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RESEARCH ARTICLE

Biometrical Characterization of Wheat Genotypes for Resistance Against Yellow Rust Under Semi-Arid Climate

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ABSTRACT

Wheat (*Triticum aestivum* L.) is the staple food crop of Pakistan fulfilling the daily caloric need of the country. Yellow rust (YLwRST) is among the most perilous disease affecting the wheat crop. Emergence of novel races of rust pathogens is making it difficult to curtail the losses caused by this disease. Development of resistant varieties is now vital to effectively manage the disease. Thus the present study was conducted, in the research field of the Department of Plant Pathology, College of Agriculture, University of Sargodha, to find out the disease response (DS) and disease severity (DS) of the 533 genotypes, against YLwRST, acquired from National Agriculture Research Council (NARC), Islamabad. The genotypes were screened against YLwRST in the semi-arid climate of Sargodha. Genotypes were sown in augmented design without replication. The results delineated that 68 genotypes were immune to YLwRST. The genotypes that showed resistant, moderately resistant (MR), moderately susceptible (MS) and susceptible responses to YLwRST included 96, 139, 173 and 57 genotypes, respectively. AUDPC based interpretation of varieties was also performed and it was found that the genotypes showed varying values of AUDPC. It is appraised that the genotypes, that were found resistant to YLwRST can be employed in future breeding programs either to find out a specific gene or a combination of genes in such genotypes to evolve durable highly resistant cultivars.

Keywords: Wheat, yellow rust, *Puccinia striiformis*, screening, resistance, genotype.

INTRODUCTION

Wheat (*Triticum aestivum* L.) belonging to the family Poaceae, is the primary cereal crop grown worldwide (Mehboob *et al.*, 2015; Arif *et al.*, 2025). The importance of this cereal is evident from the fact that it is the predominant ingredient in many foods, especially processed ones, and it also requires less water for cultivation as compared to other commensurate crops (Maças *et al.*, 2024). The consumption of wheat

accounts for 19% of the total caloric intake in the global human diet (Biel *et al.*, 2020).

Globally wheat production has decreased from 811 million tonnes in 2022 to 799 million tonnes in 2023 (FAOSTAT, 2025). This drop in yield is alarming and occurred despite the increase in cultivated area from 219 million hectares in 2022 to 220 million hectares in 2023 (FAOSTAT, 2025). China is the largest producer of

wheat with an annual production of 136.6 million tonnes (FAOSTAT, 2025). India is the second largest wheat producer having a share of 13.8% in global wheat production, followed by the Russian Federation, the United States of America (USA), and Australia which have respective shares of 11.4%, 6.1%, and 5.1% (FAOSTAT, 2025).

Anthropocene challenges are now prevalent worldwide and Pakistan is among the most vulnerable to climate change (Ahmad and Afzal, 2024; Ahmad *et al.*, 2024). The adverse effects of climate change, a non-traditional security threat, are not only limited to the destruction of infrastructure, but they are also affecting the livelihoods of farmers and agriculture across the country (Ahmad *et al.*, 2024; Hassan *et al.*, 2024; Usman *et al.*, 2025). This is alarming for a country like Pakistan where agriculture is the backbone of the country's economy (Jaffar, 2024; Lodhi *et al.*, 2024). This significance can be well understood from the fact that agriculture contributes about 24% to the country's gross domestic product (GDP) and holds a share of 37.4% in the employment generation (PES, 2024). Wheat is the staple food crop of Pakistan, holds a share of 9% in agriculture, and contributes 2.2% to the national GDP (PES, 2024). In Pakistan, the cultivated area of wheat, a Rabi crop, spans 9.6 million hectares with a production of 31.4 million tonnes (PES, 2024). Climate change is increasing the severities of rust diseases, affecting both rust pathogens and wheat crop by bringing change in their genetic make-up. New races of rusts are being reported frequently, and one of the major causes of this is climate change. Similarly, climate change is also weakening plant which in turn making wheat crop more prone to rust diseases (Caubel *et al.*, 2017). Since, in Pakistan impact of climate change is more adverse, therefore frequent screening of available germplasm and then selection of resistant genotypes is the best practice to avoid stripe rust epidemics.

