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Advances in False Smut of Rice and its Integrated Diseases Management: A Review

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ABSTRACT

Rice is an important nutritive crop and primary staple food throughout the world. To reach the increasing global grain demand and food security, rice production needs to be monitored and increased. However, abiotic and biotic stresses have impeded rice cultivation both in tropical and sub-tropical regions. Among biotic stressors, false smut of rice incited by fungus *Ustilaginoidea virens* (Cooke, 1878) is one of the most common and serious disease throughout the rice cultivation areas and cause up to 40% loss in its yield. The disease is hard to stop, because fungus infect the crop during flowering stage and symptoms of the disease are evident after emergence of rice panicle. The fungus completely destroys the grains and converts them into spore balls, which are toxic and unfit for seed production. Further, control of false smut of rice through fungicide application is feasible; however, high usage of fungicides has led to the resistance development in causal agent besides environmental pollution. In this review, we update the most recent progress regarding the pathogen, its distribution, taxonomy, disease cycle and integrated disease management.

Key words: Epidemiology, False smut, Management, *Oryza sativa*, *Ustilaginoidea virens*.

Rice (*Oryza sativa* L.) is one of the most important and familiar cereal crops throughout the world that belongs to the family Poaceae. Rice includes 20 wild species and two cultivated species *i.e Oryza sativa* and *Oryza glaberrima* (Pareja *et al*., 2011). Rice provides 20% of the dietary protein in developing countries where rice is the main food in their diet (FAO, 2004). Rice is a rich source of carbohydrate, it also has little amount of protein and fat as well as vitamin B complexes such as Niacin, Riboflavin and Thiamine (Fresco 2005). Rice grains are rich source of minerals like calcium (Ca), magnesium (Mg) and phosphorus (P) (Verma *et al*., 2018). Rice bran contains phytochemical compound with the potential anti-diseases properties, they are ϒ-oryzanol, β-sitosterol, lignin, pectin, arabinoxylan and essential amino acids such as arginine, cysteine, histidine and tryptophan (Goffman and Bergaman, 2004). Rice is grown worldwide over an area of 167 million ha with total production of 782 MT (FAO STAT, 2018). In India rice is grown over an area of 43.99 million ha with production of 109.70 MT holding second position in production after China and the productivity is 2494 kg/ha (Anonymous 2016). Rice productivity is affected by several biotic and abiotic stressors. Cultivation of rice with the use of fertilizers, pesticides and high yielding genotypes has resulted in the occurrence and intensity of biotic stresses in many countries. Among fungal disease, false smut caused by *U. virens* (Cooke) results in great loss to the rice grain yield. The disease is characterized by the development of velvety yellow to green balls which later changes to black colour, also called as false smut balls (Biswas, 2001). It can cause severe damage during favorable conditions when the rice canopy is most dense, resulting in the infection of rice flower and ultimately protrude out of the spikelets to form false smut balls (Fan *et al*., 2016). The most efficient and economical methods to manage plant disease is the use of resistant varieties, which are developed by identification of source of resistance genes against the present virulent population of the fungus. Control of pathogen through chemical application is feasible however, long term usage of these fungicides has led to the resistance development in the causal organism and it also affects the ecosystem. Further pathogen control through resistant cultivar is a potential and desirable method of disease management. Yet it has its own drawback, as the main problem is the effectiveness of qualitative resistance genes once exposed to the field conditions. However, resistance can serve longer period if qualitative resistance controlled by polygenes and supported by other measures of disease control. Therefore, the better economical and effective method to control the disease is integrated disease management. The present paper deals with various aspects such as distribution, symptomatology, losses, disease cycle, epidemiology and IDM.

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History and distribution

False smut of rice caused by fungus *U. virens* with its perfect state as *Villosiclava virens* Tanaka also known as (Green smut and considered as Lakshmi disease) of rice was first reported from Tirunelveli district of state Tamil Nadu of India in 1878 by Cooke. Later *U. virens* was reported to cause false smut of rice in many countries including almost all rice growing regions of the world *viz*. Philippines, Myanmar, Colombia, Peru, Bangladesh, Mauritious, Nigeria, Myanmar, Srilanka, Fiji, Africa (Biswas, 2001). After the first report of occurrence of false smut in India from Tamil Nadu (Cooke, 1878), False smut outbreak has been reported from other states of India like Haryana, Punjab, Uttar Pradesh, Uttarakhand, Karnataka andhra Pradesh, Bihar, Jharkhand, Gujarat, Maharashtra, Jammu and Kashmir and Pondicherry (Dodan and Singh, 1996 and Mandhare *et al*., 2008).

