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Review on Bakanae disease of rice and management

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Abstract
The Bakanae disease of rice was first known to be discovered in 1828, but it was scientifically proven in 1898. The disease is previously believed to be caused by *Fusarium moniliforme* (Teleomorph stage: *Gibberella fujikuroi*), later then, it was found out the remaining other Fusarium sp., are also involved in this for disease causation. So, consequently, this review paper states about the following: (i) History of disease discoveration (ii) Symptomatology of the disease (iii) Etiology and Epidemiological contexts (iv) The methods to control the disease. The disease controlling methods which are yet to be controversial after the attack of disease, nevertheless, the possible ways for controlling the disease have been discussed. The disease is likely to be found out that it's both soil and seed borne, and majorly confirmed by researchers that it is a seed borne, and has a long matter of survival for years. As the pathogen of this always boosts the excessive production of Gibberellic acid(GA), a growth hormone, leads to hypertrophy of abnormal elongation and ultimately rotting of plants with empty panicles, henceforth it's termed as "foolish seedling disease". In recent years, the occurrence of this disease in rice growing areas of the world is increasing, the proper management practices will help us to overcome this disease in future.

Keywords: Bakanae, rice, fusarium, seedling, soil borne, seed borne, disease management

Introduction
Rice [*Oryza sativa*], mostly cultivated in Asian countries is a major staple food crop that fulfills the dietary requirement for half of the world and these days serious hazard to rice production is caused by a fungal pathogen known as *Fusarium fujikuroi*, causing a bigger constraint in rice production in Asia and rice producing countries of world. Even Though the disease is of less occurrence, it's notably the highly serious one [A.K. Gupta *et al*., 2016] the disease is ubiquitous among the states of Haryana, Andhra Pradesh, Tamil Nadu. The disease mainly infects the plants through the roots and crowns and shows visible symptoms with abnormal elongation than the healthy plants in the field [Muhammad Naeem *et al*., 2016] [43].
This disease is also called with so many names in many regions of the world such as root rot and white head disease, Fusarium blight, Fusariosis, Thin noodle seedling, Stupid rice crop, White stalk in China, Palay lalake(man rice) in British Guiana, Elongation disease, Foot rot in Phillipines, Otoke Nae(Male seedling) in Japan [Swamei H *et al*., 2008] but the first report of this disease was from Japan in 1828, which scientifically proven was caused by fungi 1898 by Japanese researcher Shotaro Hori [Bishnu Maya Bashyal, 2018] [13]. Bakanae disease is known due to hypertrophy of plant with elongated seedlings but it ends up with empty panicles i.e, no edible grains, hence it's so called as "foolish seedling disease" [Suparyono *et al*., 2009] [61].

History and Distribution
This disease is called with various names in many parts of the world as root rot and white head disease [Saremi H *et al*., 2008] [57], 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, Bakanae in the USA, Africa and Australia, Foolish plants or Foot rot in India and Bakane in Africa, Ceylon, French Equatorial [Ram Singh, Sunder S. 1997] [52].
This disease is extensively distributed among the virtually rice growing countries of the world such as Africa, Australia, Bangladesh, Brazil, British Guiana, Ceylon, India, Indonesia, Italy, Japan, Kenya, Nepal, Nigeria, Philippines, Spain, Thailand, Trinidad, Uganda, USA and following so many rice cultivating areas. In India, it's largely found in these states as in Andhra pradesh, Assam, Uttar pradesh, Tamil nadu, Manipur, West Bengal [Ram Singh and Surendar S, 1997] [52].

Economic Importance
This notorious pathogen of this disease causes yield loss in many countries in considerable

percentage and mainly devastating in exporting rice varieties which earns substantial foreign exchange. Under favourable conditions it is known to cause 3.0-95.4% in almost to complete loss in India. The yield loss reported from other countries such as 6.7-58% in Pakistan [Yasin *et al*., 2003], 20-25% yield loss in Japan, 40% in Kurnal-4 rice variety in Nepal [Desjardins *et al*., 2000] [19], and In Asian countries remarkably as 20% yield loss [Cumagun *et al*., 2011] [14].
In India, the yield losses are reported as 15% in Eastern Uttar Pradesh [Pavgi and Singh., 1964] [49], 15.4% in Assam [Rathaiah *et al*., 1991] [54], 5-7% in Manipur [Singh *et al.* 1996] [59], 3.0-95.4% in Haryana [Sunder *et al*., 1997] [52].

