Official publication of Pakistan Phytopathological Society
Pakistan Journal of Phytopathology
ISSN: 1019-763X (Print), 2305-0284 (Online)
http://www.pakps.com

PUCCINIA TRITICINA: WHEAT STRIPE (YELLOW) RUST PATHOGEN: A REVIEW

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ABSTRACT

Stripe rust of wheat is commonly known as yellow rust disease of wheat (*Triticum aestivum* L.) caused by *Puccinia triticina*. This disease is among the most important diseases of wheat globally. Present review presents the basic and recent information regarding the epidemiology of stripe rust with signs and symptoms of disease on an infected crop. Identification and control of the disease is becoming challenging due to lack of information, thus present review had been summarized for the understanding of local farmers and experts. Yellow rust is the foliar disease of wheat, fungal spores of *P. triticina* are also termed as air born disease as causative agents of disease spread through wind. Pathogens of rust disease are the potential source of reducing yield and production. These causative agents are host specific and had a great potential to reduce yield around 70-100% in case of susceptible wheat variety. Pathogenic strains of stripe rust infect the green tissues of crops, chances of disease infection are equal at any-time of one leaf stage of crop. However, the symptoms of disease appear after one week of an infection while sporulation starts just after two weeks of infection having optimum conditions of an environment. Just after disease attacks, tiny, yellow- to orange-colored rust pustules appear on an infected area which is called as uredia, having thousands of uredinio spores in each uredium, which is not visible through naked eye. These spores are usually yellow to orange in color and are powdery in nature. The type of symptoms appearance on an infected crop depends upon the nature of resistance in specific crop. Cultivation of resistant wheat varieties with the applications of effective fungicides are the possible solutions of these pathogenic spores. However, selection of suitable wheat variety and the cultivation of crop at right time keeping in mind the other environmental factors such as temperature and moisture would be important for wheat cultivation.

Keywords: Rust disease, Wheat, Stripe rust, Crop, Yellow rust, Damage, Yield, Losses, and Resistance.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is most important food crop for the people of Pakistan, India, Bangladesh, China, and Russia, it is used as a food source in various forms in United states (Balkrishna *et al.,* 2022). Due to having a variety of important nutrients wheat has immense value and is cultivated in all the agricultural countries. As the production of this crop is always under consideration and in demand, there are certain biotic factors hindering the production of crop. Rust diseases of wheat are the among most common, it had been reported that these pathogens are causing economic losses in case if highly susceptible (HS) wheat cultivars grown (Desaint *et al.,* 2021). Approximately 40-70% yield losses had been recorded due to rust diseases of wheat. It is grown largely around the globe as occupies around 22% of the total agricultural land in the world (Leff *et al.,* 2004; Hussain *et al.,* 2011). Wheat production increased immensely during the year 2015 and 2016, (734) Mt while according to an estimation it was thought to reached 757 Mt during 2017-2018 (FAO, 2018). According to study of Siad *et al.* (2017) European Union is on the top producers of wheat with an average of 155 million tons in 2014, while China was marked as second highest wheat producer with the production of 126 million tons, production in India was

Submitted: June 19, 2023
Revised: July 24, 2023
Accepted for Publication: August 10, 2023
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recorded 95 million tons while production of wheat in Russia was recorded 59 million tons. Though United States, Canada, Australia, the European Union, Russia, Ukraine, and Argentina had been the major wheat exporters (USDA, 2014; Ruan *et al.,* 2021).

Stripe rust of wheat is also called the yellow rust disease of wheat which is caused by the attack of (*Puccinia triticina*) *Puccinia striiformis* f. sp. *tritici* (Ghimire *et al.,* 2020). It is usually marked as air born disease due to its foliar nature. However fungal pathogens causing stripe rust, flourish more rapidly in case of favorable condition (low temperature with humidity). Most suitable temperature for its growth is 10-15 °C. Due to having similarities with other rust fungi it had be thought as a macrocyclic rust. Pathogens of stripe rust had *Berberis* spp. as an alternative host and complete their complete life, which was first reported completely by Jin *et al.* (2010). *P. striiformis* commonly attack on wheat, as a primary host and on few *Hordeum vulgare* cultivars worldwide. There are some species attacking barley specifically in Europe and South America. These pathogens are from Pucciniales of the Basidiomycota, which are considered the obligate parasite due to its nature of spending half-life on wheat and half on another living host (Figueroa *et al.,* 2018).

