Journal of Cereal Research

14(1): 1-12

Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Review Article

Bakanae Disease - A Serious threat to Basmati Rice Production in India

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Article history:
Received: 21 Oct., 2021
Revised: 17 Nov., 2021
Accepted: 6 Dec., 2021

Citation:
Singh V, P Kapoor and A Kumar. 2022. Bakanae Disease - A Serious threat to Basmati Rice Production in India. *Journal of Cereal Research* ***14(1):*** *1-12.* *http://doi.org/10.25174/2582-2675/2022/119650*

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Abstract

Bakanae disease caused by *Fusarium fujikuroi* has been reported from nearly all rice-growing countries across the world, and it has become a serious threat issue in Asian countries. The disease incidence is especially high on the varieties Pusa Basmati 1121 and Pusa Basmati 1509, which are gaining popularity throughout the country, particularly in Punjab and Haryana due to its superior grain quality. It is responsible for high yield losses ranging from 3.0-95.4% and its prevalence varies depending on the region and cultivars used. The typical and distinguished symptoms of the disease are elongation and rotting of rice plants. This disease is seed borne and soil borne in nature and become more prevalent in rice-growing areas around the world in recent years. Seed treatment with fungicides is currently the most important disease management approach utilized worldwide. A systematic study of how the disease develops under the influence of variable climatic conditions is necessary to manage this emerging disease efficiently, and good management measures can help us conquer it in the future.

Keywords: Bakanae, *Fusarium fujikuroi,* management, rice, symptoms

1. History, geographical distribution and economic importance

Rice bakanae disease has been reported in Japan since 1828 (Ito and Kimura, 1931). Hori was the first to describe the disease Hori, 1898 and named the pathogen as *Fusarium heterosporum* Nees. Sawada (1917) identified the perfect stage of the pathogen and named it as *Lisea fujikuroi* Saw. The name of pathogen was changed later to *Gibberella fujikuroi* Sawada (Ito and Kimura, 1931) and the imperfect stage was changed to *Fusarium moniliforme* Sheld. *F. fujikuroi* is the pathogen's current name (Nirenberg, 1976). Kurosawa (1926) noticed that pathogen produces a substance that may be responsible for infected plants' elongation of stems and decrease in chlorophyll content. Gibberellins were found in the bakanae disease pathogen, *F. moniliforme* (Yabuta and Hayashi, 1939).

In many regions of the world, this disease is known as root rot or white head disease (Saremi *et al.,* 2008). *Fusarium* blight, elongation disease, fusariosis, white stalk in China, palay lalake (man rice) in British Guiana, foot rot in the Philippines, otoke nae (male seedling) in Japan, Australia and USA, foolish plants or foot rot in India and Bakanae in Africa, Ceylon, French Equatorial (Singh and Sunder, 2012). This disease has been reported in all rice-producing countries around the world, including Turkey, Pakistan, Thailand, Japan, European countries, America, Africa, California, the Philippines, Nepal, Bangladesh, Cameroon, Nigeria, Vietnam, Indonesia, Malaysia, Sri Lanka, Ivory Coast, Uganda, Brazil, Spain, China, Trinidad, Iran, Venezuela, Mexico, and so on (Cumagun *et al.,* 2011). Due to changes in cultivation practices, the disease is becoming a severe problem across South and Southeast Asia, including India, Nepal, Thailand, Indonesia, and Japan (Bashyal *et al.,* 2016a). Thomas (1931) was the first person to report the disease in India. This disease has been reported from the states like Uttar Pradesh (Pavgi and

Singh, 1964), Bihar, Andhra Pradesh (Vidyasekaran *et al.,* 1967), Assam, Maharashtra (Parate and Lanjewar, 1987), Punjab (Bedi and Dhaliwal, 1970), West Bengal (Hajra *et al.,* 1994), Tripura (Sarkar, 1986) and Odisha (Kauraw, 1981). In India, the bakanae symptoms are more common in Basmati-growing areas, with high disease incidence recorded in Haryana, Punjab, and Uttar Pradesh (Bashyal and Aggarwal, 2013; Bashyal *et al.,* 2014).