To feed the ever-increasing global population it is the need of the hour that the production of wheat must be increased at an expedited rate, but on the other hand, there are a variety of factors that are a hindrance in achieving a substantial increase in the production of this important cereal crop (Yanagi, 2024). Each year many diseases cause qualitative and quantitative losses to the production of wheat worldwide. About 200 diseases of wheat have been reported and 50 of them

are omnipresent and cause eminent loss (Singh *et al.*, 2023).

Wheat Rusts (WHRSTs) have had a detrimental impact on the production of wheat since the time *Homo sapiens* domesticated this crop (Figueroa *et al.*, 2018). WHRSTs hold a significant place in the study of plant diseases. They not only endanger crop production but are also a threat to global food security especially in areas that do not have ample resources to control WHRSTs (Mekonnen *et al.*, 2024). WHRSTs, obligate bio-trophic pathogens, are of three types: stem or black rust of wheat (STmRST), stripe or yellow rust of wheat (YLwRST), and leaf or brown rust of wheat (LFrRST), and their causal fungi are members of basidiomycetes family (Figueroa *et al.*, 2018).

In Pakistan, YLwRST causes significant losses to the production of this staple food crop (Din *et al.*, 2017; Hussain and Shah, 2023). YLwRST is present in over 70% of the areas where wheat is cultivated and causes losses ranging from 10 to 40% in Pakistan, 2022; Mushtaq *et al.*, 2022). Excessive use of fungicides is not only causing resistance in fungi against them but also pose severe environment and health risks (Rani *et al.*, 2024). Novel virulent races and strains of WHRSTs pathogens are emerging, which could overcome resistance in existing varieties (Ali *et al.*, 2022).

Keeping in mind the aforementioned facts, a study was conducted to identify wheat genotypes that are resistant to the YLwRST in challenging semi-arid environment of Sargodha. The objective was to shortlist YLwRST resistant wheat genotypes so that the identified durable resistant advanced lines can either be utilized directly in conventional breeding programs or YLwRST resistant genes can be taken from them to be incorporated into other varieties of wheat to make them resistant to novel races of *Puccinia striiformis* f. sp. *tritici* (PStT) causing YLwRST.

MATERIALS AND METHODS

Field trial: The research field area of the Department of Plant Pathology located at College of Agriculture (COA), University of Sargodha, Sargodha was used to execute the present research.

Acquisition of Germplasm: Five hundred thirty-three wheat genotypes were acquired from National Agricultural Research Center (NARC), Islamabad. These genotypes were then marked with specific labels and kept at room temperature in Plant Pathology laboratory of COA.

Sowing of Genotypes: The research field was prepared. Then the genotypes were sown in the last week of November 2022. The layout of the field trial was in such a way that there were groups of 10 lines and after every group there was a path left vacant. In each line, multiple seeds of a single genotype were sown. The length of each line was kept 1 meter (Figure 1). A widely known highly susceptible variety named *Morocco* was sown as spreader at the start and end of each group. Optimum application of water and fertilizers was also ensured during the research.

Preparation of Inoculum: The field was artificially inoculated with YLwRST in order to generate maximal disease pressure in the field so that the resistance of genotypes against YLwRST can be accessed at utmost prevalence of aforesaid rusts in the field. Suspension of spores of *PStT* was obtained from Crop Diseases Research Institute (CDRI), NARC Islamabad. The acquired spore suspension was mixed in water in a tank and then sprayed

across the field with the help of sprayer.

Gathering of Data and Screening of genotypes against YLwRST: Assessments began immediately upon initial appearance of YLwRST symptoms. Modified Cobb's scale was employed to take the readings of YLwRST data (Peterson *et al.*, 1948). Both the disease severity and responses of genotypes to YLwRST were examined while data collection. The data of YLwRST was acquired on dates 21 March, 28 March and 4 April 2023. The disease responses were characterized as Immune (no symptoms of *PStT* infection) = 0, Resistant (Necrotic regions that may or may not possess tiny uredia) = R, Moderately Resistant (Bearing small uredia encircled by necrotic tissue) = MR, Moderately Susceptible (Medium uredia that might bear some discernible chlorosis excluding necrosis) = MS, Susceptible (substantial uredia lacking necrosis and mild to negligible chlorosis) = S (Peterson *et al.*, 1948).



Figure 1. Sowing of wheat genotypes in the research field of COA, University of Sargodha.



