Essay

Food safety: the fungus Ug99 a global threat to wheat crops

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Abstract

The present essay aims to investigate the state of the art in the matter of the fungus Ug99 considered by international organizations as one of the main threats to world food security. To this end, the importance of wheat supply and demand at an international level is estimated and the damage that could be caused by an outbreak of the fungus Ug99 is estimated. Likewise, the origins, evolution, geographic dispersion and classification of stem rust are analyzed to differentiate their types, breeds and danger of infection of the different genes contained in wheat. In this context, the most recent evidences of its presence and the strategies for its control and combat are documented. Finally, it is concluded that even Mexico is vulnerable in case of an epidemiological outbreak in North America caused by Ug99, both on the production and consumption side.

Keywords: black stem rust, food security, Ug99, wheat crops, yellow stem rust.

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Background

In the context of food safety, an article published by the German weekly Die Zeit, Kerstin Hoppenhaus (2017) warns of the danger posed by the resurgence of the fungus Ug99, also known as *Puccina graminis* or black stem rust for the cultivation of wheat at the world. According to Hoppenhaus (2017), in 2016 there were 760 million tons of wheat produced worldwide, and for 2017, it was estimated a fall to 740 million tons of wheat. Production has grown at an annual average of 2.2% passing from 230 million tons in 1961 to 760 million in 2016. The average production is 3-4 t ha^{-1}, but they are produced under favorable conditions up to 14 t ha^{-1}.

Wheat covers 19% of the calories of human beings in the form of bread, spaghetti, ciabatta, pasta, etc. Approximately 2.5 billion people living on less than two dollars a day (Naciones Unidas, 2015), depend on wheat as a staple food, so before a possible contraction of supply, they would have to face higher prices which would give rise to world food crisis. The potential for damage is estimated at 50 million hectares of wheat or 25% of the area destined for this crop worldwide with a contribution of 19% of the global production.

The worrying thing is that Singh *et al*. (2011) considered one of the most prestigious experts in the subject stated that in most of the regions in the world where wheat is grown, there are favorable conditions for an infection of stem rust, which is a danger of epidemiological outbreak. This situation, in addition to the fact that wheat varieties are susceptible to the spread of Ug99, as well as other related pathogens, means that we are facing the danger of a disaster in wheat production that could harm food security worldwide.

The present essay intends to elaborate an exploratory-descriptive analysis that starts from the following questions. What is the fungus Ug99? Where and when did it arise? What are its main characteristics and why is it thought that it can cause a global food security problem? To answer these questions, we have divided the writing into four sections. In the first, the background of the *Puccina graminis* is explained according to recent history and based on the achievements of the 1970 Nobel Peace Prize winner, Norman Borlaug.

The second section details the main characteristics, the types of fungus that exist and the most dangerous breeds, as well as the wheat genes that have been attacked by the fungus. In the third we will address the strategies that are applied to control or eradicate the Ug99 threat. In the fourth section we document the most recent appearances of Ug99 in Europe as evidence of its mutation and adaptation process. In the end we concluded that the fight against the fungus Ug99 has not concluded, despite the significant advances in science.

Stem rust equals polio for agriculture. According to Koerner (2010), William Wagonire, disciple of Norman Borlaug, winner of the 1970 Nobel Peace Prize and father of modern agriculture, was the one who discovered the Ug99 race. There are traces of the *Puccina graminis* in archaeological sites of Israel belonging to the Bronze Age, including the Romans worshiped a god named Robigus for his power to defend them against rust and every April 25 they celebrate a festival called Robigalia where they sacrifice redheaded dogs in honor of the deity. It is known that the first British settlers in Massachusetts suffered considerable losses in their grain crops in the seventeenth century and that in Mesoamerica the plague was known as chahuistle.

Both in the nineteenth century, as in the twentieth, the plague attacked the great plains of North America. One of the most important disasters took place in the middle of the First World War, when the *Puccina graminis* affected 200 million bushels of wheat, equivalent to one third of the national consumption. In 1917, the government of the United States of North America ordered the eradication of barberries (*Berberis* sp.), a plant where it was believed that *Puccina graminis* was housed and where wheat was scarce. Rouse (1935) explains that in 50% of the Minnesota and Dakota wheat crops, as well as 25% of the total production were lost during the stem rust epidemic Race56= MCCFC that attacked the United States of America in that year (Rouse, 2013).

