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Current status and effects of bread wheat yellow rust (*Puccinia striiformis* f. sp. *tritici*): A review

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ABSTRACT

Bread wheat is one of the most significant and productive crops in the world. Numerous fungi are potential diseases for the crop. A significant global constraint on the production of bread wheat is the continued yellow rust. The pathogen that caused the disease originated in Transcaucasia and is now found worldwide wherever bread wheat is grown. One of the most significant diseases is yellow rust, which is caused by Puccinia striiformis f. sp. tritici. When the disease first strikes plants early in the growing season, plants are typically stunted and weak, which results in total output losses. Because it is an obligatory parasite, its life cycle can only be completed on a living host. It can be distinguished from other rusts by the dusty yellow lesions that appear as stripes on leaves. Expanded virulence profiles are the result of the development of new races with strong epidemic potentials and the ability to adapt to warmer climates. Disease development at the seedling stage in susceptible types can result in a complete loss of output. Growers handle bread wheat yellow rust by using a variety of management techniques, including as resistance cultivars, cultural control, biological control, fungicides and integrated disease management solutions. Still now, yellow rust leads a big problem on wheat production not only in temperate zone as well as in tropical zone. Yellow rust is now regarded as the most commercially significant wheat disease and a danger to global food security due to the scale of the generated losses. Although the disease is old, it frequently reemerges as a concern and spreads to new locations. It develops very early in the growing season and causes the plants to grow weakly and stunted, resulting in severe yield losses of up to 100%. However, the disease is still more sever or found everywhere and it needs a cooperative effort to tackle the epidemic.

Keywords: Bread wheat; Economic importance; Managements; Yellow rust; Tropical zone

Introduction

Bread wheat (*Triticum aestivum* L.), which is today grown in Syria, Turkey, Afghanistan, Iraq and Iran, originated in the Near East [1]. It is an annual species of the grasses (Poaceae) family, the *Triticeae* tribe and is commonly referred to as common wheat. Its 21 chromosomal pairs are grouped into three sub genomes, A, B and D, rendering it an allohexaploid species (genome BBAADD, 2n= 6x=42) [2]. More than 35% of the world's population depends on wheat, which has an annual global production of 772.6 million tons [3]. Globally, China, India and Russia produce the most wheat, but in sub Saharan Africa, South Africa and Ethiopia produce the most [4]. It is the second most significant grain crop in Ethiopia after Tef [5]. One of the most significant staple foods in Ethiopia is bread wheat, which is grown on 1.69 million ha of land with an average yearly yield of 4.64 million metric tons in a variety of agro ecologies [6]. Wheat used to make bread is crucial to the economic and social advancement of people everywhere [7]. It is a vital cereal crop that helps feed and increase food security worldwide [8].

The production of bread wheat is threatened by many biotic (diseases, insect pests and weeds) and abiotic (moisture stress, low soil fertility, repeated drought and others) problems, the most significant that is yellow or stripe rust caused by *Puccinia striiformis* f. sp. *tritici* [9-11]. Areas with cool, moist climates have seen a greater prevalence of yellow rust. A new level of adaptability by the pathogen to the wide temperature range, however, is suggested by recent epidemic outbreaks in nations closer to the equator [12]. Yellow rust is a polycyclic infection, and the rate at which it spreads determines much of its epidemiology [13]. The photosynthetic apparatus of the host plant is utilized by the obligatory fungal parasite *Puccinia striiformis* f.sp. *tritici* to meet its nutritional needs [14,15]. On its primary hosts of cereal crops and auxiliary hosts of wild grasses, it virtually entirely reproduces asexually. Cereal crops, wild plants and grasses act as the principal inoculum for outbreaks on cereal grains. Urediniospores can travel great distances on the wind and can also be introduced unintentionally by being carried on clothing and shoes.

Depending on local environmental factors, the fungus can survive summer and/or winter as mycelium in host tissue for months or as viable urediniospores in the air or on the surface of the host for varying amounts of time. A widespread disease with a variety of farming techniques, growth seasons and germplasm features, bread wheat yellow rust affects the major bread wheat-producing regions [16]. For instance, *Puccinia striiformis* f. sp. *tritici* caused outbreaks of wheat yellow rust can result in yield losses of more than 5.5 million tons annually worldwide. The biotrophic fungus *Puccinia striiformis* f. sp. *tritici* causes the ancient and deadly bread wheat yellow rust disease of wheat (*Triticum aestivum* L.). Yellow rust, which has been reported in more than 64 countries, can significantly lower production in all regions of the world where wheat is grown.