Symptoms

The fungal pathogen of Rice named *Fusarium fujikuroi* is a part of *Gibberella fujikuroi* complex species(GFSC) which leads to Foot rot disease [Husain H.M, S. Baharuddin and Z. Latiffan, 2011] [25], resulting in the symptoms as hyper or hypo elongation of roots, elongated growth, or stunted growth, infected plants shows hypertrophy, leaves get thinner with yellowish green colour and pale green flag leaves, which are visibly etiolated and shows chlorotic conditions than healthy ones, at early tillering the seedlings get to be dried and eventually leads to reduced tillering and drying of leaves at later stage of infection, in case of surviving plants at maturity stage it carries partially filled grains, sterile or mostly empty grains [Zainudin, N.A.I.M, A.A. Razak and B. Salleh, 2008] [68]. In Japan, infected panicles are in pink color and termed as pink panicles [Sharma VK, Bagga PS, 2007] [9]. These kinds of symptoms are produced due to the secretions of excessive amounts of Gibberellic acid. This well known pathogen also secretes many pigments following as Bikaverin, Fusarubins, Mycotoxins, Fusarins, Fusaric acid, Phytohormones, Gibberellic acid GA(3) and it's precursors GA(4), GA(7) and also many unknown metabolites [Alberman, Tudzynski and Bettina 2013] [3].

Host Range

This disease pathogen has a very wide host range. The primary host manifests the sexual cycle that have been reported in rice, maize, barley, sorghum, sugarcane, wheat, pye, rye and asparagus from Asia, Africa, South East Asia and the United States [Petrovic *et al.*, 2013] [50].
During favourable conditions pathogen survives in primary host and after for the successive life cycle completion it will come to secondary/alternate host those are reported wise such as tomato, cowpea, banana, subabul, proso millet, early water grass, and barnyard grass and these also act as reservoir for secondary inoculum in the field [Anderson and Webster 2005., Carter *et al*., 2008] [5, 15]. During unfavourable conditions, pathogens also survive in some alternate hosts such as round gourd, cucumber, pine, fig, cotton, sapodilla.

Disease Cycle

The fungus is mainly externally seed-borne but to some extent soil-borne, hence seed borne is comparatively significant and infectious because the soil borne inoculum disappears while the time passes- by. The pathogen main entry is observed as a hull. Embryo infection shows the range of 2-41% in different cultivars and the hull shows 75% isolation frequency from infected and untreated seeds of *G.fujikuroi* [Manandhar J., 2000] [40]. Severely infected seeds are discoloured. The stunting, elongation is determined by the degree of seed infection. Sprouting period was the most suitable time for disease development [Chan *et al.*, 2004] [16]. Soil moisture and soil temperature influence the disease development, which develops best at the temperature of 25 - 35oC. Nitrogenous manuring aggravates the disease. The incidence of disease will be greater in wet nurseries than in dry ones [G. Rangaswami and A. Mahadevan, 2019] [20].

Variability in Pathogen

Morphological, Physiological, Pathogenic Variability

Many scientists worked on this pathogen and found the greater variation(variability) in *F.fujikuroi* strains has been detected in the production of gibberellic acid, fusaric acid, pectic enzymes and their pathogenicity [Amatulli *et al*, 2010] [4].
Many species are involved in the causing of foot rot, some of the observed isolates were identified as *F. fujikuroi*, *F. proliferatum*, *F. verticillioides*, *F. sacchari* and *F. subglutinans* depending upon their morphological characteristics. Out of these species *F. fujikuroi* is the only species observed as the capability to produce GA3 in higher levels in infected plants and this is considered as the main physiological variation among Fusarium species [Nur Ain Izzati Mohd Zainudin *et al.*, 2008] [45]. The var *F. fujikuroi* is observed with the formation of macroconidia (long, slender, almost straight and thin walled) and microconidia type(oval, obovoid with a truncated base produced in chains and in false heads from the conidiogenous cells) in rice, so it is almost distinguishable among morphological characters [Leslie J. and Summerall B., 2006] [34]. The morphological variation and pathogenicity of F. fujikuroi isolates also given by Bashya and Aggarwal, 2013. The 48 variants of F. moniliforme has been divided on the basis of variable growth rate [Thakur *et al.*, 1998] [62], and many other important pathogenic variations also found in F. moniliforme by many researchers [Sharma VK, Bagga PS 2007] [9].
All the isolates of Fusarium species produced gibberellic acid, but, even so the fusaric acid is produced by only 45% isolates [Kaur J *et al.*, 2014] [30]. The symptom variation in the F. fujikuroi, F. proliferatum, F. verticillioides, F. saccahri have also been observed [Sharma and Bagga, 2007] [9]. Recently, the important interrelationship between the seedlings length that is treated with GA3 and bakane injury has been found by Ma *et al.* in 2014.

