AN OVERVIEW ON STEM RUST OF WHEAT AND ITS MANAGEMENT: A REVIEW

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ABSTRACT

Biotic stresses are the conspicuous inhibitions for realizing the attainable productivity in all the crops including wheat. Among these, rusts are extremely devastating pathogens of wheat occurring worldwide. It is potentially most dreadful if the varieties are susceptible and conditions are favourable for their development. Besides, its windborne movements of uredosporesare providing more feasible in build-up of epidemic in most of the susceptible wheat varieties and wheat growing areas. In central India, stem rust of wheat has historically been one of the major constraints in realizing stabilized yield of durum wheat. Thus, broadening of resistance base through exploitation of genetically diverse resistance sources are necessary for enhancing the durability of resistance to stem rust of wheat in context with the continued evolution of pathogen especially in the pretext of the changing climatic scenario. In this review, we will be discussing an overview on importance of stem rust along with their management strategies for attaining sustainable production of wheat.

KEY WORDS: Management, stem rust, wheat

INTRODUCTION

Stem rust, also known as black rust, is the most feared disease in various parts of the world due to its rapid spread at critical stages of wheat grain production (Singh *et al*., 2006). The estimates of actual losses in the yield received attention only in the 20th century due to a better understanding of disease biology and an increasing need to justify economically the financial investment in disease management programs. Roelfs (1978) compiled an overview of losses due to the cereal rusts in the United States of America from 1918 to 1976, reporting that yield reductions of 50 per cent in epidemic years due to stem rust and leaf rust. Green and Campbell (1979) also estimated that resistant wheat cultivars grown in predisposed areas of Canada provided protection valued at $C217 million annually. Severe epidemics have been recorded since the early 1800s in India (Joshi, 1976). Yield losses due to stem rust ranged from 9 per cent to 33 per cent in Scandinavia in 1951 and from 5 per cent to 20 per cent in Eastern and Central Europe in 1932 (Zadoks, 1961). In Australia, its epidemics have occurred sporadically and mainly in the warmer areas of Queensland and northern New South Wales (Rees, 1972; Watson, 1981). In China, stem rust occurs mostly in the spring wheat growing area of northern China and Inner Mongolia, and severe epidemics were reported in 1948, 1951, 1952 and 1956 (Roelfs, 1977). In the USA, it was a problem mainly for spring wheat production in the northern Great Plains, but severe epidemics occurred occasionally in southern states in winter wheat (Leonard, 2001).

In India, the Central and Peninsular southern part where the warmer temperature prevails in growing season are prone to stem rust, but has not in the wheat belt of Nothern Hill Zone and Northern Pain Zone (Joshi and Palmer, 1973). Different estimates have been published about the losses caused due to wheat rusts in India from time to time. Butler and Hayman (1906) valued the annual loss in wheat from rusts at Rs. 40 million. Ghokhale *et al.* (1950) opined that crop loss due to black rust in 1947-48 was of the value of about Rs. 50 million. Mehta (1952) reported a total loss of about Rs. 60 million annually in wheat and barley. According to Prasada (1960), nearly one million tonnes of wheat costing about Rs.392 million damaged during 1958-59.

Besides, the favorable environment for stem rust development leading to epidemic build-up exists in most of the wheat growing areas. In this situation, an alarming threat has emerged with the detection of the highly virulent race of stem rust Ug99, designated as TTKSK using North American nomenclature (Jin *et al.*, 2007) and in Uganda in 1999 (Pretorius *et al.*, 2000). Seven races belonging to the Ug99 lineage are now known (Singh *et al.*, 2008; Hodson, 2010). The primary threat from Ug99 is the susceptibility of about 90 per cent of the world's commercial wheat crop and breeding materials in the pipeline. It has now spread from eastern to southern Africa, to Kenya, Ethiopia, Zimbabwe, South Africa, Sudan, Yemen, Iran, etc. (Singh *et al.*, 2011), and Tanzania (Hale *et al.*, 2013). Its ability to overcome many additional important resistance genes like *Sr31*, *Sr24* and *Sr36*, poses a new threat to global wheat production. Further, its wind borne movement of uredospores to various wheat growing regions are prominent, as the majority of varieties in the migration path could be found to be susceptible.