Yellow rust is now regarded as the most commercially significant wheat disease and a danger to global food security due to the scale of the generated losses [17,18]. Although the disease is old, it frequently reemerges as a concern and spreads to new locations. It develops very early in the growing season and causes the plants to grow weakly and stunted, resulting in severe yield losses of up to 100%. However, stripe rust yield losses are influenced by a number of variables, including cultivar susceptibility, infection timing, disease development rate, epidemic duration, crop growth stage and meteorological conditions [19]. Due to the fact that the majority of wheat cultivars are either vulnerable to or have low levels of resistance to bread wheat yellow rust, farmers worldwide face numerous difficulties [20]. If infection occurs relatively early in the crop development stage and the disease continues to progress throughout the growing season, it can result in yield losses of up to 100% on sensitive cultivars, including Ethiopia. One of the most dreaded and a significant bottleneck in Ethiopia's highlands is the bread wheat yellow rust disease caused by *Puccinia striiformis* f. sp. *tritici*. Early 1940's reports of yellow rust incidence in Ethiopia indicate that it was originally present there; nevertheless, the disease was only discovered there in 1998 [21]. Since then, it has become increasingly destructive. More than 400,000 hectares of wheat farms were thought to have been infested with yellow rust in three regions, Oromya, Amhara, and Southern Nations Nationalities Peoples Region (SNNPR), respectively. Growers use a variety of management strategies or techniques to minimize its impact, such as the use of integrated disease management strategies, fungicides, resistant cultivars, cultural control, biological control and biological strategies. Despite increased use brought on by the incidence of severe epidemics around the world, the efficacy of fungicides in controlling yellow rust is now high [22]. An integrated yellow rust management strategy combines the use of crop cultivars with sufficient levels of resistance, early warning systems that involve routine pathogen monitoring and disease scouting, cultural methods and timely application of efficient fungicides [23,24].

Literature Review

Origin and distribution of yellow rust

Bread wheat yellow rust (*Puccinia striiformis* f. sp. *tritici*) is thought to have originated in Transcaucasia. The fungus spread outward from this point in all directions, reaching additional countries in central and western Asia, southern and eastern Asia, northern Africa and Europe [25]. Bread wheat yellow rust is found on all continents except Antarctica, but it has been seen in epiphytotic conditions more frequently in the Pacific Northwest region of North America, South America, East Asia (Northwest and Southwest China), South Asia (India, Pakistan, and Nepal), Oceania (Australia and New Zealand), the Nile Valley and Red Sea (Egypt and Yemen), West Asia (Lebanon and Yemen), North Africa (Morocco, Algeria, and Tunisia), and North Africa (E (UK, Northern and Southern France, Netherlands, Northern Germany, Denmark, Spain and Sweden) [26]. Widespread outbreaks of bread wheat yellow rust are more common in China, India, Nepal, Pakistan, Uzbekistan, Yemen, Ethiopia, Kenya, the United States, the United Kingdom, Australia, New Zealand, Chile, Peru, Ecuador, Colombia and Mexico. Yellow rust on bread wheat has the potential to reduce crop yields in these nations [27].

In many other nations, such as Canada, Russia, Kazakhstan, Afghanistan, Iran, Iraq, Syria, Turkey, France, Germany, Poland, Romania, Ukraine, Morocco, Tunisia, Tanzania and South Africa, epidemics happen two out of every five years and in more than 25% of the areas where wheat is grown, epidemics cause a loss of one to five percent of the crop. A more recent study of diseases and pests in important food crops identified yellow rust of bread wheat as one of the top pathogens globally responsible for losses greater than 1% [28]. In Azerbaijan, Ethiopia, Iran, Iraq, Kenya, Morocco, Syria, Turkey, and Uzbekistan in 2009–2010, the breakout of Year 27, an aggressive new strain of bread wheat yellow rust, significantly reduced yields and threatened the food security and way of life of commodity farmers and their communities [29]. Yellow rust is a significant disease of bread wheat production in Ethiopia's highlands, which are located between 2150 and 2850 meters above sea level. The southeastern and northwest regions of the country, which are bread wheat growing regions, have had frequent and widespread yellow rust epidemics at higher elevations. During outbreaks, bread wheat crops are susceptible to severe damage from bread wheat yellow rust [30]. If the disease spreads during the growing season on vulnerable cultivars and infection begins extremely early, it might result in a 100% yield loss. According to reports, stripe rust in Ethiopia has resulted in yield losses that have ranged from 40% to 100% depending on cultivar susceptibility, the time of initial infection, and environmental factors during epidemic development [31]. At high altitudes, yellow rust can result in yield losses of up to 100% when susceptible cultivars are grown and the environmental factors are favorable. Large scale outbreaks of bread wheat yellow rust have occurred in numerous nations throughout the world.

