and found Neemazal (3ml/l) and Wanis (5ml/l) best as compare to other at leaf spot phase as (which decreased disease about 26% and others like Neemgold, Achook, Tricure, Thuja leaves and garlic cloves decreased stalk rot intensity about 16-19%. *B. oryzae* growth inhibitory effects were observed by using *Artabotrys hexapetalus* leaf extracts (Grainge and Alvarez, 1987) and garlic extract, peppermint and piper *nigrum* (Alice and Rao, 1987). About 64% decreased mycelial growth of this fungus was obtained by *Juglans regia* (Bisht and Khulbe, 1995), 80% by aqueous extracts of *Acorus calamus* and 45.3% decreased incidence of BLS (Jitendiya-Devi and Chhetry, 2013). Ganesan and Krishnaraju (1995) reported *Spermacoce articularis*, *Leucas aspera* and *Polygonum chinense* extracts out of twenty-three plant species showed inhibition of spore germination. Likewise, the germination of conidia was inhibited by the extracts of *Ichnocarpus frutescens*, Leea species, *Anacardium occidentale*, *Macaranga peltata*, *Bixa orellana*,

Table 2: List of of phytoextract for the control of BLS disease.

Sr. No.	Plants used	Finding	Reference
1	Azadirachta indica	Reduced the fungus growth	Kumar, 2018
2	Neem extract and Nerium oleander	Reducing disease incidence 66 % and 52%	Harish., 2008
3	Euphorbia macroclada	Reduced the fungus growth	Al-Mughrabi, 2003
4	Azadirachta indica	Best	Kumar and Simon, 2016
5	Five plant extracts i.e *Azadirachta indica* (Neem), *Calotropi sprocera* (Akk), *Allium sativum* (Garlic), *Datura stramonium* (Datura) and *Zingiber officinale* (ginger	Ginger and garlic were proved best	Jatoi *et al*., 2015
6	*Thymus vulgaris*, *Cymbopogon citratus*, *Ocimum gratissimum*)	Seed treatment	Nguefack *et al*., 2008
7	neem (cake) extract and leaf extract of Nerium oleander	70% and 53% reduced the severity	Harish *et al*., 2008
8	*Chromolaena odorata* aqueous extract	Reduced (*Bipolaris oryzae*) up to 57 %	Khoa *et al*., 2011
9	Extract of ethanol and essential oil of Callis-temon citrinus and Ocimum gratissimum	Seed treatment	Nguefack *et al*., 2007
10	Extracts of Callistemon citrinus L. and Cymbopogon citratus (DC)	Reduced the fungus growth completely	Nguefack *et al*., 2013
11	10 plnats extracts	Found maximum inhibition at 0.50%	Jyotsna *et al*., 2017
12	different plant extracts at 5,10,15,20%	80% mycelium growth inhibition at 20% conc. of extract of Acorus calamus found	Devi and Chhetry, 2013
13	Ten plant extracts	(Neemazal "3 ml/l) and (Wanis "5 ml/l) best	Sunder *et al*., 2010
14	Artabotrys hexapetalus leaf extracts	Best	Grainge and Alvarez, 1987
15	Garlic extract, peppermint and Piper nigrum	Best	Alice and Rao, 1987
16	Juglans regia	64% decreased mycelial growth	Bisht and Khulbe, 1995
17	Extracts of *Acorus calamus*	80%	Jitendiya-Devi and Chhetry, 2013
18	Twenty three plant	*Spermacoce articularis*, *Leucas aspera* and *Polygonum chinense* extracts best	Ganesan and Krishnaraju,1995
19	Exracts of *Ichnocarpus frutescens*, Leea species, *Anacardium occidentale*, *Macaranga peltata*, *Bixa orellana*, and *Uvaria navum*	Germination of conidia was inhibited	Ganesan and Krishnaraju,1995
20	Six plant extracts	Inhibited the germ tube elongation	Ganesan, 1994
21	Agave Americana	Inhibited the germ tube elongation	Kumar, 2006
22	Extract of *A. sativum* and *Pithecellobium dulce*	50 to 90% inhibition of spore germination	Raju *et al*., 2004
23	Seven plant extracts	*Thuja orientalis* more effected for decreas-ing the BLS	Krishnamurthy *et al*., 2001
24	Prosopis juliflora	Best	Raghavendra *et al*., 2002
25	*A. indica* extracts	Reduced the fungus growth	Amadioha, 2002

and *Uvaria navum* extracts completely. Ganesan (1994) reported that germ tube elongation was inhibited with extracts of *Gliricidia sepium*, *Cleome aspera*, *Delonix regia*, *Zornia gibbosa*, *Quisqualis indica* and *Hibscus surattensis*. *Agave americana* at 0.1% inhibited the germ tube elongation (Kumar, 2006). The use of 10% extract of *A. sativum* and *Pithecellobium dulce* gave 50 to 90% reduction of spore germination and mycelial growth of *B. oryzae* respectively (Raju *et al*., 2004). The plant extract of *Thuja orientalis* is reported to be more effective for decreasing the BLS disease incidence as compared to other plant extracts i.e. *Tridax procumbens*, *Ruta graviolens A. indica*, *Clerodendron inermae*, *Catharanthus roseus*, *Colens aromaticus* and L. *aspera* (Krishnamurthy *et al*., 2001). *Prosopis juliflora* extract also inhibited the mycelium fungus growth completely at 800 ppm (Raghavendra *et al*., 2002). *A. indica* extracts also reported to control of BLS in the field along with radial growth of *C. miyabeanus* in culture (Amadioha, 2002) (Table 2).

1.2.4 Management through plant activators

Plant activators have a significant role in reducing the disease like Benzoic acid applied at 20mM decrease the disease incidence and severity (Shabana *et al*., 2008). Hydroquinone, salicylic acid, and benzoic acid are used to enhance the resistance in plants against fungal disease (*B. oryzae*). Benzoic acid was best among others in both in *vivo* and *in vitro* conditions (Abbas at el., 2006). Similarly, sodium benzoate effectively controlled the growth of *Geotrichum candidum* and *Candida albicans* (Wen *et al*., 2016). Salicylic acid reduced the infection process of Rhizoctonia fungi and delayed symptoms on potato tubers (Hadi and Balali, 2010). Hydroquinone is also proved to be a relatively safe antioxidant to manage seed-borne fungi (Eakil and Metwally, 2000). Similarly, plant activators like salicylic acid, Shikimic acid, and jasmonic acid have a key role in the defense mechanism of plants resulting in increased plant development (Agrios, 1997). These chemical mobiles in the plant systems and activate the defense genes (Nino-Liu *et al*., 2006). Salicylic acid induced the PAL production having resistance response and jasmonic acid increase the host plant growth (Wen *et al*., 2005).