Figure 2. Wheat leaf severely affected by YLwRST

Calculation of Area Under Disease Progress Curve (AUDPC): The Area Under YLwRST Disease Progress Curve (AUDPC) was calculated for each genotype using the formula:

Where, S_i is the disease severity percentage at the i^{th} observation, t_i = time (days) at the i^{th} observation, t_{i-1} = time interval between consecutive observations and n = total number of observations (Shaner and Finney, 1977).

RESULTS

Severity and Response of genotypes against YLwRST:

Severity and response of YLwRST was examined on 533 genotypes. Among the aforesaid genotypes, 68 showed an immune response to YLwRST. The number of resistant lines were 96. While the MR, MS and susceptible responses were demonstrated by 139, 173 and 57 genotypes respectively (Table 1). The severity data was also gathered for YLwRST. Severities

of resistant genotypes ranged from 1 to 50. The severity of YLwRST in MR and MS genotypes fell in the range of 1 to 90 and 5 to 100 respectively. While the susceptible genotypes exhibited severity levels varying from 30 to 100. Among the 173 genotypes, that demonstrated a MS response, 16 showed the maximum DS of 100. Such genotypes include SRTN 76, YRTN 6, YRTN 45, YRTN 57, LRTN 19, LRTN 57, LRTN 63, NUWYT 26, CWV 50, CWV 65, CWV 87, CWV 98, CWV 109, CWV 114, CWV 121 and CWV 134. While 29 out of the 57 susceptible genotypes, including SRTN 20, SRTN 22, SRTN 84, YRTN 15, YRTN 23, YRTN 70, LRTN 1, LRTN 4, LRTN 7, LRTN 20, CWV 11, CWV 12, CWV 23, CWV 24, CWV 29, CWV 31, CWV 40, CWV 42, CWV 47, CWV 54, CWV 55, CWV 66, CWV 84, CWV 93, CWV 107, CWV 108, CWV 120, CWV 178 and CWV 191, manifested DS of 100 (Table 2).