In the 40s of the last centuries, when World War II made philanthropic research difficult, the Rockefeller Foundation turned its attention to Mexico, where uprooted peasants suffered from hunger and chronic malnutrition. In 1944 that Foundation sent the young agronomist Norman Borlaug to Mexico to put an end to the problem. Borlaug found the presence of stem rust in wheat crops, signaling it as the main cause of hunger. Borlaug undertook the task of searching for a gene resistant to *Puccina graminis* through a process of hybridization. After several attempts, he created the stem rust 31, which he named Sr31, an extracted gene derived from rye and able to resist the *Puccina graminis*. The success was phenomenal, and the gene was distributed throughout the world through the International Center for the Improvement of Maize and Wheat (CIMMYT).

Sr31 was the cornerstone of the green revolution and by 1970 stem rust had been eradicated, saving hundreds of millions of human beings from famine. Norman Ernest Borlaug was awarded the Nobel Peace Prize in 1970 and the *Puccina graminis* ceased to occupy the investigators except for military purposes. During the Cold War, the Americans developed a cluster bomb composed of turkey feathers infested with spores of *Puccina graminis*.

It is believed that these bombs were destroyed by agreeing to give up the use of bacteriological weapons. However, the discovery of William Wagoire marked a milestone in ascertaining the presence of stem rust in a crop research center located in Kalengiere, Uganda, in 1998. Wagoire immediately contacted Ravi Singh, director of wheat incubation at CIMMYT, who confirmed that a new pathology in the stem rust race had been detected in a remote area in Uganda, capable of killing Sr31 (Koerner, 2010). Jin (2008), another well-known expert in the subject explained that also the Sr24, located in the region of the East of Africa, is vulnerable, therefore, the commercial cultures with resistance to stem rust based on the Sr24 and Sr31 genes, should be carefully monitored to avoid a potential epidemiological outbreak.

The last most severe epidemic took place in Ethiopia during 1993-4 when the *Enkoy* wheat crop suffered heavy losses. The following three decades did not register serious threats. However, the presence of two new diseases was found: rust leaf (herrumbre de hojas) caused by *Puccinia triticina* and yellow rust (roya de tallo amarilla) caused in turn by *Puccinia stritiriformis*. There is also evidence that the type of wheat crops planted in Pakistan, India and China are susceptible to Ug99.

Dr. Norman E. Borlaug warned the world of the serious danger posed by this fungus for food security. From that moment, he founded the Borlaug Global Rust initiative (BGRI) which has its website at: http://www.globalrust.org and which has been proposed as the main objective to mitigate the danger posed by this plague. It started with 15 countries in 2009 and by 2011 it was already 20. The BGRI also works with the United States Department of Agriculture (USDA) and the Durable Rust Resistance in Wheat Project (DRRW) of Cornell University. The BGRI concentrates samples, carries out tests under the strictest biosafety regulations and is the one that best knows the Ug99 fungus.

The BGRI launched in 2005 four basic recommendations to reduce the risk of a pandemic: a) monitoring the expansion of Ug99 beyond Africa, in order to intervene in time; b) be updated in the publication of resistant genes and germplasm; c) global distribution of sources, supplies and resistant incubation; and d) experiment with new varieties of genes and resistant germplasm in high productivity adult plants. According to Ravi (2011) there are two types of wheat, the *hexaploid*, used to produce bread (*Triticum aestivum*) and the tetraploid or durum wheat (*Triticum turgidum* var durum) that is used for the production of dry pasta and semolina.

In contrast to wheat for bread, varieties and germplasm of durum wheat have a resistance of 40% to 60% of cases at Ug99. Given that 90% of crop varieties are susceptible to contracting the fungus Ug99, this fungus is considered a serious threat not only to cereal production, but to world food security. Ravi (2011) states that wheat occupies 20% in human food, is the second crop that contributes more calories to the diet of people living in underdeveloped countries and their main source of protein. Wheat provides 4.5 billion people in 94 countries, 21% of calories and 20% of protein consumed in food.