1.2.5 Management through biocontrol agents

The use of biocontrol microbes against plant pathogens are eco-friendly, cost-effective, safe to health (Law *et al*., 2017) and used preferably against diseases. Biocontrol by using bacteria and fungi against plant diseases have been taken preference. The main groups commonly used as an antagonist are Pseudomonas, Bacillus, and Trichoderma against many plant diseases (Nakkeeran *et al*., 2005; Saravanakumar *et al*., 2007). Tamreihao *et al*., 2016 has been reported about the significance of *Streptomuces corchorusii* strain UCR3-16 in controlling the diseases of rice and the development of plant growth and yield. *Trichoderma harzianum* is reported to be effective in controlling the plant diseases (Abdul-Fattah *et al*., 2007). *Trichoderma viride* has a significance role in reducing the spore germination 77.03% and mycelium growth 62.92%. Moura *et al*. (2014) evaluated the potential of biocontrol agents as a seed treatment to control the pathogen transmission in seedling through using the bacteria (*Pseudomonas synxantha* DFs185), (*P. fluorescens* DFs223), (unidentified DFs306) and (*Bacillus* sp. DFs418.) and noted that the isolate DFs223 approved to be better to decrease the incidence of *B. oryzae*. Manimegalai *et al*. (2011) determined the antagonist effects of *Aspergillus terreus A. sulphureus, A. niger*, *A. flavus A. fumigates*, *Penicillium janthinellum*, *P. chrysogenum*, *Trichoderma harzianum* and *T. viride* against *B. oryzae* and found the inhibitory effects to control the pathogen (Manimegalai *et al*., 2011). Nejad *et al*. (2014) evaluated 20 tested actinomycetes isolates and found that Streptomyces isolate G showed the highest inhibitory activity against *B. oryzae*. Tamreihaoa *et al*., 2016 isolated the UCR3-16 strain of *Streptomyces corchorusii* from the rhizosphere of rice plants and reported its antifungal effect against six fungal pathogens of rice crop including *B. oryzae*. The strain found best to produce cell wall degrading enzymes like protease, chitinase, β-1,3-glucanase, lipase and β-1, 4-glucanase. Similarly, *Streptomyces philanthi* produced VOCs that repressed the mycelial development of *B. oryzae* and other rice crop pathogens (Boukaew *et al*., 2013). The chitinase enzyme produced by the *Streptomyces vinaceusdrappus* inhibited mycelial growth of *B. oryzae* and other rice fungal pathogens (Ningthoujam *et al*., 2009).

Isolates of biocontrol agent *fluorescent Pseudomonas* obtained from the rhizosphere inhibited the *B. oryzae* growth and reduced the incidence of brown leaf spot disease (Ray *et al*., 1990). *P. fluorescens* in the form of talcum also proved effective in decreasing the BLS disease by spray application (Joshi *et al*., 2007). In the field experiments, *Bacillus megaterium* reduced the BLS disease severity (Islam and Nandi, 1985). *T. viride* and *B. subtilis* also had antagonistic effects against this fungus. (Sarala *et al.*, 2004: Kumar and Mishra, 1994). Similarly, *T. pseudokoningii* showed antagonist effects to reduce the BLS disease incidence (Krishnamurthy *et al.*, 2001).

The Cladosporium species out of six phylloplane microorganisms, reported effective to reduce the spore germination and fungal growth of *B. oryzae* (Harish *et al.*, 2007) and *T. viride* reduced the growth of mycelium and spore germination 63% to 77% (Harish *et al.*, 2008). Bio formulation of *T. harzianum* reduced the infection of *B. oryzae* and mycelial growth (55-58%) (Biswas *et al.*, 2008). More yield about 70% and reduced BLS disease obtained by seed treatment with different biocontrol agents like *T. viride*, *T. harzianum* and Pseudomonas species (Joshi *et al.*, 2007; Ludwig *et al.*, 2009; Biswas *et al.*, 2010). Similarly, *T. harzianum* foliar application reduced the disease intensity. The concentration of protein and carbohydrates also enhanced photosynthesis in rice leaves (Abdel-Fattah *et al.*, 2007). *T. harzianum* and *T. viride* spore pre-application safe the infection of *B. oryzae* in rice plants, which was attributed to the increased level of total soluble protein and total phenol content (Kumawat *et al.*, 2008). Khalili *et al.* (2012) in Iran found the control of disease by two strains of *T. harzianum* and

Table 3: List of biocontrol agents used against *Bipolaris oryzae*.

Sr. No.	Biocontrol agents	Finding	Reference
1	Trichoderma harzianum	Reduced mycelium growth efficiently 65.33% in lab and 64% in field	Gupta *et al.*, 2018
2	*Streptomyces corchorusii* strain UCR3-16	Antifungal effect against six fungal pathogen of rice	Tamreihaoa *et al.*, 2016
3	Bacteria (*Pseudomonas synxantha* -DFs185), (*P. fluorescens* -DFs223), (unidentified -DFs306) and (Bacillus sp -DFs418.)	Isolate DFs223 approved to be better as seed treatment	Moura *et al.*, 2014
4	20 tested actinomycetes isolates	Streptomyces isolate G showed best	Nejad *et al.*, 2014
5	Streptomyces philanthi	Inhibited the mycelial growth	Boukaew *et al.*, 2013
6	T. harzianum	Reduced infection and improved seedling growth	Khalili *et al.*, 2012
7	Aspergillus *niger, A. terreus, A. fumigates, A. sulphureus, A. flavus, , , Penicillium janthinellum, P. chrysogenum, Trichoderma harzianum* and *T. viride*	Inhibitory effects against pathogen	Manimegalai, 2011
8	*T. viride* and *T. harzianum*	More yield about 70% and reduced BLS disease	Biswas *et al.*, 2010
9	Streptomyces vinaceusdrappus	Inhibited mycelial growth	Ningthoujam *et al.*, 2009
10	*Pseudomonas* species	Reduced the infection of pathogen	Ludwig *et al.*, 2009
11	T. viride	Reduced the growth of mycelium and spore germination 63% to 77% of pathogen	Harish *et al.*, 2008
12	T. harzianum	Reduced the infection of pathogen	Biswas *et al.*, 2008
13	*T. harzianum* and *T. viride*	Reduced the BLS disease severity	Kumawat *et al.*, 2008
14	Pseudomonas species	Reduced the infection of pathogen	Joshi *et al.*, 2007
15	Trichoderma harzianum	Reducing the spore germination 77.03% and mycelium growth 62.92%	Abdul-Fattah *et al.*, 2007
16	P. fluorescens	Reduced disease incidence	Joshi *et al.*, 2007
17	six phylloplane microorganisms	Reduce the spore germination of pathogen	Harish *et al.*, 2007
18	Trichoderma viride	Reducing the spore germination 77.03% and mycelium growth 62.92%	Harish *et al.*, 2008
19	B. subtilis	Inhibited mycelial growth	Sarala *et al.*, 2004
20	T. pseudokoningii	Reduce the BLS disease incidence	Krishnamurthy *et al.*, 2001
21	Fusarium graminearum	Reduced the growth of *C. miyabeanus*	Kim *et al.*, 1995
22	T. viride	Inhibited mycelial growth	Kumar and Mishra, 1994
23	Pseudomonas fluorescent	Reduced disease incidence	Ray *et al.*, 1990
24	Bacillus megaterium	Reduced the BLS disease severity	Islam and Nandi, 1985

