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Stem rust (ug99), seen as a threat globally

Kara pas (ug99), küresel bir tehdit olarak görülmektedir

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ABSTRACT

Stem rust caused by *Puccinia graminis* f.sp. *tritici* (Eriks & Henn.) is one of the most devastating diseases of wheat. If favorable conditions for the pathogen appear, the pathogen may cause both epidemics and pandemics. Evolution of genes of the pathogen population gives rise to emerge of new races of the pathogen. The Ug99 is a good example. In 1998, severe stem rust infections were observed on wheat in Uganda, and a race, designated as Ug99, was detected. The same race was detected in Kenya and Ethiopia in 2005. Later, Ug99 was established in Yemen in 2006, in Iran in 2007, in Tanzania and South Africa in 2009. The new race of stem rust has been seen globally as a threat to wheat production because Ug99 has spreaded from Eastern Africa to Middle East and Asia. In addition, scientists predict spreading of the pathogen towards other areas of the world through prevailed air currents. The situation is worrying for areas where wheat is grown.

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ÖZ

Puccinia graminis f.sp. *tritici* (Eriks & Henn.)'nin neden olduğu kara pas, buğdayın en tahripkâr hastalıklarından birisidir. Eğer patojen için uygun şartlar olursa, patojen gerek epidemi ve gerekse pandemilere neden olabilmektedir. Her zaman patojen popülasyonunda genetik varyasyon ihtimali bulunmaktadır ki bu, patojenin yeni ırklarının ortaya çıkmasına yol açmaktadır. Bu durumun güzel bir örneği Ug99'dir. 1998 yılında, Uganda'da buğdaylarda şiddetli kara pas enfeksiyonları gözlenmiş, yapılan çalışmalarda patojenin yeni bir ırkı tespit edilmiş ve bu ırk Ug99 olarak isimlendirilmiştir. Ug99 ırkı, 2005 yılında Kenya ve Etiyopya'da tespit edilmiştir. Ug99, daha sonra sırasıyla 2006 yılında Yemen'de, 2007 yılında İran'da 2009 yılında Tanzanya ve Güney Afrika'da saptanmıştır. Kara pasın bu yeni ırkı dünyada buğday üretimi için bir tehdit olarak görülmektedir. Çünkü Ug99 Afrikadan Orta Doğu ve Asya'ya sıçramıştır. Bunun yanı sıra bilim adamları patojenin hakim rüzgarlar aracılığıyla dünyanın diğer alanlarına yayılacağını tahmin etmektedirler. Bu durum buğday yetiştirilen alanlar için endişe vericidir.

1. Introduction

In 2008, with total production of nearly 18 million tons, wheat is major crop grown in Turkey. Likewise, wheat is one of the most significant crops with total production 689 million tons worldwide in 2008 (FAO 2010). Wheat is also a major staple food crop in modern societies, providing 20% of the caloric intake globally (Porter et al. 2007). Rust diseases have been a major scourge of wheat since biblical times (Kislev 1982). The rusts (*Puccinia* spp.) have been a scourge on humankind since the beginning of historical time. Many epidemics have been recorded over the past 150 years, in the near and far east, Europe, and the America. Several devastating rust epidemics have resulted in major famines in Asia and grain losses at a massive scale in North America in 1903 and 1905 and 1950-54 (Borlaug 2005).

Roelfs et al. (1992) reported that stem rust is the most devastating rust disease and can cause losses of 50% in one month when conditions for its development are favorable. Losses of 100% can occur with susceptible cultivars. Leonard and Szabo (2005) stated that stem rust can cause severe yield losses in susceptible cultivars of wheat in environments favorable for disease development. The stem rusts have historically caused severe crop losses and continue to threaten production today (Kleinohfs et al. 2009).

Stem rust was effectively controlled worldwide for the past 50 yr by deployment of stem rust resistance (Sr) genes in wheat cultivars. However, a new stem rust race, TTKSK (known as Ug99 or TTKS) that emerged in Eastern Africa, is a concern because it has broad virulence to currently deployed Sr genes

(Xu et al. 2009).

The new race of stem rust has overcome the some resistant genes (Sr) and spreaded from Eastern Africa to Middle East and Asia. In addition these, scientists predict more spreading of Ug99 towards other part of the world through prevailed air current. Therefore, the situation is worrying. In this review, the stem rust (Ug99) was discussed from different aspects.