So, large numbers of wheat farming families will be seriously affected, particularly in the developing countries, and ultimately it will affect global wheat markets. Therefore, details studies regarding the pathogen and its biology along with its epidemiological factors could be useful for the proper management of stem rust of wheat.

Pathogen

Stem or black rust of wheat, caused by *Puccinia graminis* f.sp. *tritici* Eriks. and E. Henn. belongs to family *Pucciniaceae*, order *Uredinales*, and class *Basidiomycetes* of *Basidiomycotina*. The first known detailed study including precise drawings of *P. graminis* was made in 1767 (Fontana, 1932). Later, the fungus named as *Aecidium berberidis* on barberry in 1791 and *Puccinia graminis* on wheat in 1794 (Persoon, 1801). De Bary (1866) showed that two fungi were different stages of a single species. Craigie (1927) made the first controlled cross between strains of *P. graminis*. Wheat stem rust pathogen is a biotroph and therefore, needs living wheat plants or other secondary hosts for survival in the absence of alternate hosts. The fungus is heteroecious in nature, alternating with a telial host in *Poaceae* and an aecial host in *Berberidaceae*, and macrocyclic producing five types of spore (Figure 2).

The fungus has five distinct stages: the pycnial and aecial stages occur on common barberry (the alternate host), and the uredial and telial stages occur on wheat. Basidia arise from teliospores and basidiospores infect barberry. Urediospores are orange-red, spiny and oblong measuring 25-30 x 17-20 µm with four median germ pores. The brown-black, two- celled teliospores measuring 40-50 x 15-20 µm have a terminal cell with pointed at the top. On germination of teliospores, a four celled promycelium (basidium) is produced and each cell gives rise to a sterigma which bears basidiospores. Pycnia are flask shaped and consist of pycniospores/spermatia and receptive hyphae. Aecia are cup shaped, enclosed by a peridium. Aeciospores are borne in chains from the base of the aecial cup, are echinulated, each have six germpores (Figure 2).

Symptoms

Stem rust occurs mainly on stems but can also be found on leaves, sheaths, glumes and awns. Initial symptoms appear as oval to elongate lesions with reddish-brown in colour. Stem rust pustules on leaves develop mostly on the dorsal side, but may penetrate and make limited sporulation on the frontal side. The initial macroscopic symptom is typically a small chlorotic fleck, which appears a few days after infection (Figure 1). As infected plants mature, uredinia change into telia, altering colour from red to dark brown to black, hence the disease is also called as black rust. Teliospores are attached tightly to plant tissue. The pathogen on the alternate host barberry produces basidiospores with raised yellow-orange lesions on leaves, petioles, blossoms and fruits (Singh *et al*., 2012). Severe infection of stems interrupts nutrient flow to the developing heads, resulting in shrivelled grains, and stems weakened by rust infection are prone to lodging (Roelfs *et al.,* 1992).

Disease cycle

Rust fungi have complex life cycles, which require two specifically different host plants, the economic host as wheat and primary alternate host as barberry (*Berberis vulgaris*), for the completion of its life cycle. The life cycle of the stem rust starts by the introduction of either aeciospores or urediniospores to a wheat plant. Epidemics developed rapidly because of uredospores produced on wheat which can cause auto-infection. This spore stage of the life cycle is known as the repeating stage. After that resting spore, teliospores with diploid nucleus, which over-winter on plant refuse and soil, undergoes meiosis and germinates into four celled promycelium, each cell bearing a single-celled globosebasidiospore, on short sterigma. The basidiospores are released forcefully and carried by wind for a few hundred meters and infect on newly developing barberry leaves producing very small pycnial pustules on the upper leaf surface of barberry. Pycnia arise by rupturing the epidermis within 3-4 days. Minute pycniospores then fertilize receptive hyphae in pycnia of the opposite mating type developing into aecia (cluster cups) on the underside of the barberry leaf as shown in Figure 2. Aeciospores produced on barberry plants infect wheat, but basidiospores which are produced on barberry itself lead to infection in barberry plants. Then, urediospores are produced which leads to broke the epidermis irregularly revealing several hundred to thousands of urediospores and easily get blown away to variable distances to thousands of kilometers to cause secondary infection in the season.