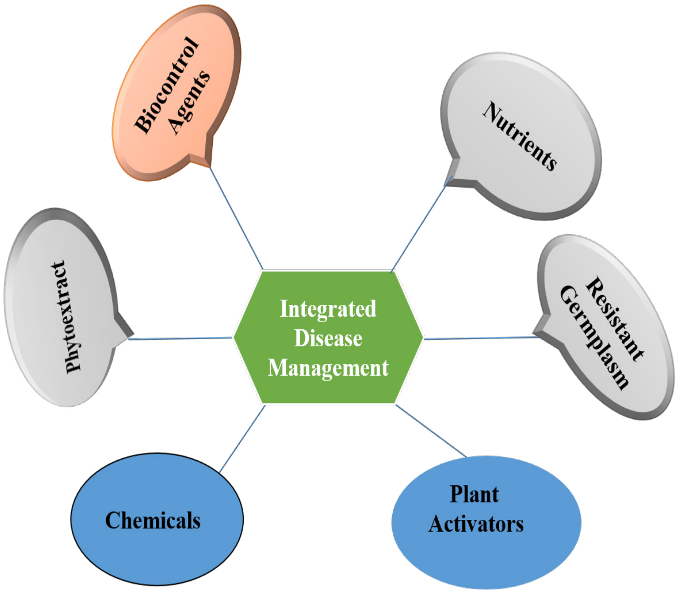

Figure 1: Integrated disease management strategies for BLS disease.

improved seedling growth by one strain of *T. atrovirid*. *Fusarium graminearum* produced antifungal substances that inhibited *C. miyabeanus* and gave 80% control of BLS disease (Kim *et al*., 1995). A virulent pathogen strain inoculation induced resistance in a susceptible host and decreased the disease index 83-85% (Sinha and Trivedi, 1969). Similar behavior found by pre-treating the plants with germinating spores (Sinha and Das, 1972) (Table 3).

1.2.6 Management through mineral nutrients

The plants which are scarce nutrients are more prone to disease as compared to nutrient deficient. The pathogen damage is compensating by a specific nutrient that reduces the disease through tolerance. The disease BLS incidence and severity influenced by different mineral nutrients i.e. Nitrogen, phosphorus, manganese, iron, and calcium (Ou, 1972: Ramakrishnan, 1971). The scarcity and surplus nitrogen enhance the level of BLS disease while in the form of ammoniacal, it decreases the disease severity if use it in the form of nitrate (Chattopadhyay and Dickson, 1960). Leaf dry matter Phosphorus (P) concentration threshold lies between 0.135 and 0.149% which limits brown spot disease development (Phelps and Shand, 1995). Leaf P content will have bearing on the concentration of other micronutrients which will ultimately reflect on brown spot severity (Kaur *et al*., 1982; 1984). If the quantity of P content high in soil correlated to decreased BLS incidence, study showed that the use of P as "48 kg ha-1 optimal and any increase of it have negative effects (Singh *et al*., 2005).

Potassium (K) nutrition besides direct effect also enhances silication which restricts brown spot development in leaves (Nogushi and Sugawara, 1966) besides conferring resistance in several ways. Carvalho *et al*. (2010) reported that higher K and N levels lowered brown spot severity by increasing the incubation period and decreased the number of lesions per cm^2 of leaf area. Jha *et al*. (2003) reported that higher K and higher N reduced brown spot severity while N alone showed a lower reduction of disease severity. Potassium in combination with zinc and iron were reported to bring about an increase in phenolic content which increased the incubation period and thus decreased sheath blight in rice (Prasad *et al*., 2010). Disease severity reducing effects of K was also well documented in other pathosystems as in soybean Phakopsora rust (Balardin *et al*., 2006). Blast severity of rice cultivar Guarani was less with high K and zinc (Filippi and Prabhu, 1998). Excess K increased resistance of barley to *H. sativum* (Sarhan *et al*., 1990).

Similarly, Silicon (Si) also has a correlation with disease reduction in rice (Datnoff *et al*., 1997; Dallagnol *et al*. (2009). Zinc (Zn) deficiency produced more susceptibility to BLS infection. Lesser brown spot severity in zinc sulfate sprayed plots than other micronutrients and control treatments in Boron rice was recorded by Minnatullah and Jha (2002). Goel *et al*. (2003) observed that Zn (3 kg/ha) in combination with N (120 kg/ha), P (30 kg/ha) and K (30 kg/ha) reduced both brown spot and sheath blight severity. Zinc was known to increase host resistance to mildews and leaf spot diseases and thus a reduction in disease severity. Calcium (Ca) 30 ppm reduced the brown spot disease while 50 ppm increased it. (Kaur *et al*., 1986). Kaur *et al*. (1979) reported a decrease in brown spot severity with soil application of Manganese (Mn) (5 to 10 ppm) in susceptible Benibhog rice variety. They concluded that the incidence of disease could be brought down to a lower order of magnitude in the susceptible variety with proper manipulation of Mn. Calcium and manganese nutrition was shown to have a negative correlation with brown spot infection (Kaur *et al*., 1986, 1987). Junior *et al*. (2009) evaluated the method and source of Si applied on Metica-1 cultivars to find resistance against BLS. Wollastonite (calcium silicate) treatment used through the soil and potassium silicate and silicic acid by application on leaves. The severity of disease decreased when using as soil application as compared to foliar application.

Conclusions and Recommendations

Different management practices are being used for the control of BLS disease. When disease appeared in epidemic form; one and only quick method is the application of the fungicide that control the disease earlier but it has a residual concern so, it should be used judiciously. Other management practices i.e. resistant varieties selection, appraisal of biocontrol agents, phytoextracts, nutrients and plant activators application were the safer having long last effects against brown leaf spot disease. The best control of this disease in current climate scenario is the use of the integrated different management approaches to cope the emerging threat of this disease for food security in future.

Acknowledgement

I am highly appreciated the scientist and researcher of Plant Pathology lab for providing me technical assistance in writing this manuscript.

Novelty Statement

A comprehensive information regarding infection and biochemical alterations in rice plant leaves due to Brown leaf spot along with its management through host resistance, plant activators, chemicals, nutrients, plant extracts and bio-control agents.

Author's Contribution

First author write up the manuscript and three others authors were supervisor committee members of first authors that equally provides technical assistance in write up.

Future direction

It is the need of hour to develop such strategies which should be ecofriendly and can bear abrupt climatic variations.

Conflict of interest

The authors have declared no conflict of interest.

References

Abbas, E.E., Ghoneem, K.M., Ali, A.A. and El-Baz, S.M., 2006. Yield maximization and chocolate spot control of some faba bean cultivars by antioxidants. *J. Agric. Sci. Mans. Univ.*, 31: 7605-7615.

Abdel-Fattah, G.M., Shabana, Y.M., Ismail, A.E. and Rashad, Y.M., 2007. *Trichoderma harzianum*: A biocontrol agent against *Bipolaris oryzae*. *Mycopathologia,* 164: 81-89. https://doi.org/10.1007/s11046-007-9032-9

Adair, C.R., 1941. *Inheritance in rice of reaction to Helminthosporium oryzae and Cercospora oryzae*. Tech. Bull. U. S. Dep. Agric. Washington, D.C. No. 772: 1-18

Agarwal, P., Mortensen, C.N. and Mathur, S., 1989. *Seed-borne diseases and seed health testing of rice*. Seed-borne diseases and seed health testing of rice. pp. 58-59.

Agrios, G., 1997. *Plant pathology 5th edition academic press*: Elsevier.

Alam, S., Seth, R.K., Singh, H., Srivastava, J. and Shukla, D., 2016. Screening of Disease Resistant Varieties against Brown Leaf Spot of *Oryza sativa* in Allahabad, India. *Am. J. Exp. Agric*., 14: 1-11. https://doi.org/10.9734/AJEA/2016/29059

Alice, D. and Rao, A.V., 1987. Antifungal effects of plant extracts on *Drechslera oryzae* in rice. *Int. Rice Res. Newsl.*, 12: 28.