2. Stem Rust (Ug99)

Stem or black rust of wheat caused by the fungus *Puccinia graminis* f. sp. *tritici* Ericks and Henn. (Pgt) is an important disease of wheat worldwide. Pgt is an obligate biotroph, heterothallic in its life cycle and heterothallic in mating type (Alexopoulos et al. 1996). The obligate parasites are highly specialized and significant variation exists in the pathogen population for virulence to specif resistance genes. Evolution of new virulence through migration, mutation, recombination of existing virulence genes and their selection has been more frequent in rust fungi (Singh et al. 2008). It is known to bear many physiologic races generated mainly by mutation (Roelfs 1985). In 1998, severe stem rust infections were observed on wheat in Uganda, and a race, designated as Ug99 with virulence on sr31, was detected (Pretorius et al. 2000). Ug99 is a new race of stem rust.

3. Epidemics and Damages of Stem Rust

Many epidemics caused by the stem rust has seen in different part of the world in the past. In 1946-1947, a stem rust epidemic in central India caused losses estimated at nearly 2 million tons, or 20 percent of total wheat production (Joshi et al. 1986). And a severe epidemic of stem rust devastated wheat crops in many East European countries in 1932. The epidemic began in Bulgaria, and spread throughout eastern and northern Europe. Its impacts were most severe in Russia (Zadoks 2008). The losses from a stem rust epidemic in Sweden in 1951 were determined as a 20 % percent reduction in winter wheat and a 50 % percent reduction in spring wheat (Stakman and Harar 1957). In 1947-48, devastating stem rust epidemic caused approximately 30 % percent of the crop loss Bajio region (Mexico) (Rupert 1951). In the United States, stem rust disease was severe in spring wheat from 1920 to 1960 and caused yield losses of 20 % in average and up to 50 % in some fields in some years (Leonard 2001). The most significant epidemics caused by stem rust in Australia in the period up to the 1950s occurred in 1889, 1899, and 1947. Each of these epidemics was assessed as having a significant impact on wheat production and the welfare of wheat farmers. In 1973, a stem rust epidemic in southeastern Australia was rated as the most severe in the history of the Australian wheat industry (Park 2007). In addition these, Shank (1994) stated that a severe stem rust epidemic developed wheat fields in Bale and Arsi regions of Ethiopia in 1993-94.

The disease has been the most biotic constraint on wheat, causing yield loss ranging from 30 to 70 % on a susceptible variety (Ephrem et al. 2000). Pretorius et al. (2000) reported that ug99 could reduce wheat yield by up to 71 % and could spread and attack many varieties of spring and winter wheat genotypes which are resistant to other strains of the fungus.

4. Dispersal Modes of Stem Rust

Urediniospores of stem rust are relatively resistant to light

and temperatures at humidities of to 30 %. Wind frequently transports urediniospores 100 km in a viable condition and sometimes up to 2000 km (Luig 1985). It is postulated that they have even been transported 8000 km from East Africa to Australia (Watson and Sousa 1983). The enabling factor in this mode of dispersal for rusts is the robust nature of spores ensuring protection against environmental damage (Rotem et al. 1985).

5. Outbreak and Distribution of Ug99

Ug99 was firstly detected in Uganda in 1998 (Pretorius et al. 2000). Race Ug99 was subsequently detected in Kenya and Ethiopia in 2005 (Wanyera et al. 2006). In 2005, Ethiopian reports confirmed its presence in at least six dispersed locations. The East African highlands are known "hot-spot" for the evolution and survival of new rust races (Saari and Prescott 1985).

The confirmed range of Ug99 continues to expand, with new sites being recorded beyond the previously confirmed three East African countries Uganda, Kenya, and Ethiopia (Singh et al. 2008). Later, Ug99 was established in Yemen in 2006 (Jin et al. 2008), in Iran in 2007 (Nazari et al. 2009), in Tanzania in 2009 (FAO 2011) and in South Africa in 2009 (Pretorius et al. 2010), respectively.

The dispersal of Ug99 has been rapid through airflow. However, likely movement of Ug99, stepwise dispersal model following prevailing winds, was outlined by Singh et al. (2008) in Figure 1.