P. striiformis Westend. f.sp. *tritici* is the pathogen of wheat which causes infection and is coined by Hylander *et al*. (1953) which was further supported by Cummins and Stevenson (Line, 2002; Chaloner *et al.,* 2021). Process of assigning specific name to these pathogens had taken huge time meanwhile there were numerous names given to specie such as, *Uredo glumarum* given by Stubbs, 1985, after that they were known as *Puccinia striaeformis* reported by Westendorp, 1854, further they were also termed as *Puccinia straminis* (Fuckel, 1860), *Puccinia glumarum* (Chen, 2005; Velásquez *et al.,* 2018). Plants of an infected crop become stunted, due to nutrient deficiency in infected plant as pathogen utilizes nutrient content crop plant (Chen, 2005; Velásquez *et al*., 2018).

Symptoms: Pathogens of stripe rust infect the green tissues of plants of cereal crops and grasses. There are equal chances of an infection at any time of one leaf stage to plant. Symptoms of disease appear after about 1 week of an infection while sporulation starts about 2 weeks after infection having all the optimum conditions of an environment. After the attack on crops these fungal pathogens form tiny, yellow- to orange-colored rust pustules which are termed as uredia, having thousands of urediniospores in each uredium, which is not visible through naked eye. These spores are usually yellow- to orange in color and are powdery in nature. Type of symptoms appearance on an infected crop depends upon the nature of resistance in specific crop (Chen, 2005). There are some important signs of stripe rust on an infected crop (wheat), such as yellow-colored streaks marked as pre-pustules. While appearance of bright yellow uredial pustules arranged on leaf in a narrow row and appears on sheath and awn of infected crop (Figure 1 A-D). In some wheat varieties a long yellow colored stripe develops on the leaves, while in some variety's leaves become brown and shrink.

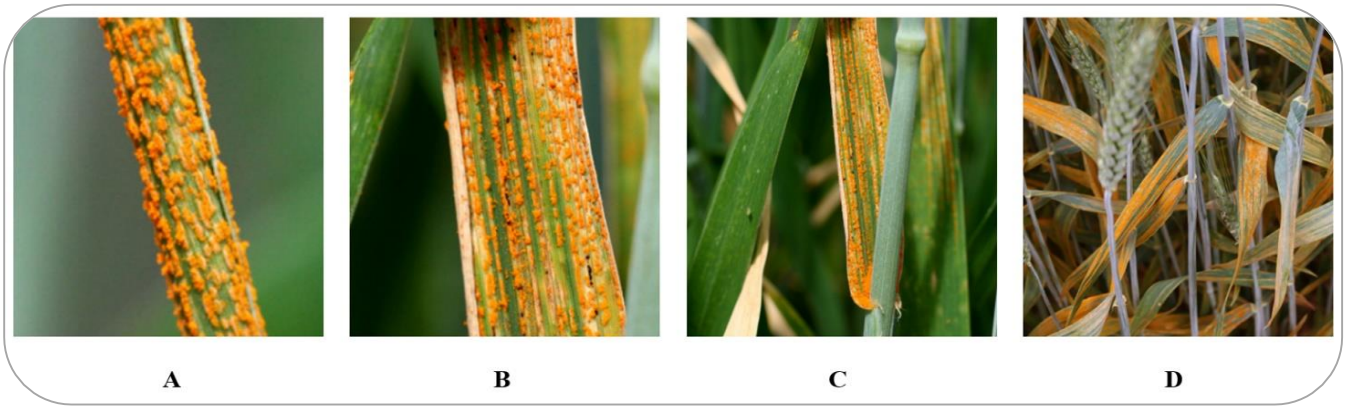

Figure 1. A-D: Bright yellow elongated uredial pustules, arranged in row on leaf sheath glumes and awns on an infected crop (Bouvet *et al.,* 2021).

Appearance of clear and bright yellow spots and flecks on wheat crop clearly indicate the attack of stripe rust on crop, which could be easily noticed morphologically. Disease starts spreading from a single infection that can result in the length of entire leaf with having small uredinia of yellow color which usually appears in a narrow rows on the leaf, along with small pustules throughout the leaf blade. Symptoms of infection are also seen on the spikes of an infected crop, telial sori develops on leaf blades and sheaths on infected plant as dark brown to black stripes that remain covered by the epidermis. Stunting growth and weakness of plants is an intimation of infections at early stages.