Al-Mughrabi, K.I., 2003. Antimicrobial activity of extracts from leaves, stems and flowers of *Euphorbia macroclada* against plant pathogenic fungi. *Phytopathologia Mediterranea*, 42: 245-250.

Aluko, M.O., 1975. Crop losses caused by the brown leaf spot disease of rice in Nigeria. *Plant Dis. Rep.*, 59: 609-613.

Amadioha, A.C., 2002. Fungitoxic effects of extracts of Azadirachta indica against *Cochliobolus miyabeanus* causing brown spot disease of rice. *Arch. Phytopathol. Pl. Prot*., 35: 37-42. https://doi.org/10.1080/03235400210000009597

Arshad, H., Khan, J. and Jamil, F., 2008. Screening of rice germplasm against blast and brown spot diseases. *Pak. J. Phytopathol*., 20: 52-57.

Aryal, L., Bhattarai, G., Subedi, A., Subedi, M., Subedi, B. and Sah, G.K., 2016. Response of rice varieties to brown spot disease of rice at Paklihawa, Rupandehi. *Glob. J. Biol. Agric. Hlth. Sci.*, 5: 50-54.

Asghar, Ayesha, Rashid, H., Ashraf, M., Khan, M. H., Chaudhry, Z., 2007. Improvement of basmati rice against fungal infection through gene transfer technology. *Pak. J. Bot*., 39(4):

1277.

Balal, M., Omar, R.A., El-Khadem, M.M. and Aidy, I.R., 1979. Inheritance of resistance to the brown spot disease of rice, *Cocoliobolus miyabeanus*. *Agric. Res. Rev.*, 57: 119-133.

Balardin, R.S., Dallagnol, L., Didone, H.T. and Navarini, L., 2006. Influence of phosphorus and potassium on severity of soy bean rust *Phakopsora pachyrhizi*. *Fitopatol. Bras.*, 31(5): 462-467. https://doi.org/10.1590/S0100-41582006000500005

Barnwal, M.K., Kotasthane, A., Magculia, N., Mukherjee, P.K., Savary, S., Sharma, A.K., Singh, H.B., Singh, U.S., Sparks, A.H. and Variar, M. and Zaidi, N., 2013. A review on crop losses, epidemiology and disease management of rice brown spot to identify research priorities and knowledge gaps. *Eur. J. Plant Pathol.* 136(3): 443-457. https://doi.org/10.1007/s10658-013-0195-6

Bisen, K., Biswas, S.K., Kumar, V., Lal, K., Kumar, R. and Kumar, N., 2015. Biochemical Changes in Relation to Brown Leaf Spot (*Drechslera oryzae*) Resistance in Different Rice Genotypes. *J. Plant Stud.*, 4(2): 81-91. https://doi.org/10.5539/jps.v4n2p81

Bisht, G.S. and Khulbe, R.D., 1995. In vitro efficacy of leaf extracts of certain indigenous medicinal plants against brown leaf spot pathogen of rice. *Indian Phytopathol.*, 48: 480-482. https://doi.org/10.1007/s10526-013-9510-6

Biswas, C., Srivastava, S.S.L. and Biswas, S.K., 2010. Effect of biotic, abiotic and botanical inducers on crop growth and severity of brown spot in rice. *Indian Phytopathol.*, 63: 187-191.

Biswas, S.K., Ved, R., Srivastava, S.S.L. and Singh, R., 2008. Influence of seed treatment with biocides and foliar spray with fungicides for management of brown leaf spot and sheath blight of paddy. *Indian Phytopathol.*, 61: 55-59.

Boukaew, S., Plubrukam, A., Prasertsan, P., 2013. Effect of volatile substances from *Streptomyces philanthi* RM-1-138 on growth of *Rhizoctonia solani* on rice leaf. *BioControl*, 58: 471-482.

Carvalho, M.P., Rodrigues, F.A., Silveira, P.R., Andrade, C.C.L., Baroni, J.C.P., Paye, H.S. and Junior, J.E.L., 2010. Rice resistance to brown spot mediated by nitrogen and potassium. *J. Phytopathol.*, 158(3): 160-166. https://doi.org/10.1111/j.1439-0434.2009.01593.x

Chakrabarti, N.K., 2001. Epidemiology and disease management of brown spot of rice in India. In: Major fungal diseases of rice recent advances. Kluwer academic publishers. Printed in the Netherlands. pp. 293-306. https://doi.org/10.1007/978-94-017-2157-8_21

Channakeshava, C. and Pankaja, N.S., 2018. Performance of Paddy Varieties against Brown Leaf Spot Disease under Flooded Conditions in Mandya District, Karnataka. *India Int. J. Curr. Microbiol. App. Sci.*, 7(12): 33-38. https://doi.org/10.20546/ijcmas.2018.712.004

Chattopadhyay, S.B. and Dickson, J.G., 1960. Relation of nitrogen to disease development in rice seedlings infected with *Helminthosporium oryzae*. *Phytopathol.*, 50: 434-438.

Choudhury, F.A., Jabeen, N., Haider, M.S. and Hussain, R., 2019. Comparative analysis of leaf spot disease in Rice Belt of Punjab, Pakistan. *Adv. Life Sci.*, 6(2): 76-80.

Cocucci, S.M., Morguttia, S., Cocuccib, M. and Gianani, L., 1983. Effects of ophiobolin A on potassium permeability, transmembrane electrical potential and proton extrusion in maize roots. *Plant Sci. Lett.*, 32: 9-16. https://doi.org/10.1016/0304-4211(83)90093-7

Dallagnol, L.J., Rodrigues, F.A., Mielli, M.V., Ma, J.F. and Datnoff, L.E., 2009. Defective active silicon uptake affects some components of rice resistance to brown spot. *Phytopathology*, 99: 116-121. https://doi.org/10.1094/PHYTO-99-1-0116

Dallagnol, L.J., Rodrigues, F.A., Mielli, M.V.B. and Ma, J.F., 2014. Rice grain resistance to brown spot and yield are increased by silicon. *Trop. Plant Pathol.*, 39(1): 56-63. https://doi.org/10.1590/S1982-56762014005000003

Dasgupta, M. and Chattopadhyay, S., 1977. Effect of different doses of N and P on the susceptibility of rice to brown spot caused by *Helminthosporium oryzae*/Wirkung unterschiedlicher Stickstoff- und Phosphorversorgung auf die Anfälligkeit von Reispflanzen für die Braunfleckenkrankheit, hervorgerufen durch *Helminthosporium oryzae*. *Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz/J. Plant Dis. Protec.*, pp. 276-285.

Datnoff, L.E., Deren, C.W. and Snyder, G.H., 1997. Silicon fertilization for disease management of rice in Florida. *Crop Protec.*, 16(6): 525-531. https://doi.org/10.1016/S0261-2194(97)00033-1

Deren, C.W., Datnoff, L.E., Snyder, G.H. and

Martin, F.G., 1994. Silicon concentration, disease response, and yield components of rice genotypes grown on flooded organic histosols. *Crop Sci.*, 34(3): 733-737. https://doi.org/10.2135/cropsci1994.0011183X003400030024x

Devi, O.J. and Chhetry, G.K.N., 2013. Evaluation of antifungal properties of certain plants against *Drechslera oryzae* causing brown leaf spot of rice in Manipur Valley. *Int. J. Sci. Res. Pub.*, 3(5): 1-3.

Eruotor, P.G., 1986. Varietal reaction of rice to isolates of *Cochliobolus miyabeanus*. *Indian Phytopathol.*, 39: 62-64.