Table 1. Disease Response of genotypes against YLwRST

Disease response	No. of Genotypes	Name of Genotypes
Immune (O)	68	SRTN 46, SRTN 69, SRTN 72, SRTN 73, SRTN 74, YRTN 9, YRTN 10, YRTN 11, YRTN 27, YRTN 29, YRTN 32, YRTN 37, YRTN 39, YRTN 46, YRTN 64, YRTN 71, YRTN 72, YRTN 80, LRTN 2, LRTN 23, LRTN 24, LRTN 26, LRTN 28, LRTN 29, LRTN 31, LRTN 37, LRTN 39, LRTN 42, LRTN 43, LRTN 61, LRTN 77, LRTN 82, NUWYT 4, NUWYT 7, NUWYT 16, NUWYT 18, NUWYT 19, NUWYT 27, NUWYT 31, NUWYT 32, NUWYT 36, NUWYT 43, NUWYT 56, NUWYT 61, NUWYT 62, NUWYT 69, NUWYT 72, NUWYT 73, NUWYT 74, NUWYT 78, CWV 1, CWV 6, CWV 7, CWV 9, CWV 62, CWV 70, CWV 146, CWV 148, CWV 149, CWV 151, CWV 152, CWV 168, CWV 176, CWV 179, CWV 182, CWV 186, CWV 199, CWV 203
Resistant (R)	96	SRTN 2, SRTN 9, SRTN 14, SRTN 18, SRTN 19, SRTN 21, SRTN 24, SRTN 25, SRTN 27, SRTN 30, SRTN 38, SRTN 40, SRTN 41, SRTN 45, SRTN 56, SRTN 58, SRTN 60, SRTN 65, SRTN 67, SRTN 70, SRTN 71, SRTN 77, SRTN 79, SRTN 81, SRTN 82, YRTN 4, YRTN 7, YRTN 8, YRTN 17, YRTN 18, YRTN 33, YRTN 34, YRTN 41, YRTN 49, YRTN 50, YRTN 54, YRTN 56, YRTN 62, YRTN 63, YRTN 65, YRTN 66, YRTN 69, YRTN 73, YRTN 76, YRTN 77, YRTN 79, LRTN 3, LRTN 9, LRTN 11, LRTN 17, LRTN 22, LRTN 27, LRTN 32, LRTN 33, LRTN 38, LRTN 44, LRTN 59, LRTN 62, LRTN 66, LRTN 67, LRTN 76, NUWYT 2, NUWYT 5, NUWYT 10, NUWYT 29, NUWYT 33, NUWYT 34, NUWYT 39, NUWYT 42, NUWYT 45, NUWYT 47, NUWYT 48, NUWYT 52, NUWYT 57, NUWYT 59, NUWYT 60, NUWYT 70, NUWYT 75, NUWYT 76, NUWYT 77, CWV 8, CWV 71, CWV 74, CWV 75, CWV 77, CWV 133, CWV 140, CWV 141, CWV 161, CWV 170, CWV 177, CWV 187, CWV 190, CWV 197, CWV 198, CWV 205
Moderately Resistant (R)	139	SRTN 3, SRTN 4, SRTN 5, SRTN 7, SRTN 12, SRTN 26, SRTN 28, SRTN 29, SRTN 34, SRTN 36, SRTN 37, SRTN 42, SRTN 44, SRTN 48, SRTN 49, SRTN 52, SRTN 53, SRTN 54, SRTN 55, SRTN 57, SRTN 59, SRTN 64, SRTN 68, SRTN 80, SRTN 83, YRTN 14, YRTN 19, YRTN 24, YRTN 30, YRTN 74, LRTN 8, LRTN 14, LRTN 15, LRTN 25, LRTN 30, LRTN 34, LRTN 35, LRTN 36, LRTN 45, LRTN 58, LRTN 60, LRTN 64, LRTN 70, LRTN 71, LRTN 72, LRTN 78, LRTN 79, LRTN 80, LRTN 81, LRTN 83, LRTN 84, NUWYT 1, NUWYT 3, NUWYT 6, NUWYT 8, NUWYT 9, NUWYT 11, NUWYT 12, NUWYT 13, NUWYT 14, NUWYT 17, NUWYT 23, NUWYT 24, NUWYT 30, NUWYT 35, NUWYT 37, NUWYT 40, NUWYT 41, NUWYT 44, NUWYT 51, NUWYT 55, NUWYT 65, NUWYT 67, NUWYT 71, NUWYT 79, CWV 2, CWV 3, CWV 16, CWV 17, CWV 19, CWV 20, CWV 25, CWV 26, CWV 35, CWV 36, CWV 37, CWV 38, CWV 39, CWV 41, CWV 45, CWV 49, CWV 52, CWV 53, CWV 57, CWV 61, CWV 68, CWV 69, CWV 72, CWV 76, CWV 78, CWV 79, CWV 94, CWV 96, CWV 99, CWV 100, CWV 110, CWV 111, CWV 123, CWV 124, CWV 125, CWV 127, CWV 129, CWV 130, CWV 135, CWV 137, CWV 138, CWV 139, CWV 143, CWV 147, CWV 153, CWV 156, CWV 158, CWV 164, CWV 167, CWV 169, CWV 171, CWV 172, CWV 173, CWV 175, CWV 180, CWV 181, CWV 183, CWV 184, CWV 185, CWV 192, CWV 195, CWV 200, CWV 201, CWV 202
Moderately Susceptible (S)	173	SRTN 1, SRTN 6, SRTN 8, SRTN 10, SRTN 11, SRTN 13, SRTN 15, SRTN 16, SRTN 17, SRTN 31, SRTN 32, SRTN 33, SRTN 35, SRTN 47, SRTN 51, SRTN 61, SRTN 63, SRTN 66, SRTN 76, SRTN 78, YRTN 1, YRTN 2, YRTN 3, YRTN 5, YRTN 6, YRTN 12, YRTN 26, YRTN 28, YRTN 31, YRTN 35, YRTN 36, YRTN 38, YRTN 40, YRTN 42, YRTN 43, YRTN 45, YRTN 47, YRTN 48, YRTN 52, YRTN 53, YRTN 55, YRTN 57, YRTN 58, YRTN 59, YRTN 60, YRTN 61, YRTN 68, YRTN 75, YRTN 78, LRTN 5, LRTN 6, LRTN 10, LRTN 12, LRTN 13, LRTN 16, LRTN 19, LRTN 21, LRTN 40, LRTN 41, LRTN 46, LRTN 48, LRTN 49, LRTN 50, LRTN 51, LRTN 53, LRTN 54, LRTN 57, LRTN 63, LRTN 65, LRTN 68, LRTN 69, LRTN 73, LRTN 74, LRTN 75, LRTN 85, NUWYT 15, NUWYT 20, NUWYT 21, NUWYT 22, NUWYT 25, NUWYT 26, NUWYT 28, NUWYT 38, NUWYT 46, NUWYT 49, NUWYT 50, NUWYT 53, NUWYT 54, NUWYT 58, NUWYT 63, NUWYT 64, NUWYT 66, NUWYT 68, NUWYT 80, CWV 5, CWV 10, CWV 13, CWV 14, CWV 15, CWV 18, CWV 21, CWV 27, CWV 28, CWV 32, CWV 34, CWV 43, CWV 44, CWV 46, CWV 48, CWV 50, CWV 56, CWV 58, CWV 59, CWV 60, CWV 63, CWV 64, CWV 65, CWV 67, CWV 73, CWV