It is one of the first rice disease to be reported, causing production losses ranging from 3.0 to 95.4 per cent, depending upon the location and cultivar (Singh and Sunder, 2012). In favourable environmental conditions, the disease has been recorded to cause yield reductions of up to 70% in various parts of the world (Hajra *et al.,* 1994; Singh *et al.,* 1996). Ito and Kimura (1931) reported up to 20-50% losses in Japan a Kanjanasoon (1965) found 3.7-14.7% loss in Thailand. Susceptible cultivars have been shown to lose up to 25% of their yield in Bangladesh (Hossain *et al.,* 2011). Khokhar (1990) was the first to report the bakanae disease in Pakistan, and now it has become a serious disease, since last decade inflicting 10-50% yield losses (Bhalli *et al.,* 2001; Ghazanfar *et al.,* 2013). Bakanae disease has been found in India, mainly on basmati rice cultivars (Bashyal *et al.,* 2014; Gupta *et al.,* 2014). Uttar Pradesh, Assam, Andhra Pradesh, Tamil Nadu, Haryana, and Punjab states in India have recorded yield losses ranging from 15 to 25 % (Pannu *et al.,* 2012; Sunder *et al.,* 2014).

2. Symptoms

One or more *Fusarium* species are responsible for the disease and complex of disease symptoms includes seedling blight, root rot, crown rot, stunting, and the most prominent symptoms of etiolation, hypertrophy effect or excessive elongation of infected plants (Fig.1 a & b), foot rot, seedlings rot, grain sterility, grain discoloration, and the ultimate effect on yield and seed quality have all been documented in various parts of the world (Desjardins *et al.,* 2000). The bakanae-infected seedlings grow higher, with chlorotic stems and leaves that turn yellowish-green to light in colour as the infection progresses. Both the nursery stage and the main field are susceptible to the disease. Seedlings that survive the infection in the nursery may succumb to the attack shortly after being transplanted. The formation of adventitious roots from lower nodes of the stem was reported in India and hence foot rot name was given to the disease (Thomas, 1931). Sasaki (1973) documented the production of lesions on rice leaves. At the plant's base, a pinkish white cottony growth of fungal mycelium can be seen (Fig1.c). Gibberellins are growth-stimulating chemicals produced by the fungus which are responsible for excessive plant elongation (Malonek *et al.,* 2005). The fungus also releases a phytotoxin called fusaric acid, which is a nonspecific chemical that is poisonous to plants (Desjardins *et al.,* 2000).

Fig.1 a & b: Yellowish-green and taller bakanae infected plants in field; c: Whitish fungal growth

3. Host Range

Fusarium fujikuroi can infect a wide range of hosts. It completes its sexual cycle in rice, maize, barley, sorghum, sugarcane, wheat, pine, and rye, which have been reported from Asia, Africa, Southeast Asia, and the United States (Petrovic *et al.,* 2013). Pathogen survive in its primary hosts under favorable conditions and spend the rest of their time in their alternate hosts. Cowpea, tomato, banana, proso millet, early water grass, and barnyard grass have been reported to be vulnerable to the rice disease Bakanae, suggesting that they could serve as an alternate host (Anderson and Webster, 2005; Carter *et al.,* 2008). During poor conditions, the pathogen can also be found in round gourd, cucumber, fig, pine, *Musa* (banana), cotton, sapodilla, and *Leucaena*.

4. The pathogen

F. fujikuroi Nirenberg causes the bakanae disease, however other *Fusarium* species, such as *F. proliferatum* (Mats.) Nirenberg and *Fusarium verticillioides* (Sacc.) Nirenberg, have also been associated with the disease (Desjardins *et al.,* 2000). *Gibberella fujikuroi* Sawada is sexual stage for species of genus *Fusarium* under the *Liseola* section (Leslie and Summerell, 2006). This is a filamentous fungus that belongs to the Phylum Ascomycota of the Fungi kingdom. The fungus is member of the *Sordariomycetes* class, the *Hypocreales* order, and the *Nectriaceae* family. Ascus and ascospores are known to be produced by the pathogen. White mycelium is known to be produced by the infection. In most cases, sporodochia do not appear, but if they do, they are pale orange in colour. Asci with an oval to spherical shape and a size of 250-330 × 220-280 µm are formed under perithecia or ascocarps. Asci are 4-8 spored piston shaped cylindrical with a size of 90-102 × 7-9 µm. Both macro and micro conidiophores carrying macro and micro conidia are known to exist in the pathogen. Three to five septate apically tapered and slightly slender macroconidia and 0-1 septate oval or club shaped with fattened base microconidia are produced by the pathogen. Polyphialides produces false heads which after proliferation forms monophialides, and chlamyldo spores are not formed (Leslie and Summerell, 2006).