Elwakil, M.A. and El-Metwally, M.A., 2000. Hydroquinone, a promising antioxidant for managing seed-borne pathogenic fungi of peanut. *Pak. J. Biological Sci.*, 3(3): 374-375.

Estrada, A.B., 1984. *Selection of differential varieties for race study of Helminthosporium oryzae*. M.S. thesis. College, Leguna, the Philippines: University of Philippines at Las Banos, Philippines.

FAO, IFAD, UNICEF, 2004. *WFP, WHO (2004) The state of food security and nutrition in the world 2017*. Building resilience for peace and food security food and agriculture organization, Rome.

Filippi, M.C. and Prabhu, A.S., 1998. Relationship between panicle blast severity and mineral nutrient content of plant tissue in upland rice. *J. Plant Nutr.*, 21(8): 1577-1587. https://doi.org/10.1080/01904169809365505

Fiori, A.C.G., Schwan-Estrada, K.R.F., Stangarlin, J.R., Vida, J.B., Scapim, C.A., Cruz, M.E.S. and Pascholati, S.F., 2000. Antifungal activity of leaf extracts and essential oils of some medicinal plants against *Didymella bryoniae*. *J. Phytopathol.*, 148: 483-487. https://doi.org/10.1046/j.1439-0434.2000.00524.x

Ganesan, T. and Krishnaraju, J., 1995. Antifungal properties of wild plants. *Adv. Pl. Sci.*, 8: 194-196.

Ganesan, T., 1994. Antifungal properties of wild plants. *Adv. Pl. Sci.*, 7: 185-187.

Goel, R.K., Bala, R. and Sinh, K., 2006. Genetic characterization of resistance to brown leaf spot caused by *Drechslera oryzae* in some wild rice (Oryza sativa) lines. *Indian J. Agric. Sci.*, 76(11): 705-707.

Goel, R.K., Rekhi, R.S., Singh, S. and Parminder, K., 2003. Integrated nutrient management in relation to the occurrence of some major diseases and grain yield in rice. *Pl. Disease Res. Ludhiana, India*, 18(1): 34-36.

Grainge, M.D. and Alvarez, A.M., 1987. Antibacterial and antifungal activity of *Artabotrys hexapetalus* leaf extracts. *Int. J. Trop. Pl. Dis.*, 5: 173-179.

Gupta, V., Shamas, N., Razdan, V.K., Sharma, B.C., Sharma, R., Kaur, K., Singh, I., John, D. and Kumar A., 2013. Foliar application of fungicides for the management of brown spot disease in rice (*Oryza sativa* L.) caused by *Bipolaris oryzae*. *Afr. J. Agric. Res.*, 8(25): 3303-3309.

Hadi, M. and Balali, G., 2010. The effect of salicylic acid on the reduction of *Rhizoctonia solani* damage in the tubers of marfona potato cultivar. *Am. Eur. J. Agric. Environ. Sci.*, 7: 492-496.

Harish, S., Saravanakumar, D., Radjacommare, R., Ebenezar, E. and Seetharaman, K., 2008. Use of plant extracts and biocontrol agents for the management of brown spot disease in rice. *BioControl*, 53: 555. https://doi.org/10.1007/s10526-007-9098-9

Harish, S., Saravanakumar. D., Kamalakannan, A., Vivekananthan, R., Ebenezar, E.G. and Seetharaman, K., 2007. Phylloplane microorganisms as a potential biocontrol agent against *Helminthosporium oryzae* Breda de Haan, the incitant of rice brown spot. *Arch. Phytopathol. Pl. Prot.*, 40: 148-157. https://doi.org/10.1080/03235400500383651

Hegde, Y.R., Angadi, V.V. and Kumar, H.D.M., 1999. Effect of irrigation on the brown spot of rice. *Karnataka J. Agric. Sci.*, 12: 200-201.

Hossain, M., Khalequzzaman, K.M., Mollah, M.R.A., Hussain, M.A. and Rahim, M.A., 2004. Reaction of breeding lines/cultivars of rice against brown spot and blast under field condition. *Asian J. Pl. Sci.*, 3: 614-617. https://doi.org/10.3923/ajps.2004.614.617

Iqbal, M.F., Hussain, M. and Waqar, MQ., 2015. Evaluation of best fungicide for controlling brown leaf spot in transplanted rice. *Int. J. Adv. Res. Biol. Sci.*, 2(7): 44-48.

Islam, K.Z. and Nandi. B., 1985. Control of brown spot of rice by *Bacillus megaterium*. *Z. Pflanzenkrankh. Pflanzensch.*, 92: 241-246.

Jatoi, G.H., Abro, M.A., Memon, S., Hussain, S., Mangi, N. and Maari, S.A., 2015. Efficacy of different Botanical extracts on the linear colony growth of the *Helminthosporium oryzae*. *Eur.*

Acad. Res., 3(7): 8383-8397.

Jatoi, G.H., Abro, M.A., Tariq, J.A., Memon, S., Mangi, N., Maitlo, S.A., Kerio, A., Hussain, S. and Mengal, A.S., 2016. Efficacy of selected fungicides on the linear colony growth of the *Helminthosporium oryzae* caused by brown spot disease of rice. *Pak. J. Biotechnol.*, 13(1): 13-17.

Jha, A.C., Rai, B., Jha, M.M. and Kumar, B., 2003. Effect of inorganic nutrients on brown spot of rice. *Annal. Biol.*, 19(2): 187-189.

Jitendiya, Devi, O. and Chhetry, G.K.N., 2013. Evaluation of antifungal properties of certain plants against *Drechslera oryzae* brown spot of rice in Manipur valley. *Int. J. Sci. Res. Publ.*, 3: 1-3.

John, A. and Fielding, M., 2014. Rice production constraints and 'new'challenges for South Asian smallholders: insights into de facto research priorities. *Agric. Food Secur.*, 3: 18. https://doi.org/10.1186/2048-7010-3-18

Joshi, N., Brar, K.S., Pannu, P.P.S. and Singh, P., 2007. Field efficacy of fungal and bacterial antagonists against brown spot of rice. *J. Biol. Contr.*, 21: 159-162.

Junior, L.A.Z., Rodrigues, F.A., Fontes, R.L.F., Korndorfer, G.H. and Neves, J.C.L., 2009. Rice Resistance to Brown Spot Mediated by Silicon and its Interaction with Manganese. *J. Phytopathol.*, 157: 73-78. https://doi.org/10.1111/j.1439-0434.2008.01447.x

Jyotsna, J., Das, S. and Kumar, B., 2017. Efficacy of aqueous leaf extract of medicinal plants against blast and brown spot disease of rice. *Int. J. Curr. Microbiol. App. Sci.*, 6(12): 4138-4144. https://doi.org/10.20546/ijcmas.2017.612.475

Katasntones, G., Koutrovbas S., Ntanos, D. and Lupoho, E., 2007. A comparison of three experimental designs for the field assessment of resistance to rice brown leaf spot of rice disease (*Bipolaris oryzae*). *J. Phytopath.*, 155: 204-210.

Kaur, P., Kaur, S. and Padmanabhan, S.Y., 1979. Effect of manganese and iron on incidence of brown spot disease of rice. *Indian Phytopathol.*, 32: 288-289.

Kaur, P., Kaur, S. and Padmanabhan, S.Y., 1982. Relationship of phosphorus concentration in the host and brown spot disease in rice. *Indian Phytopathol.*, 35: 393-398.