Genomics of *Fusarium fujikuroi*

Between 2010 to 2017, nearly during one decade, the various multiple whole genomes of a *Fusarium spp*, were collected, sequenced and studied, therefore, it helped for the understanding of host-pathogen interaction and their defense mechanism [King *et al.*, 2015] [32]. Yet now, totally thirteen genomes of *F.fujikuroi* have been published from different countries [Bashyal *et al*. 2017 [11]; Niehaus *et al*. 2017 [44]; Chiara *et al*. 2015 [17]; Wiemann *et al*. 2013 [66]; Jeong *et al*. 2013] [26] 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. Additionally, based on this gene profiling, the symptoms developed (rotting and stunting) isolates were drawn as two distinct pathotypes [Niehaus *et al.*, 2017] [44]. 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 & species	Originated country and host	Genome size(MB)	References
F 250, *F.fujikuroi*	India	42.4	Bashyal *et al.*, 2017 [11]
IMI 58289, *F.fujikuroi*	Taiwan, rice	43.9	Wiemann *et al.*, 2013 [66]
FGSC 8932, *F.fujikuroi*	Taiwan, rice	43.0	Chiara *et al.*, 2015 [17]
KSU 3368, *F. fujikuroi*	Thailand, rice (1990)	43.1	Chiara *et al.*, 2015 [17]
KSU X-10626, *F.fujikuroi*	Konza Prairie (USA), Schizachyrium scoparium (1997)	43.1	Chiara *et al.*, 2015 [17]
B 14, *F.fujikuroi*	South Korea, rice	44.0	Jeong *et al.*, 2013 [26]
m 567, *F.fujikuroi*	Japan, infected rice	44.0	Niehaus *et al.*, 2017 [44]
MRC 2276, *F.fujikuroi*	Philippines, infected rice	45.0	Niehaus *et al.*, 2017 [44]
C 1995, *F.fujikuroi*	Taiwan, infected rice	45.8	Niehaus *et al.*, 2017 [44]
E 282, *F.fujikuroi*	Italy, infected rice	46.1	Niehaus *et al.*, 2017 [44]
FSU 48, *F.fujikuroi*	Germany, maize	46.1	Niehaus *et al.*, 2017 [44]
NCIM 1100, *F.fujikuroi*	India, infected rice	45.3	Niehaus *et al.*, 2017 [44]
B 20, *F.fujikuroi*	South Korea, infected rice	44.3	Niehaus *et al.*, 2017 [44]

Disease occurrence, incidence, and yield losses in various countries

Country	State	Disease Incidence	Yield Losses	References
India	Jammu and Kashmir (Major Basmati rice grown areas) Uttar Pradesh Andhra Pradesh Tamil Nadu Manipur West Bengal Haryana Punjab Assam Bihar Rajasthan	10 – 50 1.2 - 11.7 3 - 95.5 2.1 - 2.8 10.5 - 40 1.8 - 8.7 2.4 - 13.6	15 - 25%	Khokar, L.K, A.H. Jaffrey, 2002 [31]. Gupta, A.K, Y. Singh, A.K. Jain and D. Singh, 2014 [21]. Pannu, P.P.S, J. Kaur, G. Singh, 2012 [47]. Hossain, K.S, M. Mia, M.A. Bashar, 2013 [22].
Malaysia	Rompin Sungia Leman Sekinchan	12.5 5.3 2.5		Zainuddin *et al.*, 2008 [45].
Indonesia	East Java Padang	5 12		Zainuddin *et al.*, 2008 [45].
USA	California			Zainnuddin *et al.*, 2008 [45].
Bangladesh	Commonly all rice grown areas			Hossain *et al.*, 2013 [22].
Korea	Commonly all rice grown areas		26.7%	Hossain *et al.*, 2013 [22].
Thailand	Northern and Central Thailand		3.7 - 14.7%	Kanjanasoon, P., 1965 [28].

Disease Management

A) Use of Resistant Varieties

Rice varieties with resistance behaviour against Bakanae

Country	Resistant Varieties	References
India	Punjab mehak and PUSA Basmati No.1	Pannu *et al.*, 2013 [48].
	PAU 2343, PAU 2383, IR 67418,IR 67423, IR 67418, IR 58755, IR 64668, IR 66229, IR 67409	Bagga PS, Kumar V, 2000 [7].
	GSL-5, GSL-9, GSL-12, GSL-36, GSL-44, GSL-60, GSL-66, GSL-67, GSL-68	Ahangar *et al.*, 2012 [1]
	Co 18, Co 22, ADT 8, PTB 7, GEB 24, IR 20, IR 26, IR 32, IR 38, IR 44, IR 45	Ram Singh and Sunder, 2012 [53]