Symptomatology

The causal organism affects the rice plant at flowering stage resulting in the development of false smut balls. The symptoms of the disease have been described by number of workers from different regions of the world. Under suitable climatic conditions pathogen infects the rice plant at the time of panicle development and colonizes the internal part of rice flowers with mycelia (Tang *et al*., 2013). Young ovary of the single spikelet transformed into large velvety yellow to green color balls (Gupta *et al*., 2019). Dhua *et al*. (2015) reported that the smut balls formed not only block rice grain milking but also increases the sterility of spikelet and formation of balls resulting in poor yield. Quintana *et al* (2016) reported that these smut balls represent more than twice the diameter of normal grain and at initial stage are yellow and then change to dark green or almost black colour. Initially occurs on few grains which later infects the whole panicle but the number may increase up to 100% in case of severe disease incidence (Ladhalakshmi *et al*., 2012). It was also reported that the causal organism produced large amount of mycotoxin such as Ustiloxins and Ustilaginoidins (Zhou *et al*., 2012). Several workers (Koyama *et al*., 1988 and Wang *et al*., 2017) reported that these toxins have phytotoxic effect and suppress shoot and root growth of germinating rice seeds. Lu *et al*., (2015) observed that Ustilaginoidins have antibacterial activity to plant and human pathogens.

False Smut balls

Losses

The economic as well as nutritive loss due to this pathogen can be more serious than any other pathogen under congenial environmental conditions. False smut causes both qualitative and quantitative losses to the rice crop and also affects the germination vigor of the rice seedlings (Sanghera *et al*., 2012). The toxins produced by the pathogen are lethal to both human body and animals (Koiso *et al*., 1994). Pannu *et al.* (2010) recorded that false smut of rice causes a losses of up to 44% in Punjab. Upadhyay and Singh (2013) also recorded that yield losses due to pathogen in many areas ranges from 1 to 75%. Several workers reported that in India the percentage of infected tiller ranges from 5 to 85 per cent, which result in yield loss of 0.2 - 49 per cent depending of rice cultivar and disease severity (Dodan and Singh, 1996; Kumari and Kumar, 2015; Ladhalakshmi *et al*., 2012). Tokpah *et al*. (2017) in their study reported that RFS (Rice False Smut) disease induced infertility in infected spikelets, reduce rice grain weight and responsible for up to 75 per cent yield loss.

The pathogen

Cooke (1878) gave the first binomial name to the causative agent responsible for false smut of rice as *Ustilago virens*, but the taxonomic position of the pathogen has remained uncertain. Patouillard (1887) after studying the sample from Japan named it as *Ustilaginoidea oryzae* based on the imperfect stage and by characterization of conidial stage. Takahashi (1896) merged the pathogen name *Ustilaginoidea oryzae* and *Ustilago virens* based on their identical nature and named as *Ustilaginoidea virens*. Sakurai (1934) reported that false smut rice balls have sclerotia which are horse-shoe shaped, oblong or flat. Hashioka (1971) named *Claviceps oryzae-sativa* as the telemorphic stage of rice false smut pathogen. Bischoff *et al*. (2004) in a phylogenetic study of *Ustilaginoidea* reported that *Ustilaginoidea* is not showing affinity towards *Claviceps.* Tanaka with his co-worker (2008) renamed the teleomorphic stage as *Villosiclava virens*. Presently *U. virens* has been placed in kingdom: Fungi, phylum: Ascomycota, class: Sordariomycetes, order: Hypocreales, family*:* Incertae sedis genus: Ustilaginoidea, Species: virens (Tanaka *et al.,* 2008). The genus *U. virens* Cooke has been reported to be sporadic with in the rice crop causing smut balls on rice panicle by various workers (Nessa *et al*., 2015; Ashizawa *et al*., 2012). However, Baite and Sharma (2015) isolated the fungus from the infected spikelet of the rice plant on different cultural media such as potato dextrose agar (PDA), rice yeast dextrose agar (RYDA) and potato sucrose agar (PSA) but growth of fungus was obtained on PSA medium. Growth was creamy-white and colony attained a diameter of 40 mm after 30 days of incubation at 27°C and pH 6. Fungus growth texture was flat or raised with minor undulations and mycelium appeared fluffy, compact and leathery. The pathogen was found to be sensitive to light and the growth of colony reduced in the presence of light as compared to darkness. Ladhalakshmi *et al*. (2012) also reported that the growth of *U. virens* on PDA was slower and the fungus formed a tiny white colony after 7 days of inoculation. After 15 days the mycelium of the fungus changes from white to yellow chlamydospores, which were yellow initially, changes to olive green. The chlamydospores of the fungus are round to elliptical and size of 3-5 um in diameter (Kim and Park 2007). Ladhalakshmi *et al*. (2012) recorded that chlamydospores germinated by short germ tubes and produced conidiophores, which has large number of conidia at the apex. These conidia are small and ovoid in shape and responsible for fresh infection. Fan *et al*. (2016) reported that at low temperature false smut pathogen induced sclerotium formation. These sclerotia are black, horse shoe-shaped and irregular oblong as flat of 2 to 20 mm length. Yong *et al*. (2018) reported that sclerotia germinates under favourable environmental conditions and produces yellow mycelium that formed fruiting bodies. These fruiting bodies develop stromata full of perithecia in which large amount of ascospores are produced and these ascospores may act as primary source of infection. Fan *et al*. (2014) observed that both ascospores and chlamydospores of the fungus produced conidia. These conidia can also infect the roots and coleoptiles of rice seedling stage. It has been also reported that sclerotium and chlamydospore can survive for 10 months in the soil or crop debris (Wang, 1995). Therefore both act as primary source of inoculum for infecting new crop.