Gibberella fujikuroi species complex, which is separated into ten totally fertile mating populations, is known to cause the disease (MP A-J) (Bashyal *et al.,* 2012). The bakanae disease in rice is linked to three different mating populations (A, C, and D) of *Gibberella fujikuroi. F. verticillioides* is the conidial stage of MP-A, *F. fujikuroi* is the conidial stage of MP-C, and *F. proliferatum* is the conidial stage of MP-D (Desjardins *et al.,* 2000). Hseieh *et al.* (1977) were the first to discover Mating population C (MP-C) in pathogen strains infecting rice in Taiwan. This mating population has also been found to be linked to the bakanae disease in Italy (Amatulli *et al.,* 2010). Two mating populations A and D, were recovered from bakanae-infected rice plants in Australia, United States, and Africa, respectively, whereas MP-D was identified from bakanae-infected rice in Asia (Desjardins *et al.,* 1997). Most researchers have identified *F. fujikuroi* to be the most prevalent and virulent of all the species related with rice's bakanae disease (Amatulli *et al.,* 2010; Bashyal *et al.,* 2016a).

5. Survival and dissemination of the pathogen

Bakanae is a monocyclic disease where the pathogen is both seed and soil carried; nevertheless, seed borne inoculum is a more important source than soil borne inoculum since soil borne inoculum is rapidly depleted with time (Kanjanasoon, 1965; Ou, 1985). Infested seed is the most common source of inoculum, and it is also the most common way for the disease to spread from field to field (Anderson and Webster, 2005). Ascospores and conidia adhering to the seed germinate and infect seedlings via roots and crown (Sun, 1975). In the form of thick-walled hyphae or macroconidia, fungus lives for roughly four months in soil (Sun, 1975). Wind and water disperse the conidia, producing new infections in the rice field. Conidia formation on damaged or dead culms in the field corresponds to the crop's flowering and maturity (Seto, 1937). Seed-borne inoculum, in general, serve as an initial site or focus for secondary infection. Infected plants have the ability to produce a large number of conidia, which then infect surrounding plants under ideal conditions.

6. Predisposition factors

Weather has an impact on all stages of the host and the pathogen's life cycle, as well as disease progression. Relationships between weather and disease are routinely used for forecasting and managing epidemic diseases. In order to manage bakanae disease, it is important to understand the interaction between the host, pathogen, and the environment. Different weather variables have a major impact on the incidence and geographic distribution of this emerging rice disease (Luo *et al.,* 1988). All these weather parameters *viz,,* temperature, relative humidity, rainfall, wind speed, evaporation and sun shine hours etc., play a vital role in disease incidence, survival, reproduction and further spread. Unfortunately, the investigation on the role of weather parameters on bakanae disease is scarce or not yet studied in depth. The best temperature for pathogen infection is 27-30°C, while the idea temperature for disease development is 35°C, which is also congenial for plant growth. When the temperature was lowered, the incidence of disease was reduced (Burgess *et al.,* 1996; Saremi and Farrokhi, 2004).