It is cultivated on 215 million hectares around the world from the equator to latitudes of 60 north and 44 south and altitudes ranging from sea level to 3 000 meters above sea level. In his article entitled 'The emergence of Ug99 Races of Stem Rust Fungus is a Threat to World Wheat Production', Ravi (2011) pointed out that 630 million tons were produced annually, of which 50% originated in underdeveloped countries. According to his calculations regarding the increase in demand for wheat in those countries, he expected to increase 60% by 2050. On the other hand, he predicted a drop in wheat production 29% due to factors such as global warming derived from climate change.

These projections deteriorate with the increasing use of fertilizers and irrigation systems, new diseases and pest strains as occurs with the fungus Ug99. The current risk is represented by the great migratory flow, as well as the number of people, calculated in one billion human beings, that would be affected in case of an epidemic. Although the risk is high, a number of factors must occur in order for Ug99 to trigger a crisis in commercial wheat crops. According to Brian Steffenson, an expert in grain pathologies at the University of Minnesota, more than a billion lives would be in danger. 90% of world wheat crops lack protection against Ug99 and if not attacked, famines could be unleashed from the Red Sea to the Mongolian steppes.

China and India are the big consumers of wheat and in the event of a pandemic with Ug99, its population would be affected, mainly rural; countries such as Pakistan and Afghanistan, nations heavily dependent on imported wheat, are considered vulnerable. The fungus has also been detected in Iran and South Asia, as far as Punjab, where hundreds of millions of Hindus and Pakistanis get their food.

The Ug99: characteristics, types and races

According to SAGARPA (2016), Ug99 is also known as black stem rust. The disease is caused by the fungus *Puccinia graminis* Pers. F sp. *tritici Eriks*. and *E. Henn* and its effect has been historically devastating for the wheat harvest, becoming the most reckless pathology among wheat producers. SAGARPA has classified it in a taxonomic manner as: kingdom: *Fungi*, Phylium: *Basidiomicota*; class: *Pucciniomycotina*, subclass: *Pucciniomicetes*, order: *Puccioniales*, family: *Pucciniaceae*, genus: *Puccinea*, species: *Puccinia graminis* f. sp. *tritici*. Wheat stem rust race Ug99, is also designated as TTKSK based on the North American nomenclature. Bhavani *et al*. (2016) for its part ensures that new breeds had emerged: TTKST, TTTSK and more recently TTKTT.

This nomenclature is attributed to Wanyera (2009). aMamdouh *et al*. (2013); for example, identifies four more variants of Ug99: TTKSF, TTKSP, PTKSK and PTKST. According to Singh (2011), Ug99 not only affects wheat genes Sr31 and Sr38, present in several wheat crops in Europe and Australia, but is susceptible to infect others present around the world. In 2006 Ug99 also affected Sr24 in Kenya, Singh (2008). The diversity between the different races of fungus is well known and is located predominantly in East Africa, being Uganda, cradle of Ug99.

In these regions the fungi find ideal climatic conditions, with temperate temperatures, without exaggeratedly cold winters and regular rains. They also find large wheat crops throughout the year that fungi use to reproduce. The air and the ultraviolet rays help the fungus in the process of growth and mutation with which they manage to diversify.

The fungus Ug99, like the parasites, has several ways of reproducing itself. In some cases, the cells of the fungus separate to produce a clone. This cloning takes place in wheat crops and occurs in a massive and accelerated manner. In other cases, two fungus cells are fused, their genetic code is mixed and they reproduce. Here it is a process similar to the reproduction of mammals. Although this form is slower, it makes radical modifications possible in some cases. This sexuality in the fungus takes place in the so-called barberries (*Berberis vulgaris*) or shrubs. The presence of this type of shrubs was observed in the places where evidence of a possible derivative of Ug99 was recently found in Horstberg, Germany.

One of the experts in barley related to the fungus Ug99 is Professor Jin (2008) of the University of Minnesota, specialist in botanical pathology and advisor to the Ministry of Agriculture of the North American government. Ji (2008) carries out a genetic analysis of black stem rolla shoots worldwide. Jin’s concern is that what was found in Horstberg, Germany, could be presented elsewhere. In this hypothesis, the presence of barberries seems to be the key. The barberries come from Asia and were interned to Europe and North America thanks to migration being widely used as a bush to establish perimeters, mainly for the purpose of protecting animal husbandry and soil erosion. Its small red fruits are a substantial source of vitamin C.