Kaur, P., Kaur, S. and Padmanabhan, S.Y., 1984. Relationship of host nutrient status and brown spot disease expression in rice. *Indian Phytopathol.*, 37: 156-158.

Kaur, P., Kaur, S. and Padmanabhan, S.Y., 1986. Effect of calcium on the development of brown spot disease of rice. *Indian Phytopathol.*, 39: 57-61.

Kaur, P., Kaur, S. and Padmanabhan, S.Y., 1987. Relationship of manganese status of host and brown spot disease expression in Rice. *Indian Phytopathol.*, 40: 557-559.

Kauraw, L.P. and Samantaray, R.N., 1982. Occurrence of brown spot in rice in relation to nutritional soil status. *Int. Rice Res. Newsl.*, 7: 16.

Khalili, E., Sadravi, M., Naeimi, S. and Khosravi, V., 2012. Biological control of rice brown spot with native isolates of three Trichoderma species. *Braz. J. Microbiol.*, 43: 297-305. https://doi.org/10.1590/S1517-83822012000100035

Khoa, N.D., Thuy, P.T.H., Thuy, T.T.T., Collinge, D.B. and Jørgensen, H.J.L., 2011. Disease-reducing effect of Chromolaena odorata extract on sheath blight and other rice diseases. *Phytopathology,* 101: 231-240. https://doi.org/10.1094/PHYTO-04-10-0113

Kim, B.S., Kim, K.W., Lee, J.K., Lee, Y.W. and ChoK, Y., 1995. Isolation and purification of several substances produced by *Fusarium graminearum* and their antimicrobial activities. *Korean J. Pl. Pathol.*, 11: 158-164.

Krishnamurthy, C.D., Lokesh, S. and Shetty, H.S., 2001. Occurrence, transmission and remedial aspects of *Drechslera oryzae* in paddy (*Oryza sativa* L.). *Seed Res.*, 29: 63-70.

Kulkarni, S. and Ramakrishnan, K., 1979. Sporulation in *Drechslera oryzae. Int. Rice Res. News.*, 14: 11.

Kulkarni, S., Ramakrishnan, K. and Hegde, R.K., 1981. Epidemiology and control of brown leaf spot of rice caused by *Drechslera oryzae* (Breda de Haan) Subramanian and Jain in Karnataka, I. Estimation of loss due to glume blotch infection of brown leaf spot of rice under different agro climatic conditions of Karnataka. *Curr. Res.*, 10: 6667.

Kumar, A., 2006. Evaluation of botanicals against major pathogens of rice. *Indian Phytopathol.*, 59: 509-511.

Kumar, V., Chaudhary, V.P., Kumar, D., Kumar, A., Sagar, S. and Chaudhary, S., 2017. Efficacy of botanicals and fungicides against Rhizoctonia solani inciting sheath blight disease on Rice

(*Oryza sativa L.*). *J. Appl. Nat. Sci.*, 9(4): 1916 -1920.

Kumar, H., 2018. Comparative efficacy of certain bio-agents and fungicides in the management of brown leaf spot [*Drechslera oryzae* (Breda de Hann) Subram. and Jain] of paddy (*Oryza sativa L.*): Department of Plant Pathology and Entomology Naini Agricultural Institute (NAI) Allahabad (UP) India-211007.

Kumar, M. and Simon, S., 2016. Efficacy of certain botanical extracts in the management of brown leaf spot of rice cause by *Helminthosporium oryzae*. *Biosci. Biotechnol. Res. Asia,* 13(4): 2015-2018. https://doi.org/10.13005/bbra/2358

Kumar, R.N. and Mishra, R.R., 1994. Interaction studies in vitro between brown spot pathogen of paddy and certain epiphytic phylloplane fungi. *Plant Cell Incomp. Newsl.*, 26: 40-47.

Kumawat, G.T., Biswas, S.K. and Srivastava, S.S.L., 2008. Biochemical evidence of defence response in paddy induced by bio-agents against brown leaf spot pathogen. *Indian Phytopathol.,* 61: 197-203.

Law, J.W.F., Ser, H.L., Khan, T.M., Chuah, L.H., Pusparajah, P., Chan, K.G., Goh, B.H. and Lee, L.H., 2017. The potential of Streptomyces as biocontrol agents against the rice blast fungus, *Magnaporthe oryzae* (*Pyricularia oryzae*). *Front. Microbiol.*, 8: 3. https://doi.org/10.3389/fmicb.2017.00003

Lee, F.N., 1992. *Brown spot. In: Webster RK, Gunnell PS (eds) Compendium of rice diseases*. The American Phytopathological Society, St. Paul. pp. 14-17.

Liu, Z.Y., Huang, J.F. and Tao, R.X., 2008. Characterizing and estimating fungal disease severity of rice brown spot with hyperspectral reflectance data. *Rice Sci.*, 15: 232-242. https://doi.org/10.1016/S1672-6308(08)60047-5

Ludwig, J., Moura, A.B., dos Santos, A.S and Ribeiro, A.S., 2009. Seed microbiolization for the control of rice brown spot and leaf scald. *Trop Plant Pathol.*, 34: 322-328.

Magar, P., 2015. Screening of rice varieties against brown leaf spot disease at Jyotinagar, Chitwan, Nepal. *Int. J. Appl. Sci. Biotech.*, 3: 56-60. https://doi.org/10.3126/ijasbt.v3i1.12014

Magar, P.B., 2013. Screening of rice varieties against brown leaf spot disease at Jyotinagar, chitwan, Nepal. *Int. J. Appl. Sci. Biotech.*, 3(1): 56-60. https://doi.org/10.3126/ijasbt.v3i1.12014

Manimegalai, V., Ambikapathy, V. and Panneerselvam, A., 2011. Biological control of paddy brown spot caused by *Bipolaris oryzae* (Breda de Haan). *Eur. J. Exp. Biol.*, 1 (4): 24-28.

Mariappan, V., 1995. *Neem for the management of crop diseases*: Associated Pub. Co.

Mew, T.W. and Gonzales., 2002. A handbook of rice seedborne fungi. International rice research institute, Los.

Mia, M.A.T. and Safeeulla, K.M., 1998. Survival of seed-borne inoculum of Bipolaris oryzae, the causal agent of brown spot disease of rice. *Seed Res.*, 26: 78-82.

Minnatullah, M. and Jha, A.C., 2002. *Helminthosporium blight* management with micronutrients in Boro rice. *J. Appl. Biol.*, 12(1): 74-76.

Misra, A.K., 1985. Effect of intercepting populations of resistant cultivars on reducing brown spot disease build up in a susceptible rice cultivar. *Indian Phytopathol.,* 38: 66-69.

Moura, A.B., Ludwig, J., Santos, A.G., Schafer, J.T., Soares, V.N. and Correa, B.O., 2014. Biocontrol and seed transmission of *Bipolaris oryzae* and *Gerlachia oryzae* to rice seedlings. *J. Seed Sci.*, 36(4): 407-412. https://doi.org/10.1590/2317-1545v36n41009

Mustafa, A., Yasin, S.I., Mahmood, S., Hannan, A. and Akhtar, M., 2013. Field evaluation of new fungicides against rice (*Oryza sativa*) diseases. *Pak. J. Phytopathol.*, 25: 141-145.