Host range

False smut of rice pathogen has wide host range. The pathogen survive as alternate host on barnyard grass (*Echinochloa crusgalli*), Cogan grass (*Imperata cylindrical*) and common rice weed (*Digitaria marginata*) (Shan *et al*., 2013). Shetty and Shetty (1987) also reported two common weeds of rice *Panicum trypheron* and *Digitaria marginata* which act as the alternative hosts of false smut of rice in India. In addition to rice crop *U. virens* has been found to be pathogenic on corn and other weeds displaying similar symptoms (Atai, 2004).

Disease cycle

The fungus *U. virens* completes both sexual (Sclerotia) and asexual (Chlamydospore) stages of life cycle (Gupta *et al*., 2019). It has been reported that pathogen first infect coleoptiles and seedlings of the rice plant but these infection do not spread to the spikelets and does not show similar symptoms of the RFS (Zheng *et al*., 2009). During sexual life cycle, sclerotia are the main source of primary inoculum. These sclerotia after completing dormancy period of 2-5 months germinate (Wang, 1995), which after germination produces millions of ascospores. These ascospores produce conidia and hyphae of conidia which may infect panicle of rice plant at booting stage and spread over the surface of spikelets (Ashizawa *et al*., 2012). During asexual stage chlamydospore is responsible for secondary infection and germinates in soil and produces secondary conidia which results in secondary infection through wind and rain (Huang *et al*., 2019).

Epidemiology

The pathogenesis and epidemiology of rice false smut is influenced by some important and critical aspects such as host plant, pathogen and its structure and environmental conditions. Weather plays an important role in determining the course and intensity of disease epidemic. Wang *et al*. (2005b) reported that the disease level will be high if temperature is in between 22°C-28°C, rainy and humid climate coinciding with rice booting stage. Atia (2004) also observed that high RH (>90%) with temperature between 25-30°C and rainy days at the time of flowering are congenial for RFS infection. Wang (1988) observed that high moisture with warm temperature of 26°C can break the dormancy of chlamydospores which inturn helps in germination. Saha (2019) reported in a predication model that when spore inoculum load over rice canopy increases by one unit can results in 0.981 unit increase in disease severity. Bhargava and co-workers (2018) found that maximum disease incidence and severity were recorded at temperature between 24-32°C, relative humidity 74-88%, rainfall 6.66-6.67 mm and sunshine hrs 6.20-6.29 in many varieties. Chaudhari *et al*. (2019) reported that maximum and average temperature, morning and average relative humidity, morning and average cloudy and sunshine hours were found to be responsible for disease severity.

Integrated disease management

The crop yield loss by false smut of rice can be minimized through adapting certain cultural practices, biological control, host resistance, nutrition, bio-pesticides and use of chemical fungicides.

Cultural control

Early sown crop has less disease incidence or severity than late sown crop. Sanne (1980) also reported that false smut can be avoided by early sowing. While some workers reported that disease incidence level will be high if crop is transplanted earlier (Dodan and Singh, 1996; Chhottaray, 1991). Several workers also found that if crop is transplanted closely and enormously irrigated, it can increase the incidence of RFS and also water-logging at late stage of rice crop will lead to high humidity and results in high occurrence of disease (Wang *et al*. 2010; Yang, 2007). Zhou *et al*. 2010 reported that the occurrence of RFS is more in the old disease areas due to the inoculum of previous year infected crop. Kumar *et al*. (2018) found that furrow irrigated rice cultivation system recorded low disease severity compared to flooded rice field. It is due to the reduction of the survival period of chlamydospores in soil.