Also, they serve as food to the birds; Through the guano the barberries were expanding without the help of man. The correlation between barberries and black stem rust has been known for some time, but what is not well known is the effect of the fungus on barberries. It is very difficult to experiment with the fungus and its spores in relation to the barberries in a laboratory, because before they propagate in these, they need to go through a process of hibernation. Jin's laboratory (2008) is one of the few in the world that studies the relationship between Ug99 and barberries.

A few years ago, he was able to prove that not only black stem rust uses it as a springboard before infesting wheat crops, but also yellow stem rust. Therefore, he is convinced that a strategy to eradicate the threat of the fungus must include a meticulous study of all stages of its spread, especially where it comes into contact with barberries, since it is often overlooked. Another reason why scientists have neglected the role of barberries in the study of Ug99 is that it has not been properly studied. And is that already in the seventeenth century French agricultural producers had detected the link, after which they were given the task of eradicating the barberries.

At the beginning of the 20th century the barberries had disappeared from Europe. Similarly, in the United States, laws against the cultivation of barberries were enacted; however, it was systematically fought until the end of the First World War, after an epidemic of black stem rust threatened to destroy wheat production. Approximately 1.7 million shrubs were destroyed in 1918. Salt was used to prevent its resurgence. The campaign of eradication of barberries extended to the great depression of 1929 and served as measures for job creation. By 1972, 98% of the bushes had been finished, and the task was terminated.

However, the questions were left unanswered: in what way does the black stem rust incubate in the barberries? What role does it play in the outbreak of Ug99 epidemics and how does it favor the creation of new races? The barberries have returned to Europe and North America, but the questions remain unanswered. According to Koerner (2010), Ug99 is a fungus that produces black stem rust. Their spores fly by the wind, landing on the leaves of the wheat. From there they move to the bowels of the plant and sequester their metabolism to immediately extract the nutrients to dry it.

The pathogen is manifested through reddish pustules that appear both on the trunk and on the leaves. When these pustules burst, they expel millions of spores that look for a fresh host. Affected plants begin to wither to death and their grains become unusable. Koerner (2010) points out that in St Paul, Minnesota is the grain laboratory called USDA's Central Disease Laboratory (CDL), where close to 30 000 pathogens that attack wheat, barley and oat crops are concentrated under strict security measures. Among these are samples of all types and models belonging to Ug99.

This laboratory works permanently with a wide variety of phenotypes coming from several research centers and from different parts of the world. One of the leading researchers in the field is Les Szabo, a training geneticist, who details the ability of *Puccina graminis* to expand and coexist with its hosts. He points out that he is an efficient traveler, so that a single hectare of infected wheat can expel 10 million spores, each of which can trigger an epidemic. All that is needed are the ideal conditions: wind blowing towards wheat crops and spores surviving during the journey.

Thus, the spores of Ug99 are transported with the wind rising to the limit of the atmosphere and descending to the fields, traveling hundreds of kilometers. This explains the rapid expansion of the fungus from Uganda to Ethiopia, sub-Saharan Africa and eastern Sudan. A statement from

SAGARPA also adds that the life cycle of the fungus consists of five phases during which the fungus invades the crop and ends up dyeing it a black color. It has a latency period of 7-9 days and the infection occurs in a 26-day interval; daily sporulation is approximately 20-30 spores per injury and the infection efficiency of 20-45 lesions per spore.

It requires tissue from green plants to infect. The climatic conditions in which it reproduces go from a minimum of 4 °C to 29 °C with an optimum of 23 °C. In very dry or tropical regions the fungus does not reproduce, but the irrigation of crops could favor it. Stem rust can hibernate in the form of *teliospores* in crop residues to resurface in spring, being more susceptible in high latitudes. If the infection is severe before flowering, it is possible to completely lose the crop Secretariat of Agribusiness Development of the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA), General Directorate of Plant Health (2016).