Mwendo, M.M., Ochwo-ssemakula, M., Lamo, J., Gibson, P. and Edema, R., 2017. Reaction of upland rice genotypes to the brown spot disease pathogen *Bipolaris oryzae*. *Afr. J. Rural Dev.*, 2(1): 127-133.

Nagai, I. and Hara S., 1930. On the inheritance of variegation disease in a strain of rice plant. *Jpn. J. Genet.*, 5: 140-144.

Nakkeeran, S., Fernando, W.D. and Siddiqui, Z.A., 2005. *Plant growth promoting rhizobacteria formulations and its scope in commercialization for the management of pests and diseases*. PGPR: Biocontrol and biofertilization ed. Springer, pp. 257-296. https://doi.org/10.1007/1-4020-4152-7_10

Nejad, M.S., Bonjar, G.H.S. and Dehkaei, F.P., 2014. Control of *Bipolaris oryzae* the causal agent of rice Brown Spot Disease via soil Streptomyces Sp. Isolate G. *Int. J. Adv. Biol. Biomed. Res.*, 2(4): 310-317.

Nguefack, J., Leth, V., Dongmo, J.B.L., Torp, J., Amvam, Zollo, P.H. and Nyasse, S., 2008. Us of three essential oils as seed treatments against seed-borne fungi of rice (*Oryza sativa* L.). *Am. Eur. J. Sustain Agric.*, 4: 554-560.

Nguefack, J., Nguikwie, S.K., Fotio, D., Dongmo, B., Leth, V., Nkengfack, A.E. and Amvam, Z.P.H., 2007. Fungicidal potential of essential oils and fractions from Cymbopogon citratus, Ocimum gratissimum and Thymus vulgaris to control *Alternaria padwickii* and *Bipolaris oryzae*, two seed-Borne fungi of rice (*Oryza sativa* L.). *J. Essential Oil Res.*, 19: 581-587. https://doi.org/10.1080/10412905.2007.9699336

Nguefack, J., Somda, I., Mortensen, C.N., Amvam and Zollo, P.H., 2005. Evaluation of five essential oils from aromatic plants of Cameroon for controlling seed-borne bacteria of rice (*Oryza sativa* L.). *Seed Sci. Tech.*, 33: 397-407. https://doi.org/10.15258/sst.2005.33.2.12

Nguefack, J., Torp, J., Leth, V., Dongmo, J.B.L., Fotio, D. and Zollo, P.H.A., 2007. Effects of plant extracts and chemical fungicide in controlling a rice seed-borne fungus under laboratory and in irrigated cropping system in Ndop-Cameroon. *Afr. Crop Sci. Conf. Proc.,* 8: 791-796.

Nguefack, J., Wulff, G.E., Dongmo, J.B.L., Fouelefack, F.R., Fotio, D., Mbo, J. and Torp, J., 2013. Effect of plant extracts and an essential oil on the control of brown spot disease, tillering, number of panicles and yield increase in rice 2013. *Eur. J. Plant Pathol.*, 137: 871-882. https://doi.org/10.1007/s10658-013-0298-0

Ningthoujam, D.S., Sanasam, S., Tamreihao, K. and Nimaichand, S., 2009. Antagonistic activities of local actinoimycete isolates against rice fungal pathogens. *Afr. J. Microbiol. Res.*, 3: 737-742.

Nino-Liu, D.O., Ronald, P.C. and Bogdanove, A.J., 2006. *Xanthomonas oryzae* pathovars: Model pathogens of a model crop. *Mol. Plant Pathol.,* 7: 303–324. https://doi.org/10.1111/j.1364-3703.2006.00344.x

Nogushi, J. and Sugawara, T., 1966. *Potassium and japonica rice*. International Potash Institute, Bern, Switzerland.

Ohata, K. and Kubo, C., 1974. Studies on the mechanism of disease resistance of rice varieties to *Cochliobolus miyabeanus*. (in Japanese). *Bull. Shikoku. Agric. Exp. Stn.*, 28: 17-57.

Ohata, K., 1989. Brown spot disease. (in Japanese). In: Rice Diseases. Zenkoku Nouson Kyouiku Kyoukai, Printed in Japan. pp. 357-374.

Ono, K., 1953. Morphological studies on blast and sesame leaf spot of rice plant. (in Japanese). *Bull. Hokuriku Natl. Agric. Exp. Stn.*, 2: 1-77.

Ou, S., 1985. *Rice diseases second Edition*. Common wealth mycological institute Kew England. pp. 380.

Ou, S.A., 1972. Rice diseases. International Mycological Institute, Kew, Surrey, England. pp. 366

Padmanabhan, S.Y., 1973. The great bengal famine. *Ann. Rev. Phytopathol.*, 11(1): 11-24. https://doi.org/10.1146/annurev.py.11.090173.000303

Palla, G.T., 2012. *Variability of Bipolaris oryzae causing brown spot of rice in andhra pradesh and management of the disease with foliar application of mineral nutrients*. Acharyang ranga Agricultural University Rajendranagar, Hyderabad.

Pannu, P.P.S., Chahal, S.S., Sharma, V.K., Kaur M. and Bagga, P.S., 2006. Occurrence of brown leaf spot of rice in Punjab, its effect on grain yield and its control. *Indian Phytopath.*, 59: 190-193.

Pannu, P.P.S., Chahal, S.S., Sharma, V.K., Kaur, M. and Bagga, P.S., 2005. Occurrence of brown leaf spot of rice in Punjab, its effect on grain yield and its control. *Indian Phytopathol.,* 59: 190-193.

Percich, J., Nyvall, R., Malvick, D. and Kohls, C., 1997. Interaction of temperature and moisture on infection of wild rice by *Bipolaris oryzae* in the growth chamber. *Plant Dis.*, 81: 1193-1195. https://doi.org/10.1094/PDIS.1997.81.10.1193.Pereira, L.A.A., Coutinho, W.M., Machado, J.C., Magalhaes, F.H.L and Pena, R.C.M., 2002. Fungitoxicity in vitro of iprodione on mycelial growth of fungi associated with rice seeds. *Revista Brasileira de Sementes*. 24: 67-70.

Phelps, R.H. and Shand, C.R., 1995. Brown leaf spot disease and fertilizer interaction in irrigated rice growing on different soil types. *Nutr. Recycl. Agroecosyst.*, 42: 117-121. https://doi.org/10.1007/978-94-009-1706-4_11

Prasad, D., Singh, R. and Singh, A., 2010. Management of sheath blight of rice with integrated nutrients. *Indian Phytopathol.*, 63(1): 11-15.

Qudsia, H., Akhter, M., Riaz, A., Haider, Z. and Mahmood, A., 2017. Comparative Efficacy of Different Chemical Treatments for Paddy

Blast, Brown Leaf Spot and Bacterial Leaf Blight Diseases in Rice *(Oryza Sativa* L.). *Appl. Microbiol. Open Access.*, pp. 3. https://doi.org/10.4172/2471-9315.1000138

Quintana, L., Gutierez, S., Arriola, M., Morinigo, K. and Ortiz, A., 2017. Rice brown spot *Bipolaris oryzae* (Breda de Haan) Shoemaker in Paraguay. *Tropical. Plant Res.*, 4: 419-420. https://doi.org/10.22271/tpr.2017.v4.i3.055

Raghavendra, M.P., Satish, S. and Raveesha, K.A., 2002. Prosopis juliflora Swartz: A potential plant for the management of fungal diseases of crops. *J. Mycol. Pl. Pathol.*, 32: 392-393.