Status of yellow rust: The yellow rust disease has recently been shown to spread across the entire continent and some of this spread was previously attributed to human activity and wind dispersal. Rust epidemics happened in Delhi in 1843, as well as Allahabad, Banaras and Jhansi in 1884 and 1895. Later, in 1905, reports of a rust epidemic came from Gorakhpur's sub-mountainous regions and Punjab's Punjab [32]. In India, the 2008 wheat stripe rust outbreak in Punjab resulted in losses of about Rs 2360 million, and during the 2010–2011 growing season, yellow rust was more severe and prevalent throughout the farmlands in Jammu and Kashmir, the foothills of Punjab and Himachal Pradesh, parts of Haryana and Tarai regions of Uttarakhand. The 2005 infections in Pakistan caused losses to wheat crops estimated at $100 million USD. The most significant wheat rust disease in Afghanistan is yellow rust, which can cause output losses of up to 90% in years of epidemic.

Across many nations, the 2010 outbreak of wheat stripe rust in Central and West Asia resulted in yield losses of 20%–70%. An estimated $10 million in crop loss was caused by the 2010 pandemic in Turkey. Stripe rust is significant in all of Iran's wheat-growing areas, particularly in the Caspian Sea where outbreaks happen once every three to four years. In North America, stripe rust affects wheat more frequently in Mexico and the United States than in Canada, which experiences it less frequently [33]. Yield losses of up to 60% have been documented in Mexico. The most recent and significant stripe rust epidemics in Canada occurred in western Canada in 2010 and 2011. 2011 crop losses were substantially larger than in previous years, ranging from 15% to 35% for vulnerable cultivars, 5% to 20% for cultivars with intermediate resistance and 2% to 10% for resistant cultivars [34]. Prior to the year 2000, stripe rust in the United States was only a significant issue in the west. However, since then, the disease has spread nationwide and seriously hampered wheat output [35].

In Ethiopia, *Puccinia striiformis* f. sp. *tritici,* which causes yellow (stripe) rust, is a major wheat disease that frequently causes crop failure and substantial economic loss. The Central Research Institute for Field Crops (CRIFC) in Ankara and the Regional Cereal Rust Research Center (RCRRC) in Izmir discovered the novel *P. striiformis* race known as 'Warrior' in Turkey in 2014 [36]. The United Kingdom reported about this race earlier in 2011. Turkish commercial cultivars that had previously been known to be resistant to this new race became vulnerable. Most of the European countries and North Africa reported experiencing high frequencies of this new race called 'Warrior'. This race, which had a comparatively larger genetic diversity than other previously known races of *P. striiformis*, was also present in 2013 in Morocco and 2014 in Algeria. Syria and Turkey lost half of their 2010 wheat harvest owing to the pathogen, followed by Ethiopia (45%), Morocco, and Uzbekistan (35%) in terms of severity [37]. Turkey has had multiple yellow rust epidemics in recent decades, which have resulted in crop losses of between 10% and 30% and grain losses of between 1 and 2 million tons. One of the worst yellow rust outbreaks in recent memory devastated Ethiopia in 2010, affecting more than 600,000 acres of wheat and costing an estimated $US3.2 million in fungicides [38]. The first yellow rust outbreaks on wheat variety Laketch on state farms of Arsi and Bale happened in 1977. Another yellow rust outbreak affected the wheat variety Dashen, which carried the Yr9 gene, in the Arsi and Bale zones in 1988. Widespread bread wheat types Kubsa and Galema verities were damaged by a devastating yellow rust outbreak in 2010 and the Yr27-virulent strain of *P. striiformis* f.sp. *tritici* was identified as a major contributor to this epidemic [39,40].

The 2010–2011 rust pandemic seen on the farmer's own farm and estimated yield losses could be the impetus for farmers to alter the amount of bread wheat planted in resistant varieties and/or the variety of kinds produced as a preventative measure against a potential rust repetition [41]. It is anticipated that those farmers who were badly impacted by the rust epidemic in 2010–2011 (as determined by the estimated yield loss) would act quickly to adjust the amount of bread wheat planted and the variety of wheat varieties grown. One of the oldest recognized illnesses, yellow rust is significant on a global scale. Yellow rust has historically caused and is currently inflicting serious losses on sensitive bread wheat varieties all over the world. In order to understand (1) the pathogen biology, ecology and genetics; (2) the interactions of the pathogen with host plants and (3) the epidemiology and control of the disease, considerable progress has been made over the past century [42]. Growing fungicide-resistant cultivars, using the right cultural techniques and applying fungicides can all be used to manage yellow rust. Now it is a big problematic disease on both hot area.

Classification: Yellow rust taxonomy is the genus; Puccinia, family; Pucciniaceae, order; Pucciniales, class; Pucciniomycetes, division; Basidiomycota and kingdom; fugi, all contain the species *Puccinia striiformis* f. sp. *tritici*, which causes bread wheat yellow rust. *Puccinia striiformis* f. sp. *tritici* has uredinial and telial stages, as well as its basidial, pycnial and aecial stages, can be found on either the major host wheat or auxiliary hosts of other cereal crops and wild grasses [43].