Bal and Biswas (2018) reported that, crop transplanted on 10th June showed maximum disease incidence (24.20%) indicating that maximum air temperature is positively correlated with bakanae disease incidence, however, rainfall activity was negatively correlated, thus lowest symptom development. Raghu *et al.* (2021) found that increasing maximum temperature, minimum temperature, wind speed and rain fall has depressing effect on bakanae incidence; whereas relative humidity favoured bakanae incidence and survival, like data on relationship of bakanae disease incidence with rainfall (-0.444) had significant negative correlation during 2018, while RH (0.525 and 0.606) had significant positive correlation during 2017 and 2018. Mandal and Chaudhuri (1988) found that when nitrogenous fertilizers were applied in large doses, the pathogen population in the soil decreased. The rice plants that were transplanted had more incidence than the plants that were developed by broadcasting the seeds (Saremi and Farrokhi, 2004). Summer crop, dry nurseries, and conditions of high temperature and relative humidity were found to have a higher disease incidence. Pre-soaked seeds had a lower disease incidence than dry seeds (Kanjanasoon, 1965).

7. Genomics of *Fusarium fujikuroi*

The numerous multiple whole genomes of a *Fusarium* spp. were collected, sequenced, and examined between 2010 and 2017, nearly a decade, which aided in the understanding of host-pathogen interaction and defensive mechanisms (King *et al.,* 2015). Presently, thirteen *F. fujikuroi* genomes have been published from various countries (Bashyal *et al.,* 2017; Niehaus *et al.,* 2017; Chiara *et al.* 2015; Wiemann *et al.,* 2013; Jeong *et al.* 2013) as described in Table 1. Out of these thirteen, eight genomes of *F. fujikuroi* are sequenced from different places of the world and studied the differences in their characteristics of producing asexual spores (microconidia and macroconidia), chromosome size, secondary metabolite gene cluster profile. The evolutionary development analysis depending on the whole genome of 5 isolates (IMI58289, B14, KSU 3368, FGSC 8932 and KSU X-10,626) collected from various geographical locations of the world shows Indian isolate (F250) is nearer to the genome isolated from Taiwan (IMI58289).

Table 1. Various whole genomes of *F. fujikuroi* sequenced from different countries

Strain	Originated country and host	Genome size (MB)	References
F 250	India. rice	42.4	Bashyal *et al.*, 2017
IMI 58289	Taiwan, rice	43.9	Wiemann *et al.*, 2013
FGSC 8932	Taiwan, rice	43.0	Chiara *et al.*, 2015
KSU 3368	Thailand, rice (1990)	43.1	Chiara *et al.*, 2015
KSU X-10626	Konza Prairie (USA), *Schizachyrium scoparium* (1997)	43.1	Chiara *et al.*, 2015
B 14	South Korea, rice	44.0	Jeong *et al.*, 2013
m 567	Japan, infected rice	44.0	Niehaus *et al.*, 2017
MRC 2276	Philippines, infected rice	45.0	Niehaus *et al.*, 2017
C 1995	Taiwan, infected rice	45.8	Niehaus *et al.*, 2017
E 282	Italy, infected rice	46.1	Niehaus *et al.*, 2017
FSU 48	Germany, maize	46.1	Niehaus *et al.*, 2017
NCIM 1100	India, infected rice	45.3	Niehaus *et al.*, 2017
B 20	South Korea, infected rice	44.3	Niehaus *et al.,* 2017

8. Disease management

8.1 Physical Methods

In organic farming, thermal treatment is the best substitute of chemical pesticides. While chemical fungicides are more selective and target focused in the management of one or few infections, it is effective against a wide range of fungal species (Ora *et al.,* 2011). Seed disinfection with cold-hot water has long been a popular strategy for preventing seed-borne disease. The hot water treatment produced by omitting the cold water treatment, on the other hand, was shown to be similarly efficient in controlling the bakanae infection (Jaehwan *et al.,* 2009). Miyasaka *et al.* (2000) and Yamashita *et al.* (2000) suggested the soaking of seeds into hot water at 60ºC for 10 minutes before sowing for minimising the seed infections and bakanae incidence in nursery and fields. Infected seeds can be sterilised with heated acidic electrolyzed water at 50ºC for 10-20 minutes, according to Kusakari *et al.* (2004).

