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False smut: A potential threat to paddy cultivation in India

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Abstract
False smut of rice caused by *Ustilaginoidea virens* (Cooke), has become increasing concern in majority of rice growing areas around the world as epidemics have been reported lately. The fungus infects the plants during boot leaf stage and the symptoms are apparent only at grain formation stage converting the grains into spore balls and makes them unfit for consumption and seed production. With the increase in disease incidence and severity, yield losses have been increasing significantly. Heavy application of nitrogenous fertilizers, mono cropping of susceptible rice varieties are aggravating the repeated occurrence of the disease. It calls for emphasis on development of novel disease management strategies to contain the spread of this disease. This review summarizes the present status of the disease, biology and spread of the pathogen and various management strategies of false smut in rice.

Keywords: *Ustilaginoidea virens*, False smut, *Oryza sativa*, IDM

Introduction
Rice (*Oriza sativa* L.) is the most important staple food for more than half of theworld's population. It forms the major dietary energy form of food and it covers more than 9% of earth's arable land. It contributes 21% of global per capita energy and 15% of global per capita protein (FAO, 2016) [22]. India is the second largest producer of rice after China with an area of 43.86 million ha, production of 104.80 million tonnes and productivity of 2390 kg/ha (Status paper – Rice, 2016)
Losses due to rice diseases worldwide are enormous, varying fromcountry to country and from region to region, and are usually underestimated (Ou, 1985) [35]. Most of the reported rice diseases are caused by fungal pathogens (Awoderu, 1984) [9]. They include the two most important diseases of rice, rice blast (*Pyricularia orizae* Cav.) and brown spot (*Cochliobolus miyabeanus* (Ito and Kuribayash) Drschler ex Dastur). False smut of rice (*Ustilaginoidea virens* (Cooke) Tak.) has been regarded as minor in importance globally and not warranting any special method of control (PANS, 1974; Ou, 1985) [37, 35]. However, there have been several reports of severe incidence of false smut in Africa and Asia (Reinging, 1918; Seth, 1945; Awoderu, 1969, 1974; Awoderu and Onuorah, 1974; Adeoti, 1987; Baruah *et al*., 1992; Singh *et al*., 1992; Dodan *et al*., 1996) [40, 42, 10, 1, 13, 44]. False smut occurrence and severity was reported to be location specific (Awoderu and Onuorah, 19740) [10].
In India, *Ustilaginoidea virens* (Cooke) Takahashi, was first reported in Tirunelveli district of Tamil Nadu (Cooke, 1878) [18]. It was previously regarded as minor sporadic disease, and now it is one of the most devastating diseases in rice (Ladhalakshmi *et al*., 2012) [29]. Singh and Pophaly (2010) [43] reported false smut epidemics in different parts of country. This review provides the insight into systematics, biology of the pathogen and management options of the dreaded paddy disease.

Extent of occurrence and damage potential
False smut incidence on paddy ranges from 5- 85% and yield loss of 0.2% to 49% has been reported depending upon the rice variety and disease intensity (Ladhalakshmi *et al*., 2012; Kumari and Kumar, 2015; Pandey *et al*., 2017) [29, 28, 36]. The disease causes reduction in the quality and quantity of rice grains and also affects the germination vigour of the infected seedlings (Sanghera *et al*., 2012) [41]. Pathogen on infected grains produces antimitotic cyclic peptides, ustiloxin from its chlamydospores, poisonous to both humans and animals (Nakamura *et al*., 1994; Koiso *et al*., 1994) [34, 27]. Heavy application of nitrogenous fertilizer to high fertilizer responsive cultivars and hybrids increased disease incidence and increase in phosphorus application results in decreased disease incidence (Mohiddin *et al*., 2012; Zhang *et al*., 2014) [32, 31]. The symptom appears only after flowering, by then the fungus infects the individual grains of the panicle (Atia, 2004) [7].

The pathogen

The first false smut fungus, *Ustilago virens* was identified by Cooke (1878) [18] in India. The similar fungus was named as *Tilletia oryzae* in Japan (Patouillard, 1887) [38] and the name was changed from *Tilletia oryzae* to *Ustilaginoidea oryzae* based on the conidial stage (Brefeld, 1895) [15]. Tanaka *et al*. (2008) [15] suggested the *Villosiclava virens* as teleomorph of *U. virens*. characteristics by proving that *Tilletia oryzae* belonged tothe fungi imperfecti, and not to the basidiomycete family Ustilagineae associated with Hypocreales. *Ustilaginoidea oryzae* was combined with *Ustilago virens* as they were identical as pointed out by Takahashi (1896) [46] and named as *Ustilaginoidea virens*, based on priority of epithet. *Ustilaginoidea virens*, is the anamorph form of the pathogen (Kingdom Fungi; Phylum Ascomycota; Class Ascomycetes; Subclass Incertae sedis; Order Incertae sedis; Family Incertae sedis; Genus Ustilaginoidea). The teleomorph form is *Villosiclava virens* (Kingdom Fungi; Phylum Ascomycota; Class Ascomycetes; Subclass Sordariomycetes; Order Hypocreales; Family Clavicipitaceae; Genus Villosiclava) (Fan *et al*., 2016) [21].