It is very difficult to say which stage of plant growth is most likely to develop disease as all the growth stages of the crop are exposed and vulnerable (Line, 2002). The most common and obvious symptoms of infection are the appearance of a small, yellow spots or flecks that emerges on leaf sheaths, which develop into long and narrow stripes on leaf sheaths, glumes and awns on an infected crop. After the emergence of disease, yellow-orange masses of uredinio spores were seen released after the breakdown of mature pustules, in that way an infected cell/tissues becomes brown and dry when plants begin to senesce or become stressed. Due to severity of an infection plant growth becomes stunt as it suffers desiccation (Line, 2002; Chen, 2005; Singh *et al.,* 2017).

Life cycle: The life cycle of *P. striiformis* is complicated, it had a significant role in the spread and survival of this destructive plant pathogen (Figure 2 and 3). Understanding of its life cycle is crucial for effective management strategies for the control of disease spread to overcome damages to cereals especially wheat Life cycle of this pathogen starts at the dispersal of uredinio spores, inoculum is usually carried out through wind currents. Pathogenic spores of this crop had a great potential to infect another (alternative) host as well. These spores will reach to the susceptible crop at favorable conditions, which will germinate after reaching to vulnerable crop, and germ tube will emerge. Which will then enter in the plant parts passing through epidermal parts. After entry of spores, they will spread till tissues through developing supporting structures (haustoria) and disrupt the normal body functions of plant. After the onset of disease attack pathogens will take nutrients from an infected crop which will show visible symptoms on crop (Zheng *et al*., 2013; Carmon *et al*., 2020). Life cycle of *P. striiformis* is completed in two phases (sexual and asexual) using two hosts (Figure 1) respectively, (Berlin *et al*., 2017). The complete life cycle of this pathogenic strain comprises of five different types of spores (Schwessinger, 2017).

The most important and noticeable thing about its life cycle is that its urediniospores and teliospores are dikaryotic, whereas teliospores produce haploid basidiospores (Chen, 2005). Whereas both the pycnial and aecial spore stages of pathogen were not studied is past and are added recently (Jin *et al.,* 2010).

Urediniospores, teliospores and basidiospores are produced on the primary host which is the diakaryotic phase. Life cycle enters the next stage as the nutrient supply is cut off from an infected part. Teliospores induces the spring to yield four haploid basidiospores which causes infection in an alternate host (Sørensen, 2012; Baily, 2013) due to which both pycniospores and aeciospores are produced on the upper and lower leaf surface, respectively (Jin *et al.,* 2010).