Symptoms and signs: The first yellow rust symptoms start to manifest one week after the first infection. Small, yellow dots or flecks initially appear as symptoms on the leaf sheaths. The onset of yellow streaks (pre-pustules), followed by small, light yellow and elongated uredial pustules grouped in visible rows on the leaves, are the earliest symptoms of yellow rust [44]. These dots later transform into long, narrow stripes of rust pustules on the leaf sheaths, glumes and awns. Pustules mature and burst open, releasing masses of urediniospores that are yellow orange in color. The diseased tissues turn brown and eventually dry as the plant enters the senescence stage and throughout the stress phase (Figure 1).

Figure 1: Signs and symptoms of bread wheat yellow rust.

Source: Photo camera by Adane Fentaye.

Identification of yellow rust: An economically significant wheat disease is bread wheat yellow rust, which is driven on by *Puccinia striiformis* f. sp. *tritici*. It is also known as stripe rust due to the yellow streaks (pre-pustules) that form on the leaves before small, brightly yellow, and elongated uredial pustules are grouped in evident rows. Bright yellow (early spores) to orange (at maturity) urediniospores with a diameter of 20 um to 30 um are produced by the fungus [45]. There are pustules on the plant that contain these thick-walled spores. Large quantities of urediniospores can be created and dispersed from polluted fields at the end of the growing season. Although the majority of urediniospores are shed close to their initial host, some can travel great distances with the wind and remain on the leaves of secondary hosts like barberry (*Berberis* spp.) and Oregon grape (*Mahonia aquifolium*). Depending on the temperature of the environment, the fungus immediately multiply in the mesophyll tissue and create fruiting structures (uredinia) that release a fresh batch of infectious spores (urediniospores) in about a week (yellow rust prefers cooler conditions whereas leaf and stem rusts can tolerate slightly warmer temperatures). In adult wheat, barley (certain races with an overlapped host boundary), and foxtail barley grass, the yellow rust pathogen causes stripes of uredinia along the leaf veins [46-49].

Epidemiology of yellow rust: The epidemiological examine the disease and pathogen life cycles, inoculum sources, the survival and dissemination of pathogens, the effects of farming and the environment on disease development, and disease forecasting. It is impossible to eradicate the yellow rust disease because its urediniospores can travel thousands of kilometers on the wind or on passengers, and because the fungus can live on a variety of grass hosts. Since 2000, aggressive races of *P. striiformis* f.sp. *tritici* have spread to regions of the world that were previously less harmed by this infection because they are acclimated to higher temperature climates. Pathogens are primarily spread by wind from infected crops to healthy fields [50]. The spores are dispersed widely by wind. First off, airborne rust spores that may travel across continental and even intercontinental distances spread swiftly. Second, when spores are deposited on wheat plants, infection results when dew creation prompts germination and the fungus penetrates the plant through the stomata. Additionally, rain aids in spore spreading. *Puccinia striiformis* f.sp. *tritici* uredionio spores can disperse on a continental scale by wind currents and low level discharges. In the same growing season, they can travel from a few meters to over 8,000 kilometers by wind, or 2, 400 km in just six months. Similar to how urediniospores can spread from one continent to another through long distance travelers' clothing and footwear [51].

Life cycle: The urediniospores that infect wheat plants then produce more urediniospores in subsequent generations is the disease cycle, which is an endlessly repeating asexual cycle [52]. But the stripe rust disease cycle entails the inoculum supply, spore dissemination and landing on host plants, infection process (including spore germination, penetration, haustorial development, infectious hypha growth and reproductive structure differentiation), sporulation, and pathogen survival. Wheat and *Berberis* spp. are two distinct and unrelated host species where *Puccinia striiformis* f.sp. *tritici* completes its life cycle. The uredial, telial, and basidial phases of the *Puccinia striiformis* f.sp. *tritici* life cycle are completed on a primary host (wheat), whereas the pycnial and aecial phases require an alternative host [53]. *Puccinia striiformis* f.sp. *tritici* possesses a sophisticated and complicated infection process that involves spore attachment to the host plant, germination, the production of an appressorium and the accumulation of nutrients through the invasion of the host and the formation of haustoria. Its life cycle involves five different spore types (basidiospores, pycniospores, aeciospores, urediniospores and teliospores), two hosts that are taxonomically unrelated to one another, graminaceous host for asexual reproduction and barberry for sexual reproduction [54].