8.2 Development of resistant varieties

The greatest approach for disease management is still to use resistant types. Breeding for bakanae disease resistance is a promising technique for managing this disease. Several screening approaches against bakanae disease have been tested and verified in various countries so far. Basmati/ scented germplasm and cultivars have been shown to be more susceptible to bakanae disease than non-scented rice varieties (Gupta *et al.,* 2014). In the Northern part of India, the disease has been found to be more severe on basmati rice cultivars such as Pusa Basmati 1121, Pusa Basmati 1176, and Pusa Basmati 1509. However, other basmati rice varieties such as Pusa Basmati 1401, Pusa 2511, CSR 30, Dehradun basmati, and Pakistani basmati have also been found to be infected by the disease with 2.0-22.8 percent in India (Bashyal *et al.,* 2012; Gupta *et al.,* 2014).

Sunder and Singh (1998) used a seedling root dip inoculation method to evaluate 221 scented and non-scented rice genotypes. Only two scented rice genotypes, C 4-64 (green base) and Karjat x 13-21, were found to be resistant; however, four non-scented genotypes, BR 1067-84-1-3-2-1, BR 1257-31-1-1, BR 4363-8-11-4-9, and IR 58109-109-1-1-3, were shown to be highly resistant. Sunder *et al.* (2014) identified highly resistant genotypes such as HKR 96-561, HKR 96-565, HKR 07-40, HKR 07-53, HKR 08-13, HKR 08-21, HKR 08-22, MAUB 2009-1, PAU 3456-46-6-1-1, PNR 600 and RDN 01-2-10-9 by using seedling root dip inoculation technique. Ghazanfar *et al.* (2013) used the seedling dip inoculation method to screen various rice germplasms in Pakistan and found that IR-6 and KKS-133 are resistant with 18.80 and 19.82 percent plant infection, respectively, whereas the varieties Bas-385 and Bas-Super are susceptible with 61.99 and 61.04 percent plant infection. According to Saremi *et al.* (2008) cultivar Binam is highly resistant to the disease, whereas cultivars Kadous, Shafagh Fajr, Sahel, and Shafagh are moderately resistant.

8.3 Cultural control

The use of clean, non-infested seeds is an effective way to manage this disease. Because the pathogen is seed borne in nature, clean seeds should be utilised to reduce disease occurrence. Light weight seeds can be separated from seed lots using salt water, which may minimise seed borne inoculums (Cother and Lanoiselet, 2002). Crop residue destruction or burning in known pathogen-infected fields may give some benefits by decreasing the amount of inoculum that can be carried over to the next crop (Gupta *et al.,* 2014). The use of organic matter, crop rotation, timing and method of planting, selection of resistant types, balanced fertilization, and irrigation management can all help to reduce disease (Burgess *et al.,*1996). Bagga *et al.* (2007) observed minimum disease incidence in late planted rice crop by the end of July which they believe is due to the low temperature during the infection period. Fungus survival and population are affected by higher nitrogen and potassium levels.

Sunder *et al.* (2014) investigated the management of bakanae disease and found that disease incidence decreased in plots where the nursery was uprooted in standing water. Because CSR30 was planted with nursery uprooted in standing water and Pusa Basmati 1121 was planted with nursery uprooted under vattar conditions, the incidence of bakanae disease was less in CSR 30 and more in Pusa Basmati 1121. After eight months of incubation, a combination of NPK, $ZnSO_4$, and $FeSO_4$ drastically reduced pathogen survival (Mandal and Chaudhuri, 1988). The pathogen was suppressed in soil treated with neem cake rather than groundnut cake, according to Panneerselvam and Saravanamuthu (1996). According to Sasaki (1987) the pathogen can be destroyed by placing diseased seeds under snow or in a cold room at 5°C, whereas (Kitamura, 1975) recommended selecting rice seeds with a specific gravity greater than 1.25 because the incidence of bakanae and the presence of pathogen was lower in such rice seeds.