B) Varietal Resistance

Since the first report of foot rot disease was framed, many more attempts have been made to find out the resistant genotypic rice cultivars. Numerous resistant cultivars have been developed and identified but they only express the small inheritance of rice germplasm. The three Bakanae disease resistant cultivars that show minor resistance were recognized by Ito and Kimura in 1931. But, recently researched studies showing that thirteen genotypic cultivars invented have average and high resistance towards bakanae disease, out of those five cultivars show medium resistance, and one cultivar shows moderate resistance [W. N. A. W. A. Halim *et al.*, 2015] [64]. Among these thirteen resistant genotypes, found that the dwarf or semi-dwarf genes are contained in three resistant rice genotypes. Adding to this, three qualitative trait loci managing resistance of rice basmati to *F.moniliforme* were revealed such as qBK1.1, qBK1.2, and qBK1.3 [R.A. Fiyaz *et al.*, 2016] [51]. Still, in the temperate climatic areas of rice cultivation, there is no report of resistant cultivars. Twelve commercial rice varieties have been grown and studied in greenhouse conditions for the initiation of resistance towards the bakanae disease [S. Matic *et al.*, 2016] [55]. These recently founded cultivars show some genes regulating resistance and to some extent to the resistance using healthy seeds is a preventive method. Some of the resistant genotypes found resistance to Bakanae disease are given in Table 2 [S. Sundar, Ram Singh, D.S. Dodan 2014] [56].

Table 2: Genotypes that are found resistant to Bakanae disease

Disease Rate (Score)	Genotypes	References
0 (Highly Resistant)	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, RDN 01-2-10-9	S. Sundar *et al*., 2014 [56]
1 (Resistant)	Nil	S. Sundar *et al*., 2014 [56]
3 (Moderately Resistant)	HKR 90-403, HKR 92-401, HKR 92-447, HKR 93-401, HKR 93-402, HKR 94-414, HKR 94-415, HKR 94-417, HKR 94-418, HKR 94-419, HKR 94-416, HKR 95-435, HKR 95-436, HKR 95-449, HKR 95-514, HKR 95-515, HKR 96-437,HKR 96-501, HKR 96-523, HKR 96-538, HKR 96-539, HKR 96-540, HKR 96-574, HKR 07-34, HKR 07-35, HKR 07-36, HKR 07-50, HKR 08-5, HKR 08-9, HKR 08-11, HKR 08-14, HKR 08-16, HKR 08-17, HKR 08-43, HUBR 10-9,NDR 6271, RP 3138-60-9-6-6, UPR 3385-20-1-2	S. Sundar *et al*., 2014 [56]

C) Plant Extracts

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 and even the germination of seed after the incidence is using botanical extracts show greater results [Anderson, 2005] [6]. Effect of Botanical extracts on seed germination and infection rate of *F.moniliforme* in rice was represented below [M. S. Hossain *et al*., 2018] [42].

Botanical Name	Germination (%)	Infection (%)
Garlic	85.00	0.00
Ginger	72.00	3.50
Onion	71.75	4.75
Gada	70.50	21.25
Basak	69.75	6.50
Neem	69.00	11.75
Tulsi	67.50	27.75
Mehandi	66.75	0.00

From the above table, Garlic and Mehandi show the complete inhibition of the mycelial formation and germination percentage as high as 85% recorded in Garlic. Therefore the management of the botanical extracts reduces the infection rate frequency of *F.moniliforme*, naturally.

D) Bio Control

Several fungal antagonistics and some bacterial strains are helpful in suppressing the fungal mycelial growth, asexual spores formation (macroconidia & microconidia) and germination of *F.fujikuori* in effective method decreases disease incidence significantly. Surfactin A purified from Bacillus NH 100 and NH 217, reduces considerably 80% of the disease incidence and restores maximum antifungal activity can be used as biocontrol agent against bakanae disease [Sarwar *et al*., 2018] [58]. Induction of strain YC7007 of bacterium *Bacillus oryzicola* can be applied and used as a biocontrol agent for bakanae disease [Hossain *et al*., 2016] [24]. The hyphae of Gibberella fujikuroi gets perforated, parasitized and subjected to anti-growth activity by the mechanism of action of KNB-422, which is isolated from the rice seedlings [Miyake *et al*., 2012] [29]. The bio-control agent *Pseudomonas fluorescens* isolates PF-9,PF-13 and *Bacillus thuringiensis* isolate B-44 acts as a antagonistic against bakanae produced lytic enzymes(Chitinase and -1,3-glucanase {endo-1,3(4)- -glucanase), siderophores, SA and HCN and suppressed fungal growth & bakanae incidence [Kumar *et al*., 2007] [33]. The biocontrol agents like *Bacillus subtilis*, *Trichoderma harzianum*,*T.virens* are most effective in reducing bakanae. Some of the bio control agents are also useful in preventing fungal growth are *Trichoderma asperellum* SKT-1 [Watanabe *et al*., 2007] [65], *Talaromyces sp* [Kato *et al*., 2012] [29], *Bacillus subtilis* and *B.megaterium* [Li *et al*., 2006, Luo *et al*., 2005] [35, 37].