The lesions appear as oval pustules called *uredias* that spread along the sheath, stem and spike. The spores are reddish brown and penetrate the entire plant. If the pustules are scattered, it is a mild infection, but if they are agglutinated, it is intense (SAGARPA/CESAVEG). The Ug99 is not only underway, but continues to mutate, developing the ability to affect genes that until now were considered immune. One of the new ones has been the Sr24 gene, used in cultures of the United States of America and later the Sr36 that is used in the great plains of North America during the winter.

There are different types of fungus classified as black stem rust, which affect wheat crops; some innocuous, others very dangerous. The different ways in which the Ug99 is manifested were called TTKS based on the North American nomenclature. In a 2013 presentation by Matthew Rouse of Cornell University in New York, the researcher, who works in the Durable Rust Resistance Wheat Project, points out that the TTKS is the original phenotype, it is taken from the 04KEN156 classification and from it several races are derived. Rouse presents, through Table 1, the way in which the coding of the different phenotypes is integrated according to the level of infection to the fungus with only two values: high (H) and low (L).

Each value corresponds to a group of genes that are affected by the TTKS. The first letter T affects the types of wheat that are detailed in the second column of Table 1 and are vulnerable to the genes that appear in the third column. The fourth column shows the level of danger, which goes from 0 to 2 as low (L) and from 3 to 4 as high (H). For example, to understand the TTKS code, we start with the first letter 'T' has four levels of danger (H, H, H, H) for the corresponding genes. In the lower part of Table 1, the classification appears and is read from top to bottom, so that the first letter 'T' means four levels of danger, as well as the second; the third letter 'K' has a low level of danger and three highs (L, H, H, H) and the fourth: 'S' has three highs and one low (H, H, H, L).

Ergo, the TTKS is classified as a highly infectious fungus. Matthew Rose explains that the Sr are genes contained in different types of wheat that have levels of resistance to the fungus Ug99, and that those with greater vulnerability according to Table 1 are Sr5, Sr21, Sr9e and Sr7b, while the most resistant are Sr36. and SrTmp (Rouse, 2013).

Table 1. Nomenclature for the classification of the fungus Ug99 (04KEN156).

level	Type of wheat	Gen Sr	Danger
1 T	ISr5Ra	5	4 (high)
	T.m.deri	21	3+ (high)
	Verstein	9e	4 (high)
	ISr7bRa	7b	3 (high)
2 T	ISr11Ra	11	4(high)
	ISr6Ra	6	4(high)
	ISr8Ra	8a	4(high)
	CnsSr9g	9g	4(high)
3 K	W2691SrTt-1	36	0 (low)
	W2691Sr9b	9b	4 (high)
	BtSr30Wst	30	4 (high)
	Comb.VII	17+13	2++ (low)
4 S	ISr9aRa	9a	4 (high)
	ISr9dRa	9d	4 (high)
	W2691Sr10	10	4 (high)
	CnsSrTmp	Tmp	2+ (low)

Classification

B	C	D	F	G	H	J	K	L	M	N	P	Q	R	S	T
L	L	L	L	L	L	L	L	H	K	H	H	H	H	H	H
L	L	L	L	H	H	H	H	L	L	L	L	H	H	H	H
L	L	H	H	L	L	H	H	L	L	H	H	L	L	H	H
L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H

Source: (Rouse, 2013); H (high); L (low).

Later the TTKS was renamed after adding a fifth classification (letter K), since it happened to affect until then resistant genes like Sr24, Sr31 and Sr 38, being like finally like TTKSK, but it followed within the code, that alludes to the year and to the country, eg. 04KEN156, Kenya, 2004. Later the TTKST was created, equivalent to code 06KEN19v and TTTKS with its corresponding code 07KEN24-1. Thus, Ug99 not only affects the Sr31 gene, but also other wheat genes (Sr).

There is then an intense battle between two fronts, on the one hand, the multiplication of the races that emerge from the TTKSK with each time new variants with great adaptability and on the other, the types of wheat endowed with different *Sr* genes resistant to the fungus and result in turn from a process of scientific hybridization or stem rust resistant breeding. However, these new genes become increasingly vulnerable to occurrences of new variants of the fungus.