Ustilaginoidea virens, infects rice at the time of panicle development and the symptoms are visible only after flowering, by then the whole spikelet is covered by the fungus. The individual grains will be converted into yellowish smut ball then changes to yellowish orange to green, olive green and greenish black on maturity. Powdery dark green spores are released when smut balls burst open, Sclerotia are often formed on the false smut balls in autumn (Biswas, 2001; Atia, 2004; Fan *et al*., 2016) [14, 7, 21]. Both chlamydospores and sclerotia serve as primary sources of infection and rainfall at the rice booting stage is a major environmental factor resulting in epidemics of rice false smut disease (Fan *et al*., 2016) [21]. The pathogen also survives on weeds like *Digitaria marginata*, *Panicum trypheron*, *Echinochloa crus-galli* and *Imperata cylindrica*. However, the occurrence of infection in these potential alternative hosts is very rare (Fan *et al*., 2016) [21].

Detection and Identification

Morphologically, rice false smut ball is covered with chlamydospores, which are round to elliptical and measure from 3 to 5 µm in diameter and the surface of chlamydospores is covered with irregularly curved spines of length 200–500 nm (Kim and Park, 2007) [26]. The mature false smut ball sometimes produces sclerotia, which are black, horseshoe-shaped and irregular oblong or flat, and measure from 2 to 20 mm in length. The SEM images show the outer sclerotial wall as rough and the interior of sclerotia intertwined with compact hyphae (Fu *et al*., 2012) [23].

At the molecular level, *Ustilaginoidea virens* specific primers and corresponding nested primers have been designed based on the rDNA internal transcribed spacers (ITS1 and ITS2) and the 5.8S rRNA gene (Zhou *et al*., 2003) [53] and successfully applied for the detection of Vv in various tissues of rice, facilitating the early prediction of false smut disease in fields (Zhou *et al*., 2006) [54]. Presence of the pathogen before heading was recorded with nested PCR (Ashizawa and Kataoka, 2005) [4]. Various other novel techniques have been reported to detect the presence of U. virens in soil, rice and air samples (Ashizawa *et al*., 2010; Li H. *et al*., 2013; Zheng *et al*., 2012) [6, 30, 51].

Management of false smut disease

In recent years, false smut has become a severe threat to rice cultivation and in order to minimize direct economic loss to farmers, suitable management practices have to be devised. Conservation tillage, continuous rice cropping and moderate nitrogen fertility rates reduced false smut disease in susceptible cultivars (Brooks *et al*., 2009) [16]. The farming community has relied on fungicides for control of this disease. Various fungicides such as copper oxychloride, cuproxat, simeconazole, tebuconazole, copper hydroxide, difenoconazole and hexaconazole have beenreported for the control over 70% of rice false smut disease (Tasuda *et al*., 2006; Gao *et al*.,2010; Zhou and Wang, 2011; Liang *et al*., 2014; Tripathi *et al*., 2014) [2, 48, 24, 52, 31, 49]. The time of application of fungicides are alsoimportant to control the disease. Ashizawa *et al*. (2012) [5] reported the infection of *U. virens* from booting to flowering stage. Bagga and Kaur (2006) [11] evaluated and reported fujione40 EC (0.1, 0.2 and 0.3%) and bavistin 50 WP (0.1%) showed significant reduction in false smut incidence whenapplied at the boot leaf stage. Tasuda *et al*. (2006) [48] recommended application of simeconazole3 weeks before rice heading against rice false smut disease. Spray of propiconazole for controlling the rice false smutwas highly recommended (Barnwal *et al*., 2010; Chen *et al*., 2013) [12, 17].

Biological control of plant pathogens has many advantages *viz*., Decrease in disease intensity leading to higher production, reduction in the use of fungicides, environmental safety, non-hazardous to human beings and fits as a best option in rice integrated disease management (Mukherjee and Maheswari, 2017) [33]. Many authors have reported efficacy of biocontrol agents against false smut of paddy (El-Naggar *et al*., 2015; Kannahi *et al*., 2016; Andargie *et al*., 2017) [20, 25, 3]. Apart from bio-control agents, efficacy of plant products and oils in the management of false smut of rice was variously discussed (Raji *et al*., 2016) [39].

Conclusion

Increase in the incidence of false smut of paddy is particularly alarming for scientific community to search for novel techniques to contain the pathogen. The pathogen is an Ascomycete, infecting the paddy crop at boot leaf stage but, the symptoms are apparent only on grain formation stage. It converts entire grain in to single spore mass making it unfit for consumption and for seeding. The pathogen survives as chlamydospores and sclerotial bodies in soil and heavy rains spread them in the field. *Ustilaginoidea virens* has potential to create epidemics which are lately reported. Various early detection techniques have been reported to facilitate forecast prophylactic sprays to contain the disease. Of all the management practices, fungicidal sprays are in vogue particularly, Triazoles group which are successful in containing the fungus if sprayed at boot leaf stage and panicle emergence stages. Alternative, ecologically safe management practices like, search for bio-agents, systemic plant resistance boosters and resistant varieties have to be devised to manage such a fast spreading disease.

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