The telial stage is started in lesions where urediniospores were formed during the end of the season, when the nutrient supply in the infected tissue is declining. The remaining senesced tissues teliospores aid the fungus in surviving the challenging circumstances. Yellow rust is a polycyclic disease, and when temperature and relative humidity are favorable for the development of the illness, yellow rust outbreaks can reach significant infection rates in bread wheat varieties [55]. Several crucial stages of the yellow rust life cycle, including spore germination, infection, latent period, sporulation, spore survival and host resistance, are jointly regulated by temperature and relative humidity, all of which have an impact on the beginning of an epidemic. *Puccinia striiformis* f. sp. *tritici* has a reproductive cycle with five phases of spore development (stage 0: pycnia; stage I: aceia; stage II: uredinia; stage III: telia; and stage IV: basidial).

Infection process: When a viable urediniospore touches a wheat leaf, the infection process begins. Germination occurs when dew is present and the temperature is between 1°C and 23°C (the ideal range is 7°C-12°C). *P. Striiformis* f.sp. *tritici* infects the host using urediniospores, which after germination obtain entry through stomata. Infection can occur at any time from the one leaf stage to plant. The primary cause of the disease's onset and spread is urediniospores [56]. When urediniospores touch a wheat leaf's surface, they stick to it. Urediniospore forms a germ tube that develops towards the stoma and starts a primary infection in the stomatal cavity under ideal temperature and humidity conditions. The plant is invaded through the stomata when the germ tube generates an appressorium and the fungus then creates a series of infection structures, including the sub stomatal vesicle, primary infection hypha, haustorial mother cell and ultimately a haustorium [57]. In the secondary infection, the mesophyll tissue develops an extensive mycelial network. The haustoria serve as the structures that absorb nutrients from the host and are situated between the host cell wall and the plasma membrane. The fungus subsequently completes the asexual life cycle by producing urediniospores by forming sporogenic tissue known as uredinium near the leaf surface. Seven days after the infection, chlorotic spots start to develop on the leaf's surface. These spots signal the beginning of sporulation, which causes the development of recognizable yellow streaks on the leaf. The duration between inoculation and sporulation is 12–13 days under ideal circumstances, and the spores have the capacity for quick germination in the presence of moisture and an ideal temperature of 7°C–12°C. According to a threshold based meteorological model, conditions that reliably predicted yellow rust infections included temperatures between 4°C and 16°C, a minimum of 4 hours of continuous relative humidity >92% and rainfall below 0.1 mm.

Environmental condition: Even though it usually occurs in temperate locations with reasonably moist and cool weather, yellow rust is thought of as a low temperature illness. According to Hovmiller, et al., since 2000, the deadly outbreaks have instead taken place in warmer areas where the disease was previously less prevalent or completely absent. In light of current concerns about global warming, this suggests that populations of *Puccinia striiformis* f. sp. *tritici* have evolved a tolerance to higher temperatures. The spread of yellow rust in the presence of a sensitive host and *P. striiformis* f. sp. *tritici* inoculum is highly dependent on the weather at the time. These parameters include moisture, temperature, and wind. Moisture, a significant abiotic element, directly affects the pathogen's spore germination, infection, dissemination and survival. Rainfall, particularly light rain, creates favorable conditions for infection. High moisture, however, negatively impacts the viability of spores, which has an impact on new infections and the spread of disease. The relative humidity affects whether urediniospores spread alone or in clusters. The survival, infection, and germination of spores are all impacted by temperature. The pathogen requires a temperature of 30°C at the lowest point and 20°C at the highest point for growth. Most infections happen at night, when dew forms and the temperature is also cool.

The impact of epidemiological variables on the severity of yellow rust under early sowing conditions revealed that maximum temperature, minimum temperature, morning vapour pressure, evening vapour pressure and micro meteorological parameters (canopy temperature and soil temperature) had significantly positive correlations with the severity of yellow rust, whereas maximum relative humidity had significantly negative correlations. The models demonstrated that considerable contributions to the variance in illness severity were made by thermic and hydric factors. The development of the disease and the yellow rust infection both depend heavily on the environment. Moisture and temperature are significantly more important weather variables than other ones for the rust pathogen to infect host plants, there must be a high moisture level. For the stripe rust fungus urediniospores to germinate and enter plant tissues, there must be dew on the plant surface for at least three hours. The likelihood of infection increases with the length of the dew presence. This is the primary cause of severe yellow rust outbreaks in areas with high moisture levels during the growing season. However, excessive humidity makes it difficult for disease spores to survive. The yellow rust infection can survive better and spreads more readily in regions with relatively dry weather between crop seasons than in chronically wet regions.