According to Matt Rouse, the fight began in the 1930s and 1950s. The attack of race 56 known as MCCFC was responded with wheats *Ceres* and *Triumph* endowed with the genes Sr5, Sr28 and SrTmp, that of race 15B also known as TPMKC was answered with *Thatcher* wheat containing the Sr12, Sr9 and with the *Chris* wheat that contains the Sr6 and Sr30 genes (Rouse, 2013). Although there has not been an epidemic of the fungus in the last 50 years in the United States of America, current wheat crops are vulnerable to TTKSK, TTKST and TTTSK, so it is urgent to find more and more new *Sr* genes resistant to it (Table 2).

Table 2. Races of Ug99 identified until 2010 in several countries and their different virulence.

Race[a]	Name	Fundamental differences in virulence				Confirmed presence of the fungus
		Sr31	Sr21	Sr24	Sr36	
1. TTKSK	Ug99	Vir	Vir	Avir	Avir	Uganda (1998); Kenya (2001); Ethiopia (2003); Sudan (2006); Yemen (2006); Iran (2007)
2. TTKSF		Avir	Vir	Avir	Avir	South Africa (2000); Zimbabwe (2009)
3. TTKST	Ug99+Sr24	Vir	Vir	Vir	Avir	Kenya (2006)
4. TTTSK	Ug99+Sr36	Vir	Vir	Avir	Vir	Kenya (2007)
5. TTKSP		Avir	Vir	Vir	Avir	South Africa (2007)
6. PTKSK		Vir	Avir	Avir	Avir	Kenya (2007); Ethiopia (2007)
7. PTKST		Vir	Avir	Vir	Avir	Kenya (2008); South Africa (2009)

[a]= under the American nomenclature system. Ravi *et al*. (2011).

Ravi *et al*. (2011) for its part, ensures that already in 2011 there were seven known varieties related to Ug99 that appear in Table 2. In the first column appears the race, in the second the denomination; in the third the virulence to the type of gene and in the fourth the country and the year in which it was detected. Only the TTKSK, also found outside African territory, is known as Ug99, is virulent to Sr31, S21 and non-virulent to Sr24 and Sr36. It is feared that along the route taken by the air currents, spores of the fungus may affect crops located in Israel, Jordan and Egypt, other models suggest that the spores may expand to the Caucasus and Central Asia.

An additional contagious vehicle is represented by Asian soybean (*Phakopsora pachyrhizi*) infected with stem rust. It was first identified in Uganda in 1996, but then spread through the air to Rwanda, Zimbabwe and Zambia. Also, trade can be another way, since there is intense trade between South Africa and Kenya. This means that its contagion to Australia and South America is not ruled out. There are reports of presence of stem rust in Lebanon and Israel in 2010. The TTKST called Ug99+Sr24 is virulent to Sr31, Sr21 and Sr 36 genes, but not virulent to Sr 24. The TTsK Ug99+Sr36 is virulent to Sr31 genes, Sr21 and Sr36, but not virulent to Sr24. Singh (2008) places the Sr24 gene as one of the most resistant in Kenya.

Both the TTKST and the TTTSK are races that pose the greatest potential danger. The rest are races derived from Ug99 but they are not called Ug99. Singh points out that the PTKST race was virulent to Sr31 and Sr24 in Kenya (2008) and South Africa (2009), the PTKSK was virulent to Sr31 in Kenya (2007) and Ethiopia (2007), while the TTKSP is believed to have evolved in South Africa and that it became virulent to Sr21 and Sr24 by mutation. This led to the designation of South Africa as a unique epidemiological area. The detection of the TTKSF in Zimbabwe strengthens the hypothesis of the expansion of common breeds in the region. Likewise, the detection of PTKST, (originally located in Kenya), in South Africa proves the link of the presence of stem rust in East and South Africa.

In his document Ravi (2011) he points to Tanzania as a country where the presence of TTKST, TTTSK, and TTKSK was also detected in 2009. It is believed that he may have jumped to Zambia, Malawi and Mozambique. By 2015, 13 races had already been detected in 13 countries Bhavani *et al*. (2016). Mamdough (2013) points out that there are eight genes that confer resistance to TTKSK: Sr 13, Sr 14, Sr 22, Sr 28, Sr 33, Sr 35, Sr 42 and Sr 45. Singh (2008) explains that the TTKSK could have been present in Kenya since 1993, from where it constantly expanded in a period of 10 years. In 2005, reports from Ethiopia located an ideal region for the propagation of the fungus in the high Africans that they called 'hot spot', which started from Uganda, passing through Kenya, Ethiopia, Sudan and Yemen.