E) Chemical Control

The most followed management in control of bakanae is by using chemicals. There should be continuous attempts to study about the effective fungicides for this bakanae disease. Some fungicides such as benzimidazoles are effective in controlling the fungal mycelial growth in in-vitro and as well as in field condition.

Derosal has the inhibitory property of fungal mycelial growth therefore treating the rice seeds with Derosal at 4g/kg and soil drenching the artificially inoculated soil in pot at 500 ppm shows the complete control of this disease [Bhalli JA *et al*., 2001] [12]. Seed treatment with Benomyl or Bavistin at 0.1% for 6 - 8 hrs is reported for effective disease control [Bagga P S, Sharma V K., 2006] [8]. Seedling dip treatment with Carbendazim at 0.2% is also efficient in managing the disease and Propicanozole checked the spread of the disease and protected the grains from infection [Pannu PPS *et al*., 2009] [46]. While applying Benzimidazoles(Benomyl and Carbendazim) as foliar spray at 0.1% efficiently decreases the disease incidence and promotes grain yield and quality without obstruction [Biswas S, Das SN. 2002] [14]. The thermal treatment of Carbendazim at 72ºC for 5 min gives 98% disease control [Titone P *et al*., 2003] [63]. Hossain *et al.* in 2015 [23] investigated the effect of 15 fungicides in in-vitro conditions, all the 15 fungicides showed the efficacy in various degrees against the pathogen. Phenamacril at 0.1544 µg/ml concentration and Ipconazole at 0.0472 µg/ml have been reported for reducing the disease in an effective manner [Li *et al*., 2018] [36]. Seed treatment followed seedling dip treatment of Bavistin at 50WP @ 0.2% with pulling up the infected seedlings in nursery reduces 92.2% effectively of disease incidence [Bal *et al*., 2018] [10]. The chitosan oligosaccharides(COS) showed the fungicidal effect on hyphal growing cells and Ethylene diamine tetra acetic acid (EDTA) exhibited fungistatic effect on growth inhibition of fungal hyphal cells [Kang *et al*., 2016] [27].

Conclusion and Future Aspects to Control the Disease

As bakanae disease is spread all over the world, it causes substantial economic losses in many aspects and particularly in scented rice in quality export to other countries. To control this bakanae, still there should be continuous progress of attempting, researching, studying the various isolates from all the world should need to in upcoming times in future. Phylogenetic analysis should be in continuous research to study the pathogen evolutionary changes so that we can prevent and escape from the disease by suitable management. Despite these studies, further research on genomic sequences of pathogens for resistance development, gene mapping for virulence, pathogenic variability, biochemical and molecular aspects of pathogenesis are necessary to manage the disease. Besides this cultural and chemical control should need to be managed perfectly to prevent the occurrence of disease. Efficacy strains of bio-control agents are also required to be commercialized for disease management. Soil solarization subjected to be practiced, additionally, seed borne inoculum and epidemiology also need to be investigated consistently. The pathogen of this disease is mostly seed borne, so by undergoing seed treatment with Bavistin, Sunphanate, Nativo and Carzeb completely eradicate the pathogen from the seeds. These methods of management are important in controlling the disease, by providing the certified seeds on the basis of field inspection. Eventually, many controlled experiments and more studies based on future strategies have to be done to draw more management practices to prevent major yield losses.