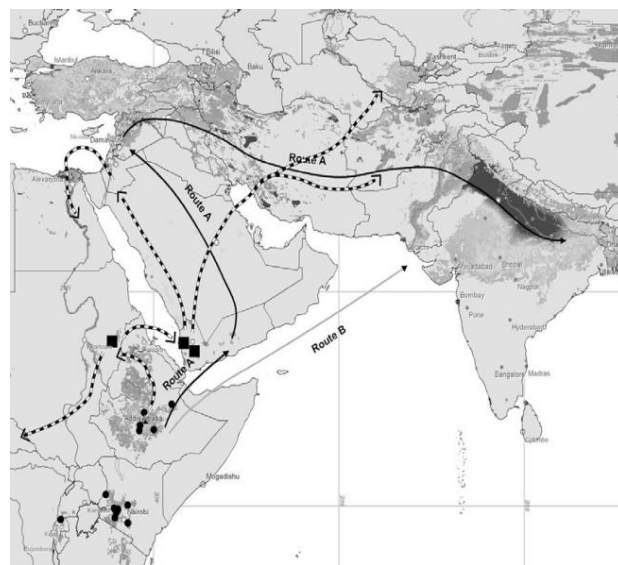


Figure 1. Updated potential migration routes of ug99 based on historical precedence and recent studies of actual wind movements (Singh et al. 2008).

6. Control of Stem Rust

Without a doubt a combination of cultural control practices with disease resistance and perhaps fungicide applications will be the most effective means o controlling the cereal rust diseases. Because of the airborne nature of the inoculum of the cereal rusts, quarantine measures against the pathogen only delay, and do not prevent entry of the disease and/or specific virulence combinations (Roelfs et al. 1992).

6.1. Cultural methods

Mexican farmers learned to sow early to avoid stem rust prior to the use of resistant cultivars (Borlaug 1954). Use of early maturing cultivars marked the initial success in controlling stem rust in Australia (McIntosh 1976). Beside these, Zadoks and Bouwman (1985) emphasized the importance of the green bridge in carrying the diseases from one crop to the next. The green bridge can be lengthen when some growers plant early and others late. Removing the green bridge with tillage or herbicides is an effective control measure for epidemics that would result from endogenous inoculum. In some areas volunteer plants must be controlled several times during the season when wheat is not grown.

Sexual stage of stem rust pathogen occurs on alternate hosts such as *Berberis vulgaris*, many species of *Berberis*, *Mahonia*, and *Mahoberberis* (Roelfs 1985). The sexual cycle of the pathogen produces a great genetic diversity, which means new races of stem rust pathogen virulent to resistant cultivars could arise (Roelfs and Groth 1980). The alternate host was a major source of new combinations of genes for virulence and aggressiveness in the pathogen (Groth and Roelfs 1982).

The barberry was the source of inoculum (aeciospores) early in the season. Generally, infected bushes were close to cereal fields of the previous season, so inoculum traveled short distances, without the loss in numbers and viability associated with long distance transport (Stakman 1923). In the United States, barberry eradication has significantly reduced the number of epidemics for many years. Since common barberry has been largely removed after the 1920s, barberry bushes have not been a major source of disease inoculum (Kolmer et al. 2007). Roelfs et al. (1992) also reported that primary inoculum for stem rust may originate locally (endemic) from volunteer plants.

Therefore, eliminating of alternate hosts and volunteer plants is very important to prevent new races of the pathogen from emerging and reduce inoculum sources.

6.2. Chemical control

Chemical control has been successfully used in Europe permitting high yields (6-7 t/ha) and where prices for wheat are supported (Stubbs and De Bruin 1970; Buchenauer 1982).

6.3. Genetic resistance

Majority of growers in developing countries like African countries can not afford to use fungicides against the disease. Besides this, negative effects of chemicals on environment are known. As a result of these, use of resistant cultivars against stem rust has become primary control practice of the disease. Therefore, many breeding efforts for development of resistant wheat germplasm to stem rust have been done in many countries. Johnson (1981) reported that the principle mechanism of control of the cereal rusts has been through the use of resistant cultivars.

Hence, use of resistant germplasms against Ug99 is crucial for stem rust management. Therefore, breeding for resistance to Ug99 and virulence of the pathogen were given in detailed below.