But under Indian conditions, there are no roles of barberry as alternate host in the completion of its life cycle, since in southern part of India, in Nilgiri Hills the susceptible hosts remains round the year, where environmental conditions favour pathogen survival and from where urediniospores are blown to other parts of India with cyclonic winds and completes its dissemination (Mehta 1940; Nagarajan and Joshi, 1985). Many collateral hosts such as *Aegilops squarrosa, A. ventricosa, A. trinecilis, Bromus carinatus, B. coloratus, B. Japonicas, B. mollis, B. patulus, Hilaria jamesii, Hordeum distichum, H. murinum, H. stenostachys, Lolium perenne* and summer sown wheat in higher hills, self-sown and volunteer plants of wheat etc. can serve as offseason hosts in the annual perpetuation of the black rust fungus.

Epidemiology

Crop losses unavoidably reflect the interplay between pathogen, host and environment at local, regional and global levels. Epidemiological studies of rusts of wheat were first taken up in India by K.C. Mehta, who showed that due to intense summer heat the inoculums of rusts in any form were completely destroyed in the plains during the summer months. But the rust survives in the hills of North and South India. Recent work has identified different foci of infection and has shown that the primary source of stem rust lies mainly in the South Indian hills. Moreover, it has been shown that the cyclones in the Bay of Bengal play a very vital role in dissemination of stem and leaf rusts from Nilgiri and Pulney hills. The ground survey data and information collected

through rain sampler, satellite television cloud photography etc. was being utilized for developing bioclimatic models and linear prediction equations (Joshi *et al.*, 1985). The disease monitoring system by mobile surveys supplemented with trap nurseries and weather satellites has provided useful information on epidemiology of wheat rusts and development of *Puccinia* path (Joshi *et al.*, 1971). On the other hand, stripe rust, comes mainly from the northern hills while leaf rust is contributed both by southern and northern hills.

The minimum, optimum and maximum temperatures for urediniospore germination are 2, 15-24 and 30°C, and for sporulation 5, 30 and 40°C (Roelfs *et al.*, 1992), thus, providing a vast range of favourable environmental conditions. Infections occur through stomata and urediniospores start germination within 1-3 h of contact with free moisture. In field conditions, 6-8 h of free moisture is required for completion of the infection process.

Stakman and Harrar (1957) reported that the incubation period of black rust can vary from 5 days to 3 months depending upon the prevailing temperature. Variations in temperature profile of southern and northern regions during crop season also appear to influence the incubation period of black rust. Joshi *et al.* (1985) reported that in Northern India, incubation period of the rust is longer. On the contrary, stem rust pathogen takes 8-10 days for sporulation in Nilgiris and the multiplication of inoculum is faster through repeated cycles of urediospores (Joshi, 1976).

Management

Genetic resistance means development of resistant varieties is the most common and effective means in order to combat the problem of wheat stem rust and also main target of the Indian wheat programme (Johnson, 1981; Sharma *et al.*, 2001). Information on genetics of wheat rust resistance is widely available (Sharma, 1990; Sawhney, 1994, Tomar and Menon, 2001; Nayar *et al.*, 2001). Resistance genes like *Sr*2, *Sr*5, *Sr*6, *Sr*7a, *Sr*7b, *Sr*8a, *Sr*8b, *Sr*9b, *Sr*9e, *Sr*11, *Sr*12, *Sr*13, *Sr*17, *Sr*21, *Sr*24, *Sr*30, *Sr31* have been characterized in Indian wheat material (Nagarajan *et al.*, 1987; Nayar *et al.*, 2001; Sawhney, 1994) and among them *Sr*26, *Sr*27, *Sr*31, *Sr*32, *Sr*33, *Sr*35, *Sr*39, *Sr*40 and *Sr*43 confer resistance against Indian population of *P. graminis tritici*. Identification and transfer of new sources of race-specific resistance from various wheat relatives are ongoing task to enhance the diversity of resistance to stem rust. Understanding effective resistance genes to stem rust and their characteristics in wheat cultivars is one of the most important promises for an effective application and distribution of the resistance source in the comprehensive control of stem rust of wheat (Cao *et al.*, 2007). Therefore, analyzing the genetic background for the presence of resistance genes in disease-resistant cultivars as well as in the main production cultivars, lines, germplasms, etc. can provide a great basis for exploring sources of resistance in the future (Han, 2009). Pyramiding of genes into a single genotype with the exploitation of reliable markers has been one of the preferred strategies in wheat rusts management and also may help in resistance breeding of wheat by resistance gene pyramiding for providing durable resistance. Breeding for durable resistance by pyramiding multiple resistance genes, both major and minor ones, were also reported to be an effective strategy in managing plant diseases (Singh *et al.,* 2001).