8.4 use of plant extracts

Plant extracts are becoming increasingly popular for the management of plant diseases. As bakanae disease is significantly caused due to seed-borne pathogen, the primary inoculum for the bakanae is infected seed, therefore to reduce the disease incidence, of botanical extract shows better results (Anderson and Webster, 2005). Yasin *et al.* (2003) observed that inhibition of mycelial growth of *F. moniliforme* (60.65%) by the leaf extract of *Lawsonia inermis* followed by root extract of *Asparagus racemosus* (50.59%). According to Mohana *et al.* (2011), a methanol extract of *Decalepis hamiltonii* inhibited *Fusarium moniliforme* mycelial growth to the greatest extent (89.90 per cent). The complete inhibition in the growth of *F. moniliforme* using oil of *Hedychium spicatum* and *Acorus calamus* was found by Mishra *et al.* (2003). Essential oils (EOS) from *Cymbopogon citratus*, *Ocimum gratissimum*, and *Thymus vulgaris* were found to be 95-100 per cent efficient in preventing *F. moniliforme* seed infection. Thymol, terpinene, p-cymene, carvacrol from *O. gratissimum*, linalool from *T. vulgaris*, and citral from *C. citrates* have all been shown to have antifungal activity (Nguefack *et al.,* 2007).

8.5 Biological Control

Biological control of plant diseases using antagonistic fungi and bacteria is an environment friendly option that could be a viable alternative to agrochemicals. *Trichoderma strictipilis*, *T. atroviride,* and *T. neokoningii*, the most common biocontrol agents, reduce the vegetative growth of the bakanae pathogen (Bhramaramba and Nagamani, 2013). The mode of action of KNB-422, which was isolated from rice seedlings, perforates, parasitizes, and inhibits the growth of *Gibberella fujikuroi* hyphae (Miyake *et al.,* 2012). *T. viride* and *P. fluorescens*, both alone and in combination, were found to be useful in the treatment of rice bakanae disease in India. Fields treated with FYM 10 t ha^{-1} + *Trichoderma* + *Pseudomonas* had a lower disease incidence (Wyawahare *et al.,* 2012). *P. fluorescens* isolate F15 was reported to be particularly efficient against *F. fujikuroi* by Kazempour and Elahinia (2007). Studies on seed coating, soil soaking, and seed coating + foliar spray using a mixture of fungicide Rovral TS and an F15 antagonistic bacterial isolate demonstrated substantial reductions in disease incidence of 6.5, 6.75, and 5.5 per cent, respectively (Luo *et al.,* 2005).

According to Kumar *et al.* (2014) extracts of *Pseudomonas fluorescens* isolates PF9 and PF-13 and *Bacillus thuringiensis* isolates B-44 operate as antagonists and reported to produce lytic enzymes, siderophores, salicylic acid, and HCN, to inhibit pathogen growth and development. Bio control agents like *Trichoderma asperellum* SKT-1 (Watanabe *et al.,* 2007), *Talaromyces spp,* (Kato *et al.,* 2012), *Bacillus subtilis* and *B. megaterium* (Luo *et al.,* 2005) are helpful in preventing fungal growth. Motomura *et al.* (1997) evaluated the efficacy of seed treatment with metabolites produced by soil-borne bacteria with Benomyl, Triflumizole, Pefurazoate, and Prochloraz and discovered that five microbial extracts effectively reduced bakanae development and were better than fungicides. Surfactin A purified from *Bacillus* NH 100 and NH 217 reduces disease incidence by 80% and recovers maximum antifungal efficacy, and can be employed as a biocontrol agent against bakanae disease (Sarwar *et al.,* 2018).

8.6 Chemical Control

Seed treatment with fungicides is the most prevalent and widely acknowledged method of bakanae disease management (Gupta *et al*., 2014; Bashyal *et al.,* 2016c). Fungicidal seed treatment with Thiram, Benomyl, Thiram+Benomyl, Thiram+Carboxim, Thiram+Carbendazim, Thiophanate-Methyl, Mancozeb, Fludioxonil, Prochloraz, Iprodione + Triticonazole, Ipconazole @ 1–2% of seed weight, was effective in Taiwan, Japan, Korea, Iran and Turkey (Bagga and Sharma, 2006; Ora *et al.,* 2011). Seedling treatment with Carbendazim or Benlate (0.1 per cent) for 6 and 8 hours significantly reduced disease incidence and enhanced grain production (Bagga and Sharma, 2006). The disease was effectively controlled by seed/seedling treatment followed by soil drenching of the benzimidazole fungicide Derosol (0.2 per cent) (Bhalli *et al.,* 2001). Bal *et al.* (2018) reported that treatment of seeds with Bavistin 50 WP @ 0.2% followed by seedling dip treatment in Bavistin 50 WP @ 0.2% and pulling up the infected seedlings in the nursery can control the disease (92.2%) in the field. This whole process is considered as a most effective method to control foot rot of rice.