References

1. Ahangar MA, Najeeb S, Rather AG, Bhat ZA, Parray GA, Sanghara GS *et al*. Evaluation of fungicides and rice genotypes for the management of bakanae. Oryza 2012;49:121-126.
2. Gupta AK, Solanki IS, Bashyal BM, Singh Y, Srivastava K. Bakanae of rice - An emerging disease in Asia, The Journal of Animal & Plant Sciences 2015;25(6):1499-1514 ISSN: 1018-7081.
3. Alberman Sabine Linnemannstoens, Pia Tudzynski, Bettina. Strategies for strain improvement in Fusarium fujikuroi: overexpression and localization of key enzymes of the isoprenoid pathway and their impact on gibberellin biosynthesis, Applied Microbiology and Biotechnology 2013;97(7):2979-2995.
4. Amatulli MT, Spadaro D, Gullino ML, Garibaldi A. Molecular identification of Fusarium Spp. associated with bakanae disease of rice in Italy and assessment of their pathogenicity. Pl. Pathol 2010;59:839-844.
5. Anderson LL, Webster RK. A comparison of assays for Gibberella fujikuroi and their ability to predict resulting bakanae from seed sources in California. Phytopath 2005;95(S4):6.
6. Anderson LL. Bakanae disease of rice in California: Investigation of disease incidence, spread and pathogen population structure. PhD Thesis. University of California, Davis 2005.
7. Bagga PS, Kumar V. Resistance to bakanae or foot disease in Basmati rice. Indian Phytopath 2000;53:321-22.
8. Bagga PS, Sharma VK. Evaluation of fungicides as seedling treatment for controlling bakanae/foot rot (Fusarium moniliforme) disease in Basmati rice. Indian Phytopath 2006;59:305-08.
9. Bagga PS, Sharma VK, Pannu PPS. Effect of transplanting dates and chemical seed treatments on foot rot disease of basmati rice caused byF. Moniliforme. Pl. Dis. Res 2007;22:60-62.
10. Bal RS, Barun Biswas. Epidemiology and Management of Foot Rot in Basmati Rice; J Krishi Vigyan; PAU's Regional Research Station, Gurdaspur -143521, Punjab 2018;6(2):87-94
11. Bashyal BM, Rawat K, Sharma S, Kulshrestha D, Singh AK, Dubey H *et al*. Whole genome sequencing of Fusarium fujikuroi provides insight into the role of secretory proteins and cell wall degrading enzymes in causing bakanae disease of rice. Frontiers Plant Sci 2017. https://doi.org/10.3389/fpls.2017.02013.
12. Bhalli JA, Aurangzeb M, Ilyyas MB. Chemical control of bakanae disease of rice caused by Fusarium moniliforme. On line J Biol Sci 2001;1(6):483-84.
13. Bishnu Maya Bashyal. Etiology of an emerging disease: bakanae of rice, Indian Phytopathology 2018;71:485–494.
14. Biswas S, Das SN. Fungicidal spraying for control of bakanae disease of rice in the field. J Mycopathol Res 2002;40(2):211-12.
15. Carter LLA, Leslie FJ, Webster RK. Population structure of Fusarium fujikuroi from California rice and water grass. Phytopathol 2008;98:992-99.
16. Chan ZL, Ding KJ, Tan GJ, Zhu SJ, Chen Q, Su XY *et al*. Epidemic regularity of rice bakanae disease. J Anhui agril Univ 2004;31(2):139-42.
17. Chiara M, Fanelli F, Mule G, Logrieco AF, Pesole G, Leslie JF *et al*. Genome sequencing of multiple isolates highlights sub telomeric genomic diversity within Fusarium fujikuroi. Genome Biol Evol 2015;7:3062–3069. https://doi.org/10.1093/gbe/evv198.
18. Cumagun, Christian Joseph R, Arcillas, Erwin and Gergon Evelyn. UP-PCR analysis of the seed borne pathogen F. fujikuroi causing bakanae disease in rice. International Journal of Agriculture and Biology 2011;13(60):1029-1032.
19. Desjardins AE, Manandhar HK, Plattner AD, Manandhar CG, Poling SM, Maragos CM. Fusarium species from Nepalese rice and production of mycotoxins and gibberellic acid by selected species, applied and Environmental Microbiology 2000;66(3):1020-1025.
20. Rangaswami G, Mahadevan A. Diseases of crop plants, Indian Phyto pathology 2019,2v.
21. Gupta AK, Singh Y, Jain AK, Singh D. Prevalence and Incidence of Bakanae disease of Rice in Northern India. Journal of Agri. Search 2014;1(4):233-237.
22. Hossain KS, Mia M, Bashar MA. New method of screening rice varieties against bakanae disease. Bangladesh J. Bot 2013;42(2):315-320.
23. Hossain KS, Taher Mia MA. Management of bakanae disease of rice; Bangladesh Journal of Botany 2015;44(2):277-283
24. Hossain MT, Ajmal Khan, Eu Jin Chung, Md. Harun-Or Rashid, Young Ryun Chung. Biological Control of Rice Bakanae by an Endophytic Bacillus oryzicola YC7007; Korean society of plant pathology 2016;32(3):228-241.
25. Hsuan HM, Baharuddin S, Latiffah Z. Molecular identification of Fusarium fujikuroi in Gibberella fujikuroi species complex from Rice, Sugarcane and Maize from Peninsular Malaysia, International Journal of Molecular Sciences 2011;12(10):6722-6732.