Gene postulation being an effective and fast method in order to assess information regarding resistance of multiple cultivars macroscopically, and widely used in the identification of resistance genes in wheat (Niu *et al.*, 2000; Yuan *et al.*, 2007; Cao *et al.*, 2010). But, the combined strategy i.e. resistance gene postulation joint with traceable pedigree along with additional validation by molecular markers and genetic analyses can improve the accuracy of resistance gene postulation against stem rust of wheat.

Gene deployment by strategic usage of resistance genes both race specific and adult plant resistance genes have been used against wheat rusts over a large area in order to reduce the threat of epidemics development. The delineation of different areas is based on the prevalence of different pathotypes in the different zones. Of course, it would be rational to use combinations of different genes to prevent evolution of a super race.

The fastest way to reduce the susceptibility of important wheat cultivars and the germplasms is to incorporate systematically diverse sources of resistance through limited or repeated backcrossing. Because most of these Ug99-effective genes are of alien origin, co-segregating with molecular markers can aid selection (Prins *et al.,* 2001; Mago *et al.,* 2005). In order to combat against the new strain Ug99, several stem rust resistant genes have been identified for imparting resistance. Some of them, like Sr2, Sr25 and Sr26, are already present in Indian wheat varieties, while a few others are available in Indian wheat germplasms and genetic stocks (Sharma *et al.,* 2015). Although 22 new Ug99-resistant varieties, *viz*. DBW17, PBW 550, Raj, Super that yield more than current popular varieties are being released and promoted in India, and also major efforts are required to displace current Ug99 susceptible varieties with varieties that have diverse race-specific or durable resistance to mitigate threat of Ug99 (Singh *et al.*, 2011).

Besides under the umbrella of the Borlaug Global Rust Initiative (BGRI), significant efforts have been made to counteract the challenges of Ug99 and its races. The most promising strategy has been to deploy spring wheat varieties possessing adult plant resistance (APR) in infested and bordering areas to decrease inoculums amount and slow down the development of new virulence (Sharma *et al.,* 2013).

Although the applications of fungicides like propiconazole, tebuconazole, azoxystrobin, hexaconazole, penconazole, tridemorph, difenoconazole, mancozeb, chlorothalonil were also effective in reducing the disease development of stem rust along with brown and yellow rust of wheat (Wanyera *et al.,* 2009; Macharia *et al*., 2013; Chaudhary and Chaudhari, 2013). It has been reported that these fungicides reduced subsequent disease progress on plant parts that were slightly infected at the time of fungicide application, but they were not effective on plant parts that has been already infected with severity responses (Beard *et al*., 2004; Tadesse *et al.,* 2009). Therefore, strategy for managing the stem rust should be through fungicide by considering the most important factor i.e. the time of onset and early detection of the disease, if economic control of the disease is anticipated (Roelfs, 1985; Beard *et al*., 2004). Thus, the adoption of effective fungicides to combat the stem rust pathogen as a short-term control strategy should be encouraged until resistant cultivars are developed (Wanyera *et al.*, 2009). However, relaying on chemical control is not feasible in environment point of view so more research are required in order to focus on the genetic control through development of resistant varieties which is an effective means to combat the problem of wheat stem rust.