		80, CWV 81, CWV 82, CWV 85, CWV 86, CWV 87, CWV 88, CWV 89, CWV 91, CWV 92, CWV 95, CWV 97, CWV 98, CWV 101, CWV 102, CWV 103, CWV 104, CWV 106, CWV 109, CWV 112, CWV 113, CWV 114, CWV 116, CWV 117, CWV 118, CWV 119, CWV 121, CWV 126, CWV 128, CWV 131, CWV 132, CWV 134, CWV 136, CWV 142, CWV 144, CWV 145, CWV 150, CWV 154, CWV 155, CWV 157, CWV 159, CWV 160, CWV 162, CWV 163, CWV 165, CWV 166, CWV 174, CWV 188, CWV 189, CWV 193, CWV 194, CWV 196, CWV 204, CWV 206
Susceptible (S)	57	SRTN 20, SRTN 22, SRTN 39, SRTN 43, SRTN 50, SRTN 62, SRTN 75, SRTN 84, SRTN 85, YRTN 13, YRTN 15, YRTN 16, YRTN 20, YRTN 23, YRTN 25, YRTN 44, YRTN 51, YRTN 67, YRTN 70, LRTN 1, LRTN 4, LRTN 7, LRTN 18, LRTN 20, LRTN 47, LRTN 52, LRTN 55, LRTN 56, CWV 4, CWV 11, CWV 12, CWV 22, CWV 23, CWV 24, CWV 29, CWV 30, CWV 31, CWV 33, CWV 40, CWV 42, CWV 47, CWV 51, CWV 54, CWV 55, CWV 66, CWV 83, CWV 84, CWV 90, CWV 93, CWV 105, CWV 107, CWV 108, CWV 115, CWV 120, CWV 122, CWV 178, CWV 191