7. Virulence of Stem Rust (Ug99)

Occurrence of new races in a geographic/epidemiologic region can be attributed to three phenomena: 1) migration from

outside the region, 2) mutation and selection for a particular virulence, and 3) recombination; both sexual (on barberry) and asexual. The first two of these mechanisms are the most important (Borlaug 2005).

Amount of variation in the pathogen (*Puccinia graminis* f. sp. *graminis*) made breeding for resistance difficult, even made it impossible. Of the virulence combinations existing one year, many would not reoccur the following year, but many new ones would appear (Roelfs 1982).

Olson (2009) reported that within the classification of formae specialis of *Pgt* exists further subdivision of the pathogen at the level of physiologic race. The differentiation of races of *Pgt* follow observation based on the gene for gene concept of H.H. Flor (1955) demonstrated that the resistance gene in the host recognizes an avirulence target in the pathogen. The designation of the races within *Pgt* is determined by specificities of avirulence and virulence to a defined set of stem rust resistance genes present in a differential set of host cultivars (Roelfs 1988).

A new race of stem rust pathogen, Ug99, with virulence to resistance gene *Sr31*, was named TTKS based on the North American stem rust race nomenclature system (Wanyera et al. 2006; Jin et al. 2008). Development of a new race of *Pgt* in Eastern Africa and the subsequent development of novel virulence in subsequent races derived from the race designated as ug99 (TTKS) has prompted a proposal to add a fifth set of genes to the current nomenclature system. The original race TTKS has now been designated TTKSK based on the addition of a fifth set of differentials (Jin and Szabo 2008).

Ug99 arisen as a result of genetic variation of the pathogen (*Pgt*) and has continued to form new variants. The stem rust population is evolving rapidly. Another race, TTKST, with virulence to the widely used gene *Sr24* was detected in Kenya in 2006 (Jin et al. 2008). Only 1 year later yet another race, TTTSK, with virulence to gene *Sr36* was discovered in Kenya (Jin et al. 2009). Most wheat cultivars currently grown are susceptible to TTKS (Jin and Singh 2006; Singh et al. 2006). It is predicted that these races will migrate to North Africa, Middle East, Asia and beyond (Singh et al. 2008).

Emergence and spread of these new races of stem rust pose an imminent threat to wheat production worldwide and demand the rapid development of wheat cultivars with durable resistance to stem rust. The durability of effective resistance genes can be enhanced by deploying them as pyramids in cultivars (Singh et al. 2006).

8. Resistance/Susceptibility of Wheat Germplasm to Stem Rust (Ug99) and Breeding for Resistance

For several decades the historically enormous problem of wheat stem rust has been solved through the use of genetic resistance. In Eastern Africa, that resistance has now been overcome by a new physiological race of the disease designated as Ug99 (Borlaug 2005).

To date, about fifty stem rust resistance genes have been identified and some of them have been mapped on different chromosomes in wheat and its relatives (McIntosh et al. 1998). All these genes are race specific except *Sr2* that has provided durable non-race-specific slow-rusting adult plant resistance (McIntosh et al. 1995; Spielmeier et al. 2003; Singh et al. 2006; Singh et al. 2007). Among these resistance genes, some genes deployed in commercial cultivars worldwide remained

effective individually or in combination with other *Sr* genes until recently (Spielmeyer et al. 2003). Moreover, the *Sr2* complex in combination with other resistance genes showed effective protection against Ug99 (Singh et al. 2006). Resistance gene *Sr26* provides resistance to current stem rust races of wheat in Australia (McIntosh et al. 1995; Margo et al. 2005). Most deployed resistance genes are susceptible to Ug99 or overcome by virulence of Ug99 except few genes such as *Sr2*, *Sr1A/1R*, *Sr26*, and *SrTmp*. *Sr31* was identified to be defeated by a virulent isolate of Ug99 in 1999 (Das et al. 2006).