Economic loss: On susceptible bread wheat cultivars all across the world, yellow rust has historically caused and is still causing large and severe losses. The most prevalent rust disease affecting bread wheat is yellow rust. Because the disease begins to spread early in the growing season, plants are typically stunted and weak, which results in severe yield losses. On susceptible varieties, disease development at the seedling stage can result in a complete yield loss. The disease affects grain production, quality, and size and in sensitive wheat cultivars, it can result in up to 100% yield losses. However, the degrees of resistance, the timing of the initial infection, the rate of illness progression and the duration of the disease all have an impact on the yield loss. The disease depletes the nutrients and water in the plant, weakening it and causing the desiccation of the leaves. A severe early infection may even cause the plants to grow more slowly. In addition, the majority of the widely utilized resistance genes employed in wheat production have broken down as a result of the introduction and spread of new yellow rust races. In order to control the crops from loss, it is producing enormous yield losses that call for significant financial investment. The main epidemics were brought on by the emergence or mutation of new races of *Puccinia striiformis* f.sp. *tritici*, followed by the rapid loss of resistance genes.

The most recent and most destructive epidemics have affected China, Northern and Eastern Africa, Western Asia, Central Asia, and the Middle East. These epidemics may become even more aggressive with the emergence of races that can endure and develop in higher temperatures. The prevalence of disease outbreaks is still being driven by the new races of yellow rust, which have greatly improved tolerance to warmer temperatures. A succession of regional yellow rust epidemic outbreaks have been documented globally during the past ten years, including in Central and West Asia, East and North Africa, and other regions. The 2009–2010 pandemic had a significant impact on a number of nations, including Morocco, Turkey, Algeria, Syria, Lebanon, Iraq, and Uzbekistan. Syria and Lebanon were particularly hard impacted by the pandemic; Syria lost over half of its wheat production for bread. Yellow rust has been a serious problem in East Africa since 2010, costing the low-input farming approach money. In 2010 widespread outbreaks were seen in Tajikistan; later, they were seen in Uzbekistan and other Central Asian nations, including

Ethiopia. These recurring outbreaks endangered the supply of seeds for the following growing season in addition to causing financial losses and increasing the requirement for fungicide sprays.

Discussion

Management strategies

Cultural practices: The utilization of a number of cultural activities greatly reinforces the already present forces of resistance. However, when used alone, cultural techniques including delayed planting, reduced irrigation, avoiding the overuse of nitrogen and removing weeds and grass plants may not be economically advantageous. The seasonal production and accumulation of urediospores are also decreased by crop rotation, along with the genetic diversity of the pathogen population [58]. Another important element affecting quantitative resistance to foliar diseases is high Nitrogen (N) content in the diet, which increases the severity of several foliar diseases. This could be caused by changes to the plant's biochemical processes or the emergence of a microclimate conducive to the growth of fungal diseases as a result of increased crop density and canopy size. The availability of nitrogen to a crop can thus be one of the crucial factors controlling canopy growth as well as the incidence and severity of yellow rust [59]. Cultural practices can help control yellow rust epidemics by avoiding over fertilization with nitrogen based fertilizers, eliminating refuges for the disease like susceptible grasses and volunteer wheat, avoiding overwatering, especially when conditions are favorable for infection, and reducing connectivity of susceptible host populations. Although cultural approaches can have a considerable impact on the management of yellow rust, they are typically constrained by the environment and crop productivity.

Use of resistance host: The most efficient, affordable, user friendly and ecologically responsible method of controlling yellow rust is seen to be the development and cultivation of resistant cultivars. Nine genes for yellow rust resistance from bread wheat have so far been cloned, and they have substantially advanced our understanding of the trait. These genes are *Yr18, Yr36, Yr10, Yr46, Yr5, Yr7, YrSP, Yr15*, and *YrAS2388R*. The most economical and eco-friendly method of creating resistant cultivars of wheat is to enhance genotypes by adding yellow rust resistance genes and testing them in hot spot areas. There are numerous ways in which genetics, environment, and their interactions affect the yield of bread wheat cultivars. The best way to reduce yellow rust-related losses in wheat is to grow new strains that have been found to be disease resistant [60]. Over 300 Quantitative Trait Loci (QTL) for yellow rust resistance have been reported so far, along with 83 formally named genes, 67 provisionally designated resistance genes and 67 genes. The majority of these QTL and genes have been generated with markers for marker assisted selection, especially those that have been discovered in the last ten years. To create wheat cultivars with sufficient and long lasting resistance to yellow rust, phenotypic testing of breeding materials is still necessary. This must be done (1) In the field and under controlled conditions, (2) At various growth stages, and (3) At various temperatures, with (4) Dominant races of the pathogen. Due to this genetic trait, virulent *Puccinia striiformis* f.sp. *tritici* races quickly arise. The high repeatability, genetic diversity as a result of sexual recombination, long-distance dispersal capability, and environmental adaptability of this virus all contribute to its great variability.