Table 2. Disease Severity of genotypes against YLwRST

Disease severity	No. of Genotypes	Name of Genotypes
0-20	238	SRTN 2, SRTN 3, SRTN 4, SRTN 6, SRTN 9, SRTN 13, SRTN 14, SRTN 15, SRTN 18, SRTN 19, SRTN 21, SRTN 24, SRTN 25, SRTN 26, SRTN 27, SRTN 34, SRTN 35, SRTN 37, SRTN 38, SRTN 41, SRTN 42, SRTN 44, SRTN 46, SRTN 52, SRTN 53, SRTN 55, SRTN 56, SRTN 57, SRTN 58, SRTN 60, SRTN 61, SRTN 64, SRTN 67, SRTN 69, SRTN 70, SRTN 71, SRTN 72, SRTN 73, SRTN 74, SRTN 79, SRTN 82, YRTN 2, YRTN 4, YRTN 8, YRTN 9, YRTN 10, YRTN 11, YRTN 14, YRTN 17, YRTN 18, YRTN 24, YRTN 27, YRTN 29, YRTN 30, YRTN 32, YRTN 33, YRTN 37, YRTN 39, YRTN 41, YRTN 46, YRTN 50, YRTN 52, YRTN 54, YRTN 56, YRTN 59, YRTN 62, YRTN 64, YRTN 65, YRTN 66, YRTN 69, YRTN 71, YRTN 72, YRTN 74, YRTN 76, YRTN 79, YRTN 80, LRTN 2, LRTN 3, LRTN 8, LRTN 9, LRTN 13, LRTN 16, LRTN 17, LRTN 22, LRTN 23, LRTN 24, LRTN 26, LRTN 27, LRTN 28, LRTN 29, LRTN 30, LRTN 31, LRTN 32, LRTN 33, LRTN 34, LRTN 35, LRTN 36, LRTN 37, LRTN 38, LRTN 39, LRTN 40, LRTN 42, LRTN 43, LRTN 45, LRTN 50, LRTN 58, LRTN 59, LRTN 60, LRTN 61, LRTN 62, LRTN 66, LRTN 70, LRTN 71, LRTN 73, LRTN 74, LRTN 76, LRTN 77, LRTN 78, LRTN 79, LRTN 80, LRTN 82, LRTN 84, NUWYT 3, NUWYT 4, NUWYT 7, NUWYT 8, NUWYT 9, NUWYT 10, NUWYT 11, NUWYT 12, NUWYT 13, NUWYT 16, NUWYT 18, NUWYT 19, NUWYT 20, NUWYT 22, NUWYT 23, NUWYT 27, NUWYT 30, NUWYT 31, NUWYT 32, NUWYT 33, NUWYT 36, NUWYT 38, NUWYT 39, NUWYT 41, NUWYT 43, NUWYT 46, NUWYT 48, NUWYT 52, NUWYT 54, NUWYT 56, NUWYT 57, NUWYT 59, NUWYT 61, NUWYT 62, NUWYT 65, NUWYT 69, NUWYT 70, NUWYT 72, NUWYT 73, NUWYT 74, NUWYT 75, NUWYT 76, NUWYT 78, NUWYT 79, CWV 1, CWV 2, CWV 5, CWV 6, CWV 7, CWV 9, CWV 21, CWV 25, CWV 36, CWV 37, CWV 41, CWV 62, CWV 69, CWV 70, CWV 71, CWV 74, CWV 75, CWV 76, CWV 85, CWV 88, CWV 92, CWV 100, CWV 110, CWV 112, CWV 123, CWV 124, CWV 128, CWV 133, CWV 135, CWV 137, CWV 138, CWV 139, CWV 140, CWV 141, CWV 143, CWV 146, CWV 147, CWV 148, CWV 149, CWV 151, CWV 152, CWV 153, CWV 156, CWV 161, CWV 162, CWV 167, CWV 168, CWV 170, CWV 171, CWV 172, CWV 175, CWV 176, CWV 177, CWV 179, CWV 180, CWV 182, CWV 183, CWV 184, CWV 185, CWV 186, CWV 187, CWV 188, CWV 190, CWV 192, CWV 193, CWV 195, CWV 197, CWV 198, CWV 199, CWV 201, CWV 203, CWV 205
21-40	109	SRTN 5, SRTN 28, SRTN 30, SRTN 33, SRTN 36, SRTN 40, SRTN 43, SRTN 45, SRTN 48, SRTN 49, SRTN 50, SRTN 54, SRTN 59, SRTN 62, SRTN 63, SRTN 65, SRTN 77, SRTN 78, SRTN 80, SRTN 81, SRTN 83, YRTN 3, YRTN 5, YRTN 7, YRTN 12, YRTN 19, YRTN 28, YRTN 34, YRTN 38, YRTN 40, YRTN 47, YRTN 49, YRTN 61, YRTN 63, YRTN 68, YRTN 73, YRTN 75, YRTN 77, YRTN 78, LRTN 6, LRTN 11, LRTN 12, LRTN 15, LRTN 25, LRTN 41, LRTN 44, LRTN 49, LRTN 55, LRTN 65, LRTN 69, LRTN 72, NUWYT 1, NUWYT 2, NUWYT 5, NUWYT 6, NUWYT 14, NUWYT 15, NUWYT 24, NUWYT 29, NUWYT 34, NUWYT 40, NUWYT 42, NUWYT 44, NUWYT 45, NUWYT 47, NUWYT 49, NUWYT 51, NUWYT 53, NUWYT 60,