CONCLUSION

Due to the evolution and spread of the highly virulent Ug99 group of races stem rust disease has once again become a threat to global food security. But, proper utilization of race specific resistance in combinations with focussing on breeding programme for developing resistant wheat varieties which have adult plant resistance might be able to mitigate from the new threat of Ug99. Thus, resistance breeding will benefit extremely and rapidly with molecular information through a rapid diagnosis of resistance genes as well as a rational combination of qualitative and quantitative resistance factors are likely to become realistic in the coming year. The basic objective should be to reduce the selection pressure of pathogen for its virulence. Exploration for new resistance genes from across the genera and species ought to be intensified. Thus, more research in the areas of both applied and basic research might able to receive high priority to combat the threats of stem rust of wheat.

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Fig.1: Symptoms of wheat stem rust

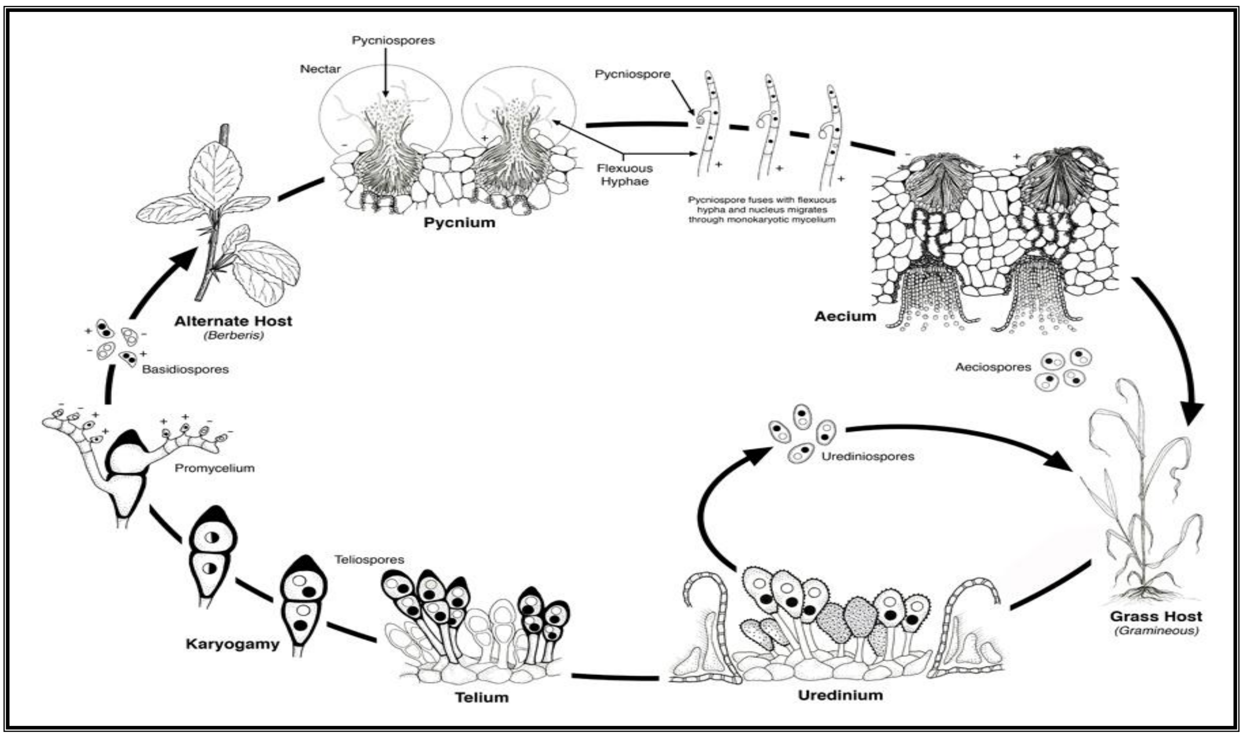

Fig. 2: Disease cycle of stem rust of wheat. (Courtesy of Jin et al., 2007)

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