Biological control

Biological control is an eco-friendly tool to manage plant diseases and successfully used by many workers in their research studies. Kannahi *et al*. (2016) studied the disease control potential of 9 isolates of *Trichoderma viride*, *Trichoderma virens*, *Trichoderma harzianum* and *Trichoderma reesei* that were isolated from the rhizosphere of rice crop and found that all the isolates have antagonistic properties against the fungal pathogen. Liang *et al*. (2014) reported that if wenquning a combi-product of *Bacillus subtilis* (BS-916) and validamycin 2.5% is used against the causal organism, it may provide >90% reduction in disease with one spray at the late booting stage of rice crop. Andargie *et al*. (2017) in their *in vitro* and *in vivo* study found first time that plant extract potential in reducing the negative effect of Rice false smut. Raji *et al.* (2016) studied different plant extract such as bulb extract of garlic (*Allium sativum*), bael (Aeglemarmelos), leaf extract of lantana (*Lantana camara*), extract of turmeric (*Curcuma longa),* Lemon grass (*Cymbopogan flexuous*), cinnamon (*Cinnamomum zeylanicum*) and palmarosa (*Cymbopogan martini*) under *in vitro* conditions against *U. virens* and found that these extract have completely inhibited the growth of pathogen.

Nutrition

Type of fertilizers, dosage and time of application have significant effect on incidence and severity of the rice false smut. Several workers observed that if nitrogen fertilizers applied late in the season, the incidence of RFS was high (Bhardwaj, 1990). Rani *et al*. (2015) reported that incidence of RFS infected panicles and number of balls/plant were increased with increase in the level of nitrogen and disease severity was maximum at 100 kg of nitrogen dosage in tested cultivar.

Host plant resisitance

Host plant resistance is the most effective, low-cost and environmental friendly mechanism for disease management. Singh and Singh (2005) evaluated 27 rice genotypes from 98 rice germplasn which are resistant to false smut pathogen. Kaur *et al*. (2015) identified nine varieties VNR-211, GK-5025, HRI-140, IRH-74, PRSH-9018, KPH-467, RH-10488, 27P64 and KR4-4 that are completely resistant to rice false smut disease. Chaudhari *et al*. (2019) evaluated eighteen varieties against the pathogen and found that seven *viz*. GNR-2, GNR-3, GNR-5, GNRH-1, Mahirajan, NAVR-1 and Dandi were found completely resistant to the pathogen.

Chemical control

Use of chemical can be effective method of disease control but it may not be economical and environmental friendly. Dodan and Singh (1997) found that copper oxychloride and copper hydroxide are highly effective in managing the disease. Application of propiconazole 25EC (0.1%) and copper oxychloride 50WP (0.3%) were found most effective (Bagga and Kaur, 2006). Combination of azoxystrobin and difenconazole spray was effective and reduced disease upto the 94% (Maniraju *et al*. 2017). Raji *et al*. (2016) found that propiconazole 25 EC (0.1%) treatment resulted in lowest disease severity than other fungicides followed by trifloxistrobin and tebuconazole 75 WG combination when applied at 50% panicle emergence. Barnwal *et al*. (2010) found that application of propiconazole and hexaconazole were effective in managing the disease.

CONCLUSION

Rice false smut is favoured by medium temperature, rainy days and high humid conditions. The major factor behind RFS outbreaks are wide host range, presence of large amount of disease inoculum in soil, lack of awareness and approach to best control strategies. The common practice used by the farmer for the eradication was by applying chemicals, which if not used at proper time with care, has negative impact on plant health. The prolonged use of fungicide leads to its resistance to the fungus as well as soil pollution. A more integrated approach for RFS control in rice, with less dependency on chemical fungicides, is to make use of natural bio-products such as *Allium sativum* and *Curcuma longa etc*. and biological control agents such as *Trichoderma asperellum* and *Trichoderma harzianum* etc. Further, application of fungicides with biological control agents at proper time such as at booting stage to inhibit *U. virens* infection will strengthen the strategies for RFS management. The main cause of RFS outbreak is considered due to excess use of nitrogenous fertilizers, use of susceptible crop variety, performing early transplanting with less spacing between plants. The excellent alternate to reduce the impact of infection or restrict fresh infection is by adopting proper spacing, using non-host crops while performing crop-rotation. Disease including RFS need to be studied extensively by including basic as well as advance research depending on changing climate scenario. Research outcomes and recommendations should reach the stakeholders through publications as well as by other dissemination strategies by including government and non-government (NGO) agencies. Creating awareness on RFS disease and its management helps the farmers to adopt latest technologies, cultural methodologies, resistant/ tolerant crop varieties and efficient bio-control agents to reduce such infection. Implementing need based application of fungicide and prediction system can improve the RFS infection rate to a great extend.

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