This last country could have served as a springboard for the spread of the virus to the Middle East and Asia, Singh (2008). Singh (2011) explains that for 2007 Ug99 presence was confirmed in Uganda, Kenya, Ethiopia, Sudan and Yemen. Its expansion towards the Middle East and Asia was perceived. The TTKSK race in Iran was subsequently confirmed in March 2008. So, starting that year it has expanded over thousands of kilometers from East Africa, including South Africa, Egypt, the Middle East and Iran. In 2008, 80% of wheat types were susceptible to acquiring Ug99.

Combat strategies

To combat Ug99 basically two tools are used. In the first place is the desperate search for genes resistant to the fungus. One of the most used strategies has been the identification of genes with cumulative effects that transmit a lasting resistance capacity against Ug99, as is the case of the transfer of Sr2 from *tetraploid* wheats to *hexaploid* wheats. Singh (2011) explains that it is believed that the Sr 2 complex has provided a base of long-term resistance to stem rust in germplasms found at the University of Minnesota in the United States of America, at the University of Sydney Australia, but also in a wheat germplasm developed by Dr. Borlaug at CIMMYT in Mexico.

For his part, Matt Rouse works on a project of genes resistant to the fungus that divides into three sections: a) *T. monococcum*; b) Thatcher wheat; and c) chromosome 2BL. In the first case, it identifies two wheat species that, due to their genetic composition, have proved successful in resistance to more than one race of Ug99 and for their content of novel genes: the *Triticum monococcum* susceptible to contain genes of the type Sr35, Sr22, Sr21, SrTm4 and SrTm5 and *Aegilops tauschii*, susceptible to contain genes of the type Sr33, Sr45, SrTA1662, SrTA10187 and SrTA10171. In particular, it uses cloning procedures in the Sr35 and Sr33 genes to be able to incorporate them in different types of *Triticum monococcum* and *Aegilops tauschii*.

In the second, Matt Rouse also works with combinations that include Sr12 and 1AL which he calls *QTL* in Wheat type Thatcher and McNeal obtaining encouraging results. Third, chromosome 2BL has also been shown to be resistant to the fungus by tests with Sr28 and SrGabo56. In his presentation of 2013, Rouse explained that in a period of 5 years, the number of genes resistant to the fungus had doubled (Rouse, 2013). For its part, Les Szabo says that fungicides can be used, but only as an emergency measure, because they are poisonous to the environment, scarce and expensive.

All tradable wheat crops are susceptible to acquire this virus, so it becomes necessary to apply fungicides. In the past, the scourge had been reduced without the need for fungicides, through cultures resistant to the fungus. But with the passage of time and through the emergence of new races of Ug99, resistant crops become vulnerable. So, it is urgent to find new resistant crops, but in the meantime, fungicides are resorted to. Although the problem has been attacked with the use of fungicides, Wanyera (2009) points out that there is not enough information on the efficiency of its use, but he is convinced that fungicides are not a long-term solution.

For its part, the SAGARPA (2016) adds that the fungicide azoxystrobin at 200 g L^{-1} + ciproconazole at 80 g L^{-1}, tebuconazole and tebuconazole + tridimenol were effective in reducing the populations of the race Ug99 in sites tested. On the other hand, those that were not successful were trifloxystrobin + propiconazole, hexaconazole, epoxiconazole + carbendazim, cyproconazole at 80 g L^{-1} + propiconazole at 250 g L^{-1}, and epoxiconazole at 125 g L^{-1} + carbendazim at 125 g L^{-1}.

Ug99 resurfaces in Italy and Germany

Varga (2007) already reported the presence of mushrooms in European agriculture. He points out that in Austria there was evidence of the presence of fungi in seeds of different agricultural products marketed in that country. In 2013, an indication of Ug99 was found in Germany, a fact that alarmed the scientists. In a matter of weeks, reports were received of the possible presence of Ug99 in Upper and Lower Saxony, as well as in Thüringen and Brandenburg. Subsequently, in 2016 two cases of stem black rust were found in Lower Saxony, Germany, but they remained under control. In 2013, several samples of Ug99 found in Horstbergs, Germany, were studied in the laboratory.