Seed/seedling treatment, followed by a 0.2 per cent benzimidazole fungicide Derosol drenching in the soil, was shown to be very efficient in controlling the disease (Pannu *et al.,* 2009). Seed treatment and Carbendazim sand mixed application at 1 g m^{-2} in nursery beds, as well as seedling dipping in 0.1 per cent Carbendazim for 3 hours, were all found to be effective against the disease. When Carbendazim was used as a foliar spray during the flowering stage, the incidence of bakanae disease was reduced by 73.9 to 35.0 per cent (Sunder *et al.,* 2014). Li *et al.* (2018) reported that use of Phenamacril and Ipconazole individually and in mixture can reduce the disease incidence. Their study concluded that application of Phenamacril at the concentration of 0.1544 µg ml^{-1} and ipconazole at the concentration of 0.0472 µg ml^{-1}, EC50 exhibit significant antifungal effectiveness against *Fusarium fujikuroi* mycelial development when they are treated separately. When Phenamacril and Ipconazole were mixed in a 2:1 ratio, the pathogen's mycelial development was inhibited synergistically. *F. fujikuroi* sporulation was inhibited most effectively by Ipconazole alone, intermediately by the 2:1 mixture, and least effectively by Phenamacril alone.

Hossain *et al.* (2015) investigated the impact of fungicides on diseased plants *in-vitro,* testing 15 different fungicides. All fungicides tested were found to be effective against the disease's pathogen to varying degrees. The most successful follow-up was Carbendazim (50 % WP) followed by Folicur (25% Tebuconazole EC), Protaf (25% Propiconazole EC) and Celest extra (2.5% Fludioxonil and 2.5% Difenoconazole EC). Kumar *et al.* (2016) found that spraying Tebuconazole 250 EC on the leaves reduced the incidence of bakanae disease and boosted grain production. Titone *et al.* (2003) investigated the efficacy of thermal and chemical treatments with Carbendazim, mancozeb, Iprodione + Propiconazole, and Carboxin + Thiram, and discovered that the thermal (72°C for 5 min) and Carbendazim treatments offered 98% disease control. Integrated management module against the bakanae disease of rice which is helpful to reduce 95% incidence of bakanae disease of rice was developed. Effect of nursery drenching with Carbendazim was evaluated against bakanae disease of rice. Eighteen days old seedlings of rice variety Pusa Basmati 1121 were drenched with diferent concentration of Carbendazim and transplanted after 5 days of treatment. Minimum disease incidence was observed in 0.2% Carbendazim. Seeds of each treatment were subjected to residue analysis. Results indicated that the use of 0.2% Carbendazim as nursery drenching is safe without any residual effect (Anonymous, 2018).

9. Conclusion

Bakanae disease is developing as a significant hazard to rice farming around the world, including India, where it has caused massive losses in basmati cultivars. Because the pathogen is seed borne in nature. Developing field-based, simple, and reliable diagnostics will aid in reducing the primary inoculum source. It is necessary to do research into the manipulation of various cultural practices to reduce pathogen populations. Seed treatments combined with seedling dip treatments and chemical/biological soil amendments can be a successful management strategy. Therefore, chemical and biological control approaches can be used with a variety of other effective strategies to effectively manage bakanae disease and maintain rice output. Furthermore, more study on host-pathogen interactions, racial profiling, variability, QTL mapping, virulence pattern, biochemical and molecular elements of pathogenesis is required and should be prioritized and still more epidemiological studies are required to strengthen the forecasting and prediction mechanism of the disease which will ultimately minimize the yield losses caused by the disease.

Author Contributions

All the authors contributed to the article and approved the submitted version.

Conflict of Interest

No commercial or financial relationships that could be construed as a potential conflict of interest.

Compliance with ethical standards

Yes

10. References

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