Biological control: Pathologists current research focuses on the use of bio control agents to prevent rust. In bread wheat field trials, the efficacy of biological controls, including Bacillus subtilis strain QST 713 suspension concentrate (Serenad®ASO), was examined for the prevention of yellow rust. There have been a few documented cases of yellow rust biocontrol or yellow rust urediniospore suppression using plant extracts or endophytic microorganisms. Easily isolated from plant tissues or cleaned surfaces are endophytes, which are germs. In order to treat the infection without endangering the environment, endophytic bacteria were isolated from bread wheat varieties that were resistant to yellow rust. Bacterial strains *Serratia marcescens, Bacillus megaterium, Paneibacillus xylanexedens, Bacillus subtilis* and *Staphyloccus agentis* greatly suppressed the germination of urediniospores. Bacillus subtilis has been one of the most thoroughly studied biological control agents for yellow rust. Bacillus subtilis QST713 treatments in semi field settings have shown that timing is crucial for effective control. On the day of the vaccination or one day later, the best control was attained.

Fungicidal control: Unfortunately, wheat breeding programs are not well equipped to handle these strains, leaving farmers with cultivars that are extremely vulnerable to rusts and necessitate the use of fungicides. Yellow rust management heavily relies on the use of fungicides due to the lack of bread wheat cultivars resistant to all *Puccinia* *striiformis* f.sp. *tritici* races and the fact that Yr genes are defeated by new, continuously created strains. The creation of powerful fungicides is one of the key accomplishments in the fight against plant diseases, particularly stripe rust [61]. Farmers were frequently helpless before the early 1980's if yellow rust began to affect their crops. Today's farmers can control yellow rust with more than 40 chemical formulations and have access to more defense weapons against plant infections. Since late treatment of fungicides renders them ineffective, timely application is necessary. Numerous factors must be taken into account for chemical control to be effective, including the following:

- The stripe rust season lasts several months since the stripe rust pathogen can infect wheat plants from emergence to foliage turning yellow.

- Because fungicides typically protect crops for 20 to 40 days depending on the chemical, two or more applications are sometimes required. Foliar fungicide treatment had increased as a result of wheat varieties' decreased yellow rust resistance.

Since 2000, new, aggressive strains have appeared and crossed international borders, triggering catastrophic pandemics in the world's warmer regions. In the last 20 years, this new scenario has caused yellow rust to spread globally, necessitating the use of fungicides as a crucial disease control measure [62]. For instance, the worst yellow rust epidemics since the 1930's devastated Argentina in 2017, affecting about 3,000,000 hectares.

Field trials revealed average yield losses of 3,700 kg ha^{-1} (53%) and up to 4,700 kg ha^{-1} (70%) in extreme cases where the disease was not controlled by fungicides, demonstrating a negative correlation between grain production and disease severity. If not, economic losses could reach $500 USD every year. Fungicides can be used efficiently and on time to boost crop production. The spray interval is a crucial factor in reducing disease severity and the rate at which epidemics develop since, under experimental conditions, sprayed plots generated significantly more than unsprayed plots [63]. The life of fungus and creatures that resemble fungi is dependent on a number of cellular processes that fungicides affect. The mode or Mechanism of Action (MOA) of a fungicide molecule is one approach to categorize how it prevents the growth or eradicates a certain fungus. There are currently 11 different modes of action included in the Fungicide Resistance Action Committee (FRAC) program [64]. It is advantageous to treat seeds with fungicides to prevent yellow rust, particularly in areas where the disease is common, highly sensitive types are produced and attacks by *Puccinia striiformis* f.sp. *tritici* happen during the early vegetative phases of wheat. Sometimes, fields that were effectively treated against yellow rust before they were seeded can postpone or reduce the number of foliar sprays.

In all locations of the world where bread wheat is grown, there are already a wide variety of fungicide commercial formulations with one or more active components that are registered and/or advised for controlling yellow rust. Although the efficiency of the fungicide active ingredients may vary depending on the field dose, the most of the registered fungicides have demonstrated high yellow rust control when used as directed. The amount of inoculum in the field plot decreases when fungicides are applied timely to infections in lower leaves, even before the top leaves have developed. Given that the inoculum in the field plot is minimized, this method is useful for applying indirect protection to leaves that have not yet emerged. In most cases, wind is responsible for spreading the initial or primary inoculum of bread wheat yellow rusts into fields, although multiple reinfections within a field are primarily caused by previously infected leaves, especially the lower ones in the canopy. The best time to apply fungicides is not predetermined, according to Chen and Kang and it basically depends on the moment when the disease in the crop first appears, the concerned cultivar, the environment, the region taken into consideration, and the economic factors at play [65]. Sharma, et al. demonstrated, however, that lower concentrations of various fungicides can provide effective control and be profitable when the disease pressure is not too great. Generally speaking, the quantity of fungicide applications required to control bread wheat yellow rust depends on the inoculum pressure, the cultivars level of resistance, the timing of the disease's emergence in the field and the presence of conditions that favor the spread of an epidemic of yellow rust.