Although it was detected that it was not Ug99, it turned out to be a new variant classified as: TKTTF. It is believed that the TKTTF caused serious damage in countries such as Turkey (2005) and Ethiopia (2013, 2014 and 2015) (Bhavani *et al*., 2016). Singh (2015), for his part, assures that the TKTTF is highly virulent in *Digalu* type wheats, cultivated in Ethiopia and the Middle East. The experience of crop affectation due to the presence of the TKTTF ignited the alarm due to its high devastating potential. On the other hand, in Sicily that same year 10 thousand hectares of black stem rust wheat were infected, reason why it is believed that the number of spores that float in Europe is relatively high.

Despite having no news of outbreaks, investigators turned on warning lights. According to the RustTracker.org, on February 2, 2017 was published the detection of an outbreak stem rust in the Mediterranean basin (Yalemayehu, 2017). The samples obtained in Sicily point to the emergence of another new breed now baptized under the name of TTTTF. This was detected in both bread wheat and durum wheat during the April-June 2016 period in Sicily, Italy. This new TTTTF affects the Sr9 and Sr13 resistant genes, with a history in Turkey. Experts say that it is not related to the group of races of the Ug99 family and that it is avirulent to the Sr31, Sr24 and Sr25 genes.

Due to the extension of the affected area in Sicily, it is one of the most severe outbreaks of the most recent stem rust in Europe. Because of the large amount of contaminated crops, it is feared that it will generate a large quantity of spores that will be dispersed during 2017. Due to the geographical location, countries such as Greece, Albania, Montenegro, Bosnia Herzegovina, Croatia and Slovenia could be affected, as well as the north of Libya and the northeast of Tunisia. Mogen HovmØller from the University of Aarhus in Denmark is director of the Globale Rost-Referenzzentrum (GRRC) where he monitors international outbreaks of diseases related to stem rust.

His specialty is the rust of yellow stem that has been detected in Central Europe; this is less aggressive than black stem rust but can spoil up to 40% of the crop. Although the presence of yellow stem rust was sporadic in Europe, as of 2011 two new breeds were found: *Warrior* and *Kranich* Carmona (2017). The names were derived from the type of wheat in which they were discovered. These spread and nested in the region at the expense of other types of yellow-stemmed rust.

After several efforts to find where they came from, Mogen HovmØller pointed out that they originated in the Himalayas. The specialist affirms that the rust of yellow stem expands in Europe not only through these two new races, but of other variants. So far, the fungus has been controlled with fungicides and an attempt is made to maintain a warning system to immediately combat the pest in its initial periods.

Conclusions

The recent occurrences of yellow-stemmed rust in Europe and the spread of black-stemmed rust in East Africa and the Middle East have ignited red hot spots in the academic community. The threat posed by the fungus Ug99 to wheat crops, adds to a series of problems that afflict world food security. While on the one hand science continues to show substantial progress in the creation of new genes resistant to the fungus, the multiplication of races classified as highly dangerous has not stopped, so that their eradication is still far away.

That is to say, there are the occurrences of stem rust of the TTTTF type in Europe, as well as of the Warrior and Kranich types in yellow-stemmed rust, and on the other, the advance in the leading laboratories of St Paul in Minnesota as well as in the University of Aarhus in Denmark, that have given positive results by using technology such as cloning and genomics. Add to this the danger posed by the use of fungicides and herbicides in agriculture to human health and the environment, with which we not only have a threat to the production of food, but to public health as in the scandal that recently caused glyphosate, a herbicide widely used in agriculture linked to cancer.

Mexico has a deficit in wheat bread that covers imports from the American Union, whose wheat crops are vulnerable to TTKSK, TTKST and TTTSK, before an epidemiological outbreak in the northern neighbor, Mexico would be affected. Fortunately, the presence of CIMMYT in Mexico and the international cooperation of its researchers have taken note of the danger and the Ug99 is already on their agendas and lines of research.

It is only necessary to continue vigilant to prevent and, where appropriate, take the necessary measures in the face of an unusual epidemiological outbreak in the national territory, especially in the states of Sonora and Guanajuato, which are the most vulnerable, since they would face losses that could go, as analyzed in this study, from 25% to 50% of their wheat production.

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