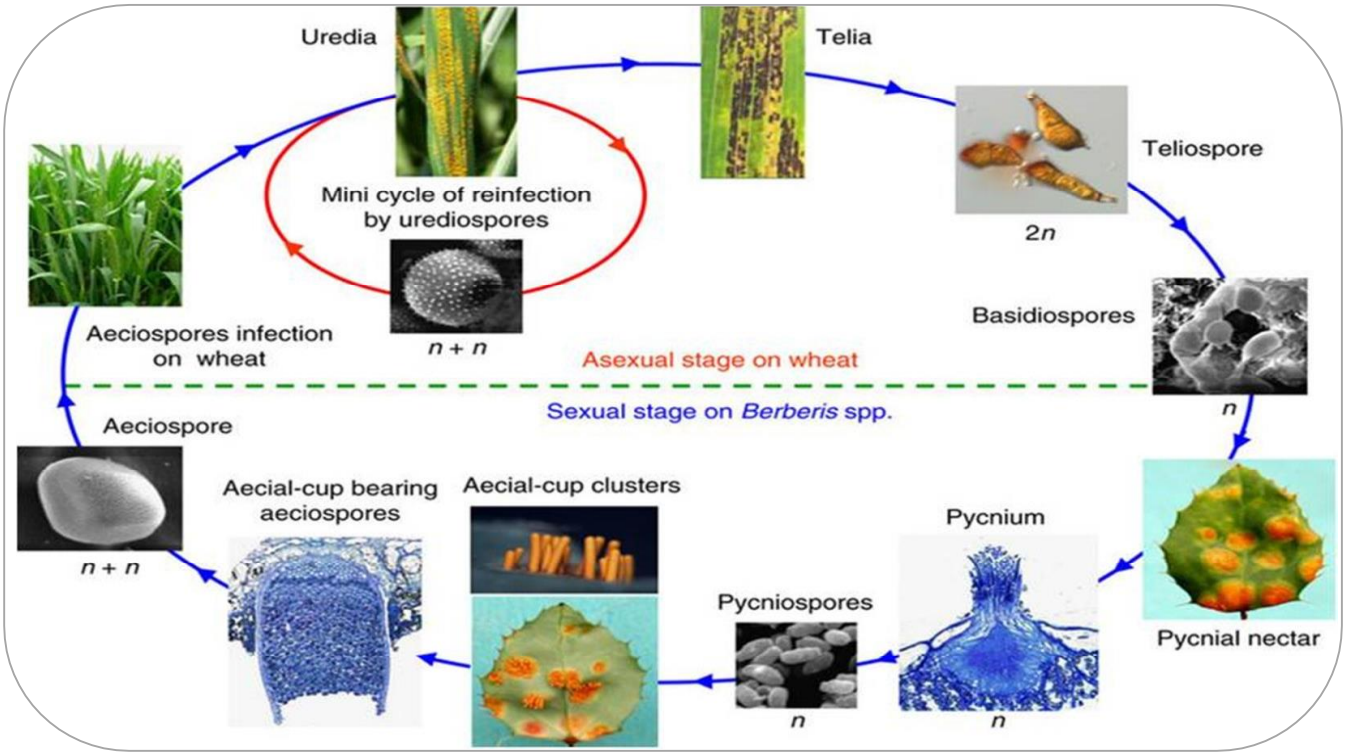

Figure 2. The life cycle of *Puccinia striiformis* f.sp. *tritici* (Zheng *et al.,* 2013; Carmon *et al.,* 2020)