Integrated management: When other disease control measures are unsuccessful, integrated disease management employs selective pesticide application based on agronomic factors (such as crop rotation and management), mechanical, physical and biological considerations. An integrated strategy combining the production of disease resistant cultivars, prudent application of fungicides and proper cultural methods can control the disease on crops. With the use of modern techniques, growers may now minimize potentially substantial output losses by using an integrated management strategy that combines cultivar resistance, prudent fungicide usage, and proper cultural practices. To effectively combat bread wheat yellow rust disease, comprehensive management measures are required due to the pathogen's complexity. Long term prevention requires integrated methods and practices rather than a single control tool. The use of disease resistant cultivars is the primary technique of disease prevention, but further precautions should also be taken to stop any potential outbreaks by correctly applying fungicides. For effective disease monitoring and timely pesticide application, forecasting models and technologies are required. Additional agronomic strategies like eliminating green bridges between crop cycles, variety rollout, sufficient watering and fertilization should also be taken into account. The best disease management requires complete understanding of the pathogens life cycle and adoption of all available management methods. Depending on the types of plants to be grown and the diseases, a range of techniques are used in integrated management systems [66]. It involves a number of different techniques, such as variety selection, crop rotation, volunteer management, stump removal, clean seed use, seed and/or fertilizer treatments and foliar fungicide sprays.

According to Hovmller, et al., research on various topics related to the proper use of fungicides to control cereal rusts (optimal time of application, optimal field dose, effectiveness of new molecules, monitoring sensitivity/resistance to fungicides, etc.) has received little attention and funding in many areas. Many resources for research on cereal rusts have concentrated on the genetic molecular identification of races and development of resistant wheat genotypes, despite the pathogens being crop destructive, having high epidemiological rates, having genetic variability of races and some of them having sexual reproduction [67]. According to the following two factors, this situation might be explained: It is obvious that genetic resistance has traditionally had great effectiveness in the control of various rusts, particularly the yellow rust, at least up until 2011, when new races that were better adapted and more aggressive broke the resistance of several cultivars in significant wheat regions [68]. Many triazoles, including triticonazole, flutriafol, fluquinconazole and the novel carbo amide fluxapiroxad fungicide, which shown great control efficacy, are currently advised for use as a seed treatment for yellow rust prevention. The integrated disease program should take fungicide seed treatments for yellow rust control into consideration [69].

Conclusion

Bread wheat is serves as a major portion of the global population's fundamental staple diet. However, a variety of fungi can cause diseases to the crop. Everywhere bread wheat is grown around the world, rust is a serious airborne disease caused by *Puccinia striiformis* f. sp. *tritici*. Environmental factors favor yellow rust infection, which can occasionally develop into an epidemic, across the majority of wheat growing regions of the world. It is an obligatory parasite that must have a living host in order to complete its life cycle. The yellow lesions that develop systemically as streaks between veins and on leaf sheaths set yellow rust apart from other rusts. Because the symptoms include narrow, yellow orange stripes of pustules, the infection is also known as yellow rust. Depending on environmental factors, inoculum levels and sensitive host varieties, yellow rust disease affects cultivated wheat to varying degrees. This disease reduces the quality and yield of the wheat crop and damages the leaves, which results in a stagnation in grain filling, a drop in kernel weight, thin seeds, and a reduction in yield. Yellow rust can spread to new geographical areas due to the long distance transmission of the yellow rust pathogen in the air and occasionally by human activities.

Expanded virulence profiles are a result of the establishment of newer races of *Puccinia striiformis* f. sp. *tritici* with high epidemic potential and the ability to adapt to warmer temperatures. Therefore, races are more aggressive than those that were previously described. However, a significant issue is the breakdown of variety resistance that occurs after the introduction of additional resistance genes. The primary methods for preventing yellow rust include early sowing, foliar fungicide application, and development of resistant cultivars and integration of these methods. Since yellow rust is an old issue, it is also necessary to monitor the pathogen constantly and to do additional research to create cultivars that are resistant to it because it will continue to pose a threat to the world's output of wheat. In order to validate the role of the host in nature and since *Berberis* species could be a major method of pathogen survival between cropping seasons, the researcher should take these species into consideration while conducting surveys in areas of interest.

Conflict of Interest

The authors have no any conflict of interest.

Data availability statement

The reviewed and datasets generated and/or collected during the current review are available from the corresponding author on reasonable request.

Competing interests

The authors have no relevant financial or non-financial interests.

Author contribution

Adane Fentaye Belay (BSc.) original draft preparation, conceptualization, methodology, data arrangement, writing, reviewing and editing.

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