One of the most important *Sr* genes was *Sr31*, which was deployed worldwide in many cultivars (Singh et al. 2006). Another, very effective stem rust resistance gene is the *Sr36* (Purnhauser and Bóna 2009). In Hungary, both *Sr31* and especially the *Sr36* still provide an effective protection against stem rust infection (Csósz et al. 2001). However, new race of stem rust pathogen, Ug99 (TTKS), with virulence to *Sr31*, was detected in Uganda in 1999 (Pretorius et al. 2000), another race, TTTSK, with virulence to gene *Sr36* was discovered in Kenya (Jin et al. 2009). To determine the frequency of *Sr31* and the *Sr36* gene, among wheat cultivars registered in Hungary in the past 35 year's period, a study was carried out by Purnhauser and Bóna (2009). The results of this study indicated that both *Sr31* and *Sr36* genes had widely spread in wheat cultivars registered in Hungary in the last 35 year period (Purnhauser and Bóna 2009).

Seedlings of 41 emmer (*Triticum dicoccum*), 56 durum (*T. durum*) wheat accessions were tested for their response to stem rust (*P. graminis* f. sp. *tritici*) infection under greenhouse condition in Ethiopia. Eighteen emmer and 6 durum accessions were found to be good sources of resistance to stem rust infection (Beteselassie et al. 2006).

Jin and Singh (2006) compared seedling reactions of US wheat cultivars and germplasm with highly virulent races present in the USA and race Ug99. Several wheat lines, especially spring wheat that were highly resistant to US races and did not carry the 1BL.1RS translocation, were also found to be susceptible to Ug99. Kolmer et al. (2007) also reported that in seedling tests many hard red winter wheat cultivars, soft red winter wheat cultivars, and hard red spring wheat cultivars that are grown in the US are susceptible to this new race (TTKS).

The major cause of the ineffectiveness of wheat varieties against stem rust is the narrow genetic base on which the breeding for resistance has been founded. In areas where mono culture of wheat production it is not uncommon to see the existing gene(s) for resistance being ineffective due to occurrence of physiologic races with the new virulence characteristics (Alex et al. 1997). Due to a narrow genetic base and continuously evolving pathogen races, resistant varieties become susceptible to the disease when grown over vast areas (Assefa and Fehrman 2004). *Sr3* is considered one of the most highly effective genes against the new African race Ug99, also known as TTKS (Jin et al. 2007). Durable resistance to rusts and powdery mildew has been supported by minor genes such as *Lr34* for over 50 years (Krattinger et al. 2009). An approach in which major gene resistance, conferred by genes such as *Sr35*, is combined with minor gene resistance should be effective against the threat of Ug99 (Babiker et al. 2009).

Pyramiding of several genes into one cultivar can be an effective strategy to use these resistance genes to enhance durability of wheat resistance to stem rust (Leonard and Szabo 2005). Gene pyramiding using conventional method is difficult

and time-consuming. Therefore, marker-assisted selection (MAS) is a powerful alternative to facilitate new gene deployment and gene pyramiding for quick release of rust-resistant cultivars (Wu 2008).

9. Conclusions

Reynolds and Borlaug (2006) estimated that the potential area under the risk from Ug99 along the natural migration path in North Africa, Middle East and Asia (excluding China) might amount to 50 million ha of wheat, that is, about 25% of the world's wheat area and accounting for an estimated 19% of global production amounting to about 117 million tons. An estimated 1 billion people live within these wheat production areas.

With the aim of containing the threat of wheat rusts, Borlaug Global Rust Initiative (BGRI), was founded. Likewise, Rust Spore web portal, and RustMapper displaying current rust survey sites were established.

Ug99 is a serious threat to wheat production of the world particularly in developing countries. Because, wheat is a major crop and has a significant impact on economy of such countries. With emergence of new variants of stem rust, virulent to majority of the cultivars grown currently, is worrying due to rapid spreading of the pathogen towards new areas. Hence, All necessary precautions against Ug99 and new variants of the pathogen must be taken. Otherwise, many wheat production areas of the world could be encountered with epidemics. Besides this, the people living in those areas, whose livelihood is depend on wheat, can face with economic difficulties and famine.

For the part of Turkey, the situation is also concerning. However, Akan et al. (2010) reported that A total of 44 winter wheat genotypes in Turkey was sent to Kenya for testing for Ug99 in 2009. In these genotypes, 17 genotypes were determined as a resistant to Ug99. This knowledge is promising. In addition to such studies, much more studies must be conducted to protect wheat cultivars grown in Turkey from Ug99 and its new variants. Therefore, in the short term all the precautions should be taken by growing resistant cultivars and using fungicides, as for, in the long term, breeding for resistance to Ug99 and its variant must be prevailed.

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