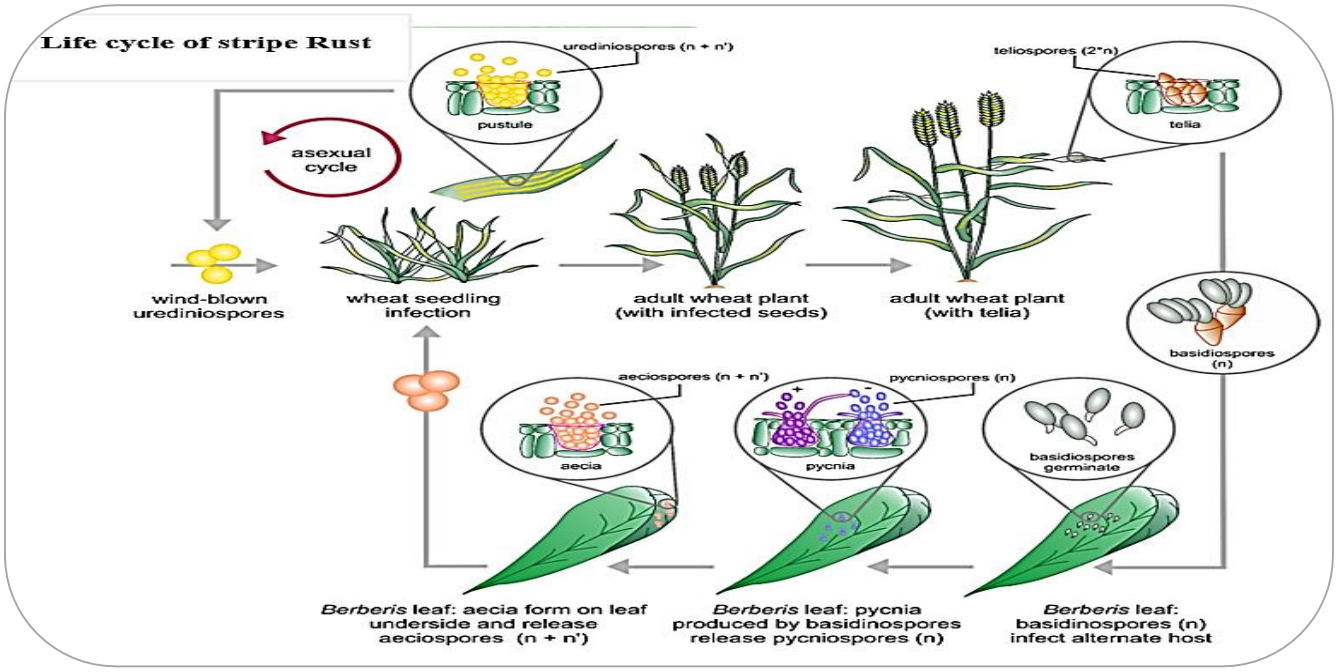

Figure 3. Illustration of Stripe rust (*Pst*) life-cycle (Bouvet *et al.,* 2021).

Morphological observations of Spores: Urediospores, of *P. striiformis* are yellow to orange in color, while they are very small in size having a diameter of 20-30 *µm* having spherical shapes. Therefore, their teliospores are entirely different in color (dark brown to black) and are two cells in thickness. There are no clear differences in the size and shape to those of *P. recondita*, so differentiation of spores on the basis of size and shape of spores becomes difficult. The only difference is in the cap or crown which is flattened not rounded in stripe rust. Figure 4 presents the morphological pattern of *P. Striiformis* (Chaves, 2008).

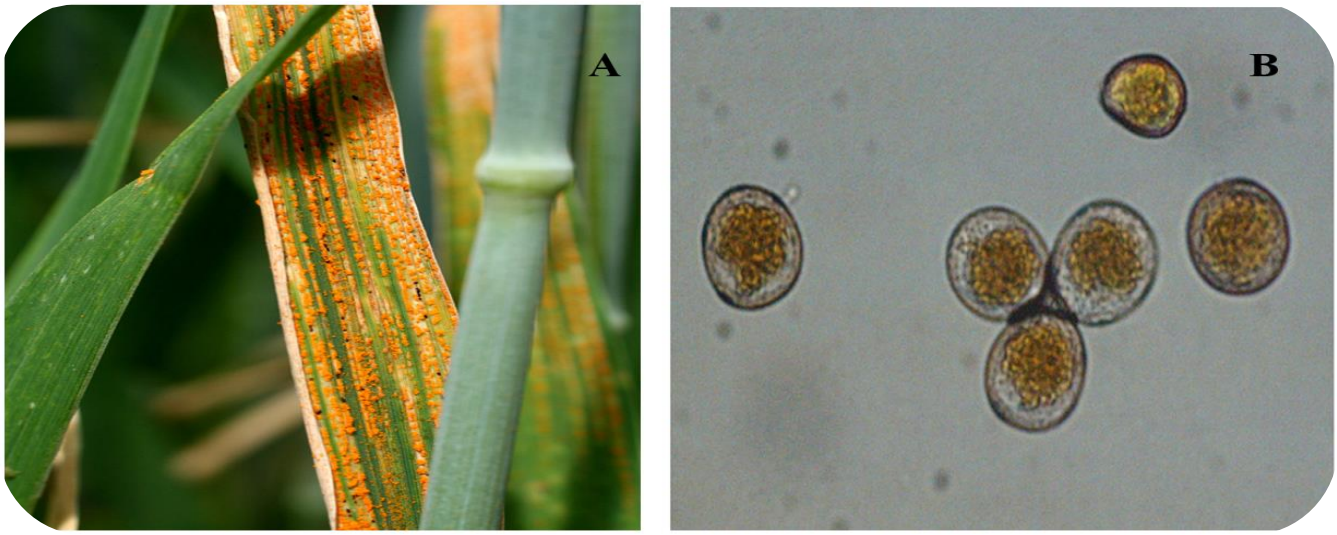

Figure 4. A: Morphological patterns on an infected crop B: orange to yellow color uredospore's

Due to certain limitations, the detailed process of infection was not clear till, 1981 by Cartwright and Russell. They conducted a study using leaf samples from both seedling and mature plants. They have reported that these pathogens entered the crop through stomata. After the germination of spores germinative tube formed which moves along the leaf after growth and enter via stomatal opening (Sørensen, 2012). It had been reported that *P. striiformis* does not differentiated in to an appressorium (Moldenhauer *et al.,* 2006; Kumar *et al.,* 2020). The process of primary infection initiated after the entry of pathogen to stomatal apparatus, which

further initiated the formation of a haustoria mother cell (hmc), which usually develops between cell wall and plasma membrane (Sørensen, 2012). After primary infection, pathogenicity goes to the next level, which is secondary infection, at which hyphae develops from that of primary infection. Symptoms of disease appeared after one week of infection, in the form of chlorosis, flecks and spots. Clear, yellow-colored distinctive spots on the leaf appear just after sporulation (Chen, 2005; Sørensen, 2012).