26. Jeong H, Lee S, Choi GJ, Lee T, Yun SH. Draft genome sequence of Fusarium fujikuroi B14, the causal agent of the bakanae disease of rice. Genome Announc 2013. https://doi.org/10.1128/genomea.00035-13.
27. Kang, Yang-Soon Kim, Wan Joong Kim, Yeon Ju Jung, Ki-Hong Choi, Ul-Su. Bakanae Disease Reduction Effect by Use of Silicate Coated Seed in Wet Direct-Seeded Rice. Korean journal of crop science 2016;61(1):9-16.
28. Kanjanasoon P. Studies on the bakanae disease of rice in Thailand. Doc. Agric. Thesis, Tokyo University, Japan 1965.
29. Kato A, Miyake T, Tateishi KNH, Taraoka T, Arie T. Use of fluorescent proteins to visualize interactions between the bakanae disease pathogen Gibberella fujikuroi and the biocontrol agent Talaromyces sp., KNB-422 J. Gen Plant Pathology 2012;78:51-6.
30. Kaur J, Pannu PPS, Sharma S. Morphological, biochemical and molecular characterization of isolates causing bakanae disease of basmati rice. J Mycol Plant Pathology 2014;44:78-82.
31. Khokhar LK, Jaffrey AH. Identification of sources of resistance against bakanae and foot rot disease in rice. Pakistan J. Agric. Res 2002;17:176-177.
32. King R, Urban M, Hammond MCU, Pak KH, Hammond KE. The completed genome sequence of the pathogenic ascomycete fungus Fusarium graminearum. BMC Genom 2015;16:544.
33. Kumar MN, Laha GS, Reddy CS. Role of antagonistic bacteria in suppression of bakanae disease of rice caused by Fusarium monliforme Sheld. J. Bio control 2007;21:91-104.
34. Leslie JF, Summerell BA. The Fusarium laboratory manual. Blackwell Publishing, Oxford 2006,388p.
35. Li B, Xie GL, Lu YL, Hao XJ, Luo JY, Liu, B *et al*. Community composition of gram positive bacteria associated with rice and their antagonists against the pathogens of sheath blight and bakanae disease of rice. Chinese J. Rice Science 2006;20:84-88.
36. Li Meixia, Tao Li, Yabing Duan, Ying Yang, Jian Wu, Donglei Zhao *et al*. Evaluation of Phenamacril and Ipconazole for Control of rice Bakanae Disease Caused by Fusarium fujikuroi; The American phytopathological society 2018;102(7):1234-1239
37. Luo JY, Xie GL, Li B, Luo YC, Zhao LH, Wang X *et al*. Gram positive bacteria associated with rice in China and their antagonists against the pathogens of sheath blight and bakanae disease in rice. Rice Sci 2005;12:213-218.
38. Ma LY, Ji ZJ, Bao JS, Zhu XD, Li XM, Zhuang JY *et al*. Responses of rice genotypes carrying different dwarf genes to Fusarium moniliforme and gibberellic acid. Plant Prod Sci 2008;11:134-138.
39. Ma LY, Ji ZJ, Bao JS, Zhu XD, Li XM, Zhuang JY *et al*. Responses of rice genotypes carrying different dwarf genes to Fusarium moniliforme and gibberellic acid. Plant Prod. Sci 2008;11(1):134-138.
40. Manandhar J. Fusarium moniliforme in rice seeds: its infection, isolation and longevity. Z Pflkrankh Pflschutz 2000;106:598-607.
41. Miyake T, Akihiro Kato, Hideaki Tateishi, Tsutomu Arie. Mode of action of Talaromyces sp. KNB422, A biocontrol agent against rice seedling diseases. Journal of Pesticide Science 2012;37(1):56-61.
42. Hossain MS, Ayub Ali M, Moni ZR, Parveen S, Hussen MAM. Use of non-chemicals to manage seed borne fusarium moniliforme: causing bakanae disease of rice.Bangladesh J. Agri. 2016-2018 2018;41-43:31-40.
43. Muhammad Naeem, Muhammad Iqbal, Nasira Parveen, Sami-Ul-Allh, Qamar Abbas, Abdur Rehman *et al*. An over view of Bakanae disease of rice. American Eurasian J. Agric and Environ. Sci 2016;16(2):270-277.
44. Niehaus EM, Kim HK, MuÈnsterkoÈtter M, Janevska S, Arndt B, Kalinina SA *et al*. Comparative genomics of geographically distant Fusarium fujikuroi isolates revealed two distinct pathotypes correlating with secondary metabolite profiles. PLoS Pathogen 2017;13(10):e1006670. https://doi.org/10.1371/journal.ppat.1006670.
45. Nur Ain Izzati Mohd Zainuddin, Azmi Abd. Razak, Badaruddin Salleh. Journal of plant protection research 2008,48(4).
46. Pannu PPS, Singh N, Rewal HS, Sabhiki HS, Raheja S. Integrated management of foot rot of Basmati rice Proc. National Symp. Plant Pathology in the Changing Global Scenario organised by Indian Society Plant Pathologists, Feb. 27-28, 2009, NBPGR, N. Delhi 2009,13/32p.
47. Pannu PPS, Kaur J, Singh G, Kaur J. Survival of Fusarium moniliforme causing foot rot of rice and its virulence on different genotypes of rice and basmati rice. (Abstracts) Indian Phytopathology 2012;65:149-209.
48. Pannu PPS, Kaur J, Kaur J, Bansal GK, Kaur H. Virulence of on different genotypes of rice and its management 2013;50:18-23.
49. Pavgi MS, Singh J. Bakanae and foot rot of rice in Uttar Pradesh, India. Pl. Dis. Reptr 1964;48:340-342.
50. Petrovic T, Burgess LW, Cowie I, Warren RA, Harvey PR. Diversity and fertility of Fusarium sacchari from wild rice (Oryza australiensis) in Northern Australia, and pathogenicity tests with wild rice, rice, sorghum and maize, European Journal of Plant Pathology 2013;136:773-788.
51. Fiyaz RA, Yadav AK, Krishnan SG, Ellur RK, Bashyal BM, N. Grover PK *et al*. Mapping quantitative trait loci responsible for resistance to Bakanae disease in rice. Rice (NY) 2016;9:45.
52. Ram Singh, Sunder S. Foot rot and bakanae of rice: retrospects and prospects. Int J Trop Pl Dis 1997;15:153-176.
53. Ram Singh, Sunder S. Foot rot and Bakanae of rice - An overview, Rev. Plant Pathol 2012,5v.
54. Rathaiah Y, Das GR, Upendra Singh HK. Estimation of yield loss and chemical control of bakanae disease of rice. Oryza 1991;28:509-512.
55. Matić S, Bagnaresi P, Biselli C, Orru' L, Amaral Carneiro G, Siciliano I *et al*. Comparative transcriptome profiling of resistant and susceptible rice genotypes in response to the seed borne pathogen Fusarium fujikuroi. BMC Genomics 2016;17:19.
56. Sundar S, Ram Singh, Dodan DS. Management of bakanae disease of rice caused by Fusarium moniliforme, Indian Journal of Agricultural Sciences 2014;84(1):48–52.
57. Saremi H, Ammarellou A, Marefat A, Okhovat SM. Binam a rice cultivar, resistant for root rot disease on rice caused by Fusarium moniliforme in Northwest, Iran. Int J Bot 2008;4:383–38.
58. Sarwar Ambrin, Muhammad Nadeem Hassan, Muhammad Imran, Mazzar Iqbal, Saima Majeed. Biocontrol activity of surfactin A purified from Bacillus