Raju, K., Manian, S. and Anbuganapathi, G., 2004. Effects of certain herbal extracts on the rice brown leaf spot pathogen. *J. Ecotoxicol. Environ. Monitor.*, 14: 31-37.

Ramakrishnan, T.S., 1971. Diseases of rice. Indian Council of Agricultural Research, New Delhi. pp. 150.

Ray, S., Ghosh, M. and Mukharjee, N., 1990. Fluorescent pseudomonads for plant disease control. *J. Mycopathol. Res.*, 28: 135-140.

Sandeep, P., 2015. *In vitro* study of Fungicides in controlling *Helminthosporium oryzae* causal organism of leaf brown spot of Rice. *Int. Res. J. Biological. Sci.*, 4(10):48-51.

Sarala, L., Muthusamy, M. and Karunanithi, K., 2004. Management of grain discolouration of rice with antagonistic organisms. *Res. Crops,* 5: 165-167.

Saravanakumar, D., Vijayakumar, C., Kumar, N. and Samiyappan, R., 2007. PGPR-induced defense responses in the tea plant against blister blight disease. *Crop protection,* 26: 556-565. https://doi.org/10.1016/j.cropro.2006.05.007

Sarhan, T.A., Djalal, A. and Djalal, T.R., 1990. Influence of balanced nitrogen and potassium supply on susceptibility of barley plant to leaf spot disease. *Arab J. Plant Protec.*, 8(2): 68-71.

Satija, A., Chahal, S.S. and Pannu, P.P.S., 2005. Evaluation of rice genotypes against brown spot disease. *Plant Dis. Res.*, 20: 163-164.

Seck, P.A., Diagne, A., Mohanty, S. and Wopereis, M.C.S., 2012. Crops that feed the world 7. *Rice Food Secur.*, 4(2012): 7-24. https://doi.org/10.1007/s12571-012-0168-1

Shabana, Y., Abdel-Fattah, G., Ismail, A. and Rashad, Y., 2008. Control of brown spot pathogen of rice (*Bipolaris oryzae*) using some phenolic antioxidants. *Braz. J. Microbiol.*, 39: 438-444. https://doi.org/10.1590/S1517-83822008000300006

Sherf, A., Page, R., Tullis, E. and Morgan, T., 1947. Studies on factors affecting the infectivity of *Helminthosporium oryzae*. *Phytopathology,* 37: 281-290.

Shrestha, S., Aryal, L., Parajuli, B., Panthi, J., Sharma, P. and Saud, Y.S., 2017. Field experiment to evaluate the efficacy of different doses of chemical fungicides against Rice brown leaf spot disease caused by *Bipolaris oryzae* L. at Paklihawa, Rupandehi, Nepal. *World J. Agric. Res.*, 5(3): 162-168. https://doi.org/10.12691/wjar-5-3-6

Shukla, V.D., Chauhan, J.S., Variar, M., Maiti, D., Chauhan, V.S. and Tomar, J.B., 1995. Reaction of traditional rainfed rice accessions to brown spot, blast and sheath rot diseases. *Indian Phytopathol.,* 48: 433-435.

Singh, R., Dabur, K. and Malik, R., 2005. Long-term response of zero tillage: Soil Fungi, Nematodes and Diseases of Rice-Wheat System. *Tech. Bull.*, 7: 16.

Sinha, A.K. and Das, N.C., 1972. Induced resistance in rice plants to *Helminthosporium oryzae*. *Physiol. Pl. Pathol.*, 2: 401-410. https://doi.org/10.1016/0048-4059(72)90065-3

Sinha, A.K. and Trivedi, N., 1969. Immunization of rice plants against Helminthosporium infection. *Nature*, 223: 963-967. https://doi.org/10.1038/223963a0

Sunder, S., Singh, R. and Dodan, D.S., 2010. Evaluation of fungicides, botanicals and non-conventional chemicals against brown spot of rice. *Indian Phytopathol.,* 63(2): 192-194.

Sunder, S., Singh, R., Dodan, D.S. and Mehla, D.S., 2005. Effect of different nitrogen levels on brown spot (*Drechslera oryzae*) of rice and its management through host resistance and fungicides. *Pl. Dis. Res.*, 20(2): 111-114.

Tamreihao, K., Ningthoujam, D.S., Nimaichand, S., Singh, E.S., Reena, P., Singh, S.H. and Nongthomba, U., 2016. Biocontrol and plant growth promoting activities of a *Streptomyces corchorusii* strain UCR3-16 and preparation of powder formulation for application as biofertilizer agents for rice plant. *Microbiol. Res.*, 192: 260-270. https://doi.org/10.1016/j.micres.2016.08.005

Thind, T.S., Mohan, C., Raj, P. and Arora, J.K., 2004. Activity spectrum of strobilurins, a new generation of ecofungicides against some fungal pathogens. *Indian Phytopathol*., 57: 104-106.

Tipton, C.L., Paulsen, P.V. and Betts, R.E., 1977. Effects of ophiobolin A onion leakage and hexose uptake by maize roots. *Plant Physiol*., 59: 907-910. https://doi.org/10.1104/pp.59.5.907

Tullis, E.C., 1935. Histological studies of rice leaves infected with *Helminthosporium oryzae*. *J. Agric. Res*., 50: 82-90.

Webster, R.K. and Gunnell, P.S., 1992. *Compendium of rice diseases*. American phytopathological society, St. Paul, Minnesota. pp. 62.

Wen, H., Kang, J., Li, D., Wen, W., Yang, F., Hu, H. and Liu C., 2016. Antifungal Activities of Anthocyanins from Purple Sweet Potato in the presence of food preservatives. *Food Sci. Biotechnol*., 25(1): 165-171. https://doi.org/10.1007/s10068-016-0025-7

Wen, P.F., Chen, J.Y., Kong, W.F., Pan, Q.H., Wan, S.B. and Huang, W.D., 2005. Salicylic acid induced the expression of phenylalanine ammonia-lyase gene in grape berry. *Plant Sci*., 169: 928-934. https://doi.org/10.1016/j.plantsci.2005.06.011

Wubneh, W.Y. and Bayu, F.A., 2016. Assessment of diseases on rice (*Oriza sativa* L.) in major growing fields of Pawe district, Northwestern Ethiopia. *World Sci. News*. 42: 13-23.

Xiao, J.Z., Tsuda, M., Doke, N. and Nishimura, S., 1991. Phytotoxins produced by germinating spores of *Bipolaris oryzae*. *Phytopathol*., 81: 58-64. https://doi.org/10.1094/Phyto-81-58

Yaqoob, M., Mann, R.A., Iqbal, S.M. and Anwar, M., 2011. Reaction of rice genotypes to brown spot disease pathogen *Cochliobolus miyabeanus* under drought conditions. *Mycopathology,* 9(1): 9-11.

Yasumasa, J., Kakizaki, M., Fukatsu, R. and Shimada, N., 1962. Studies on brown spot disease (in Japanese). *Bull. Yamagata Agric. Exp. Stn*., 1: 1-229.

Yoshii, H. and Matsumoto, M., 1951. Studies on the resistance to Helminthosporiose of the rice varieties introduced to Japan (1). (in Japanese). *Bull. Matsuyama Agric. College*, 6: 25-60.

Zadoks, J.C., 2002. Fifty years of crop protection. 1950-2000. *Netherland J. Agric. Sci*., 50(2): 181-193. https://doi.org/10.1016/S1573-5214(03)80006-4