Types of Infections: Formation of uredinia on an infected crop leaves in a clear indication of disease, which can lead towards cellular death, due to which chlorosis or necrosis appears as spots and flecks. Therefore, different parts of infected crops are presented in Figure 5 as necrosis versus sporulated areas which is used as infection types (ITs) for the description of plant-pathogen interactions.

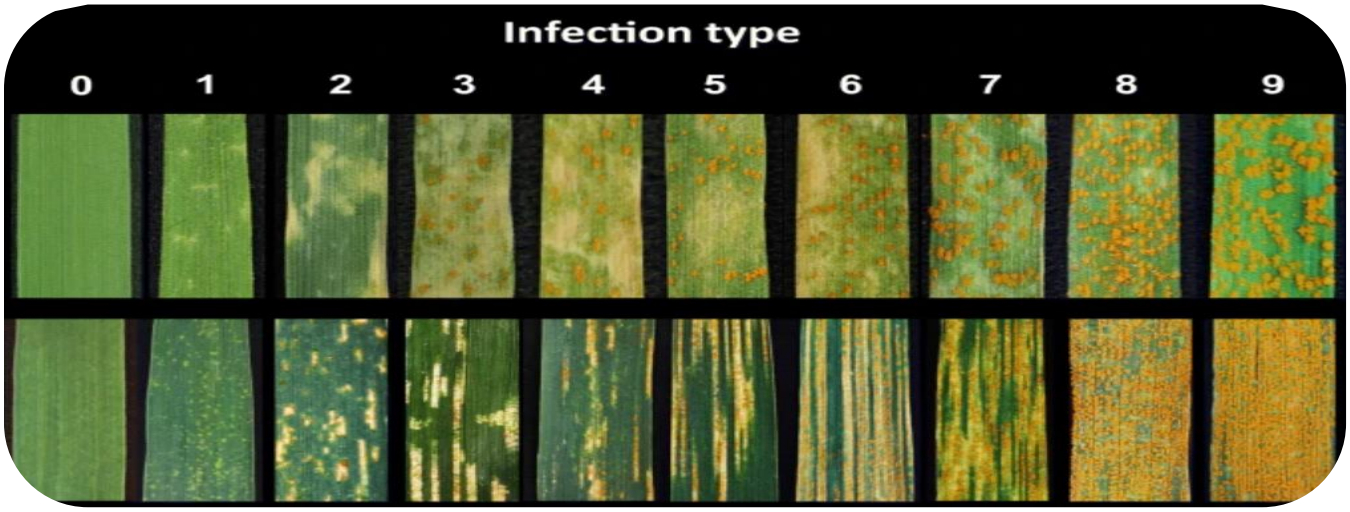

Figure 5. Illustration of types of infections of *Pst* shown on both seedling (top) and mature plants (bottom).

Impact of stripe rust: Stripe rust is one of the most dangerous diseases of wheat which causes huge yield losses worldwide, this is not only reducing grain, but forage is also affected negatively. Seeds banks stored after harvesting diseases crops also have negative impact in nutrition as well in production. If crop is exposed to the disease in very early ages, there would be a chance of getting 100% yield loses. Degree of infection and severity of disease depends upon the type of variety which was cultivated. There are some other factors affecting the severity of disease such as time, temperature along with the environmental factors. Severity of infection increases 10-70% depending upon the types of cultivars being cultivated. Yield loses due to this pathogen is reported globally, though such records were not reported until 1958 when a loss of 2.9 million bushels (about 78 996 t and 4% of production) was recorded for the State of Washington (Shahin *et al.,* 2020; Chaloner *et al.,* 2021). Although the worst record of yield losses was seen in Washington State such as 25% (591 108 t) in 1960 and 17% (787 236 t) in 1976. However, it had been reported since last 46 years in the states of Washington that stripe rust of wheat is the most important reason of yield losses, which attack this crop annually (Kumar *et al.,* 2020). Stripe rust of wheat had been recorded as the important reason of crop damage as it appears very early in crop and stunt the plant growth worldwide. It is not only responsible for reducing yield but the forage and the quality of seed which becomes the alarming barrier for grain export. However, in case of vulnerable wheat varieties sign of infection start development at seedling (Chen, 2005).