NH-100 and NH-217 against rice bakanae disease. Microbiological research 2018;209:1-13.
59. Singh NI, Devi RKT, Singh LNK. Withering of growing shoot of rice caused by Fusarium moniliforme. Pl. Dis. Res. 1996;11:99-100.
60. Sunder Satyavir S, Virk KS. Studies on correlation between bakanae incidence and yield loss in paddy. Indian Phytopath 1997;50:99-101.
61. Suparyono, Catindig JLA, Castilla NP, Elazegui F. "Rice Doctor's Bakanae Fact Sheet". Cereal Knowledge Bank (CKB) 2009 the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT) 2011.
62. Thakur KSS. Role of gibberellic acid, fusaric acid and pectic enzymes in the foot-rot disease of rice. Riso 1974;23:191-207.
63. Titone P, Tamborini L, Polenghi L, Garibaldi A. Efficacy of chemical and physical seed dressing against bakanae disease of rice: Comparison of fungicide treatment and heat treatment. Sementi Elette 2003;49(4):23-27.
64. Halim WNAWA, Razak AA, Ali J, Zainudin NAIM. Susceptibility of Malaysian rice varieties to Fusarium fujikuroi and in vitro activity of Trichoderma harzianum as biocontrol agent. Malays J Microbiol 2015;11:20-26.
65. Watanabe S, Kumakura K, Izawa N, Nagayama K, Mitachi T, Kanamori M *et al*. Mode of action of Trichoderma asperellum SKT-1, a biocontrol agent against Gibberella fujikuroi J.Pestic Sci 2007;32:222-228.
66. Wiemann P, Sieber CM, Von Bargen KW, Studt L, Niehaus EM, Espino JJ *et al*. Deciphering the cryptic genome: genome-wide analyses of the rice pathogen Fusarium fujikuroi reveal complex regulation of secondary metabolism and novel metabolites. PLoS Pathog 2013;9(6):e1003475.
67. Yasin SI, Khan TZ, Akhtar KM, Muhammad A, Mushtaq A. Economic evaluation of bakanae disease of rice. Mycopath 2003;1(2):115-117.
68. Zainudin NAIM, Razak AA, Salleh B. Bakanae Disease of rice in Malaysia and Indonesia: Etiology of the causal agent based on morphological, physiological and pathogenicity characteristics. J Plant Protec. Res, 2008, 4(48).