Stripe rust management: For the management of disease, it had been thought commonly that use of resistant varieties instead of old and traditional varieties could be the best possible solution. However, disease attack will be manageable if cultivation of wheat is done after the application of effective control measures. The most important measure is the monitoring of crops and trap nurseries so that early decision can be made on whether fungicide sprays would be beneficial or not (Cook, 2003).

Using plant resistance: With the advancement of technology and science it has been made possible to control crop damage due to these fungal pathogens. Use of modern and resistant cultivars is the most efficient method of controlling disease/infection which is considered as an economic tool. Though till now around 187 rust resistance genes had been reported by experts (Aktar-Uz-Zaman *et*

al., 2017). With the conservation of more than half a million wheat genetic resources, along with their wild relatives in gene banks. For increasing yield breeding of these resources is crucial with the appropriate genetic diversity, which is the need of an hour (Longin *et al.,* 2014; Ghimire *et al.,* 2020).

Using fungicides: Use of chemical-based solutions to combat these crop enemies are common now a days. Fungicidal applications are the most important in case of susceptible or tolerant species (Line, 2002; Chen, 2005; Wan *et al.,* 2007). There are certain compounds and substances which are available to solve these problems. There are numerous fungicides available at commercial level globally such as, Tilt, Evito, Quadri, Prosaro, Stratego and Quilt (Chen, 2005; Carmona *et al.,* 2020). Morocco is one of the most vulnerable wheat varieties, there are some active constituents which had been labelled to control stripe rust such as propiconazole, azoxystrobin, propiconazole in combination with trifloxystrobin, strobilurin and azoxystrobinin combination with propiconazole.

Cultural methods: There are certain cultural methods, used traditionally to partially control wheat stripe rust, these practices enhance the natural resistance in crops. Crop managemental strategies include combination of crop choices, selection of right time for cultivation, seedings with the removal of tillers of cereals (Roelfs, 1992; Wan *et al.,* 2007). These fungal pathogens required green material for their survival from one season to next, it is known as "green bridge". Removing volunteer plants which support the stripe rust would be an important and effective control to manage epidemics which arises from endogenous inoculum (Roelfs, 1992).

Challenge of stripe rust control: With numerous other factors, climatic conditions are the most important challenge such as increased temperature that affects the normal growth and development of wheat crop (Juroszek *et al.,* 2013). Increase and decrease in temperature affect the crop positively and negatively, some-times grain filling remains low and plant senescence increased in case of increase in temperature more than 34 °C (Asseng *et al.,* 2011; Asseng *et al.,* 2015). This increase in the senescence period would negatively impact the crop thus enhancing the chances of development of infections and conditions become suitable for pathogen attack. Likewise increase in temperatures also directly increased diseases development (Juroszek *et al.,* 2013). Results clearly indicate that pathogens have adopted the defense mechanism and are adapted to high temperature (Chakraborty *et al.,* 2011; Rolnick *et al.,* 2022).

CONCLUSION

Based on collected data and information it is concluded that stripe rust is the deadly disease of wheat which appears as yellow to orange spots on wheat stripes. Due to having very small size these fungal spores are not seen with naked eye initially, but spores become prominent as necrotic spots and flecks on an infected crop. Cultivation of resistant varieties instead of susceptible cultivars overcomes the yield losses and would be helpful to solve the problem of world hunger.

Future recommendations: Collection and presentation of more appropriate and summarized information for stripe rust of wheat is required for future studies.

AUTHOR CONTRIBUTION

RB: Collected data and prepared the first draft and give final form to the review for publication; All others review and give consent for publication in Pakistan Journal of Phytopathology.

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Sidra Batool	:	Helped in data collection
Afshan Arshad	:	English editing services and formatting
Qurat U.A. Fatima	:	Helped in data collection
Atef A. Shahin	:	Reviewed the whole manuscript carefully and give final approval
Shamma Firdous	:	Helped in the identification of fungal strains
Mafia Shafique	:	Technical support