		NUWYT 64, NUWYT 67, NUWYT 71, NUWYT 77, CWV 3, CWV 8, CWV 17, CWV 20, CWV 26, CWV 30, CWV 38, CWV 43, CWV 45, CWV 49, CWV 52, CWV 53, CWV 61, CWV 72, CWV 77, CWV 79, CWV 94, CWV 99, CWV 103, CWV 106, CWV 111, CWV 127, CWV 132, CWV 145, CWV 150, CWV 154, CWV 155, CWV 157, CWV 160, CWV 163, CWV 165, CWV 166, CWV 173, CWV 174, CWV 200, CWV 202
41-60	63	SRTN 7, SRTN 10, SRTN 12, SRTN 16, SRTN 17, SRTN 29, SRTN 32, SRTN 39, SRTN 47, SRTN 66, SRTN 68, SRTN 85, YRTN 1, YRTN 31, YRTN 36, YRTN 43, YRTN 48, YRTN 53, YRTN 55, YRTN 60, LRTN 5, LRTN 46, LRTN 52, LRTN 53, LRTN 64, LRTN 67, LRTN 75, LRTN 83, NUWYT 17, NUWYT 21, NUWYT 28, NUWYT 35, NUWYT 50, NUWYT 55, NUWYT 58, NUWYT 66, NUWYT 68, CWV 13, CWV 16, CWV 22, CWV 57, CWV 59, CWV 63, CWV 67, CWV 78, CWV 81, CWV 82, CWV 86, CWV 89, CWV 97, CWV 113, CWV 116, CWV 117, CWV 119, CWV 125, CWV 130, CWV 131, CWV 136, CWV 142, CWV 158, CWV 164, CWV 169, CWV 181
61-80	42	SRTN 1, SRTN 8, SRTN 11, SRTN 31, SRTN 51, YRTN 26, YRTN 44, YRTN 58, LRTN 10, LRTN 14, LRTN 21, LRTN 47, LRTN 51, LRTN 54, LRTN 68, LRTN 85, NUWYT 25, NUWYT 37, NUWYT 63, CWV 14, CWV 27, CWV 28, CWV 34, CWV 35, CWV 39, CWV 48, CWV 56, CWV 68, CWV 73, CWV 91, CWV 95, CWV 101, CWV 104, CWV 115, CWV 118, CWV 126, CWV 129, CWV 144, CWV 189, CWV 194, CWV 204, CWV 206
81-100	81	SRTN 20, SRTN 22, SRTN 75, SRTN 76, SRTN 84, YRTN 6, YRTN 13, YRTN 15, YRTN 16, YRTN 20, YRTN 23, YRTN 25, YRTN 35, YRTN 42, YRTN 45, YRTN 51, YRTN 57, YRTN 67, YRTN 70, LRTN 1, LRTN 4, LRTN 7, LRTN 18, LRTN 19, LRTN 20, LRTN 48, LRTN 56, LRTN 57, LRTN 63, LRTN 81, NUWYT 26, NUWYT 80, CWV 4, CWV 10, CWV 11, CWV 12, CWV 15, CWV 18, CWV 19, CWV 23, CWV 24, CWV 29, CWV 31, CWV 32, CWV 33, CWV 40, CWV 42, CWV 44, CWV 46, CWV 47, CWV 50, CWV 51, CWV 54, CWV 55, CWV 58, CWV 60, CWV 64, CWV 65, CWV 66, CWV 80, CWV 83, CWV 84, CWV 87, CWV 90, CWV 93, CWV 96, CWV 98, CWV 102, CWV 105, CWV 107, CWV 108, CWV 109, CWV 114, CWV 120, CWV 121, CWV 122, CWV 134, CWV 159, CWV 178, CWV 191, CWV 196

Table 3. Number of Genotypes per disease severity range showing specific responses

Disease Severity Range	Disease Response				
	O	R	MR	MS	S
0-20	68	70	71	29	0
21-40	0	25	41	38	5
41-60	0	1	18	40	4
61-80	0	0	6	33	3
81-100	0	0	3	33	45

Area Under YLwRST Disease Progress Curve (YLwRST AUDPC): The YLwRST AUDPC values, of 533 genotypes under study, were also examined. The evaluation delineated that out of the aforesaid genotypes 68 showed zero AUDPC values and thus were immune to *PstT* infection. The AUDPC values of the remaining 465 genotypes were categorized into seven distinct ranges. The minimum and maximum values demonstrated by genotypes were 24 and 1600 respectively. Highly

susceptible genotypes were those that displayed AUDPC values near to 1600. One hundred and forty, eighty-three, sixty-four, fifty-seven, thirty-three, forty-eight and forty genotypes were found in the AUDPC value ranges of 24-249, 250-475, 476-701, 702-927, 928-1153, 1154-1379 and 12380-1605 respectively. The lowest number of genotypes occurred inside the range 928-1153, while the maximum occurred in the range of 24-249. The names of genotypes occurring in each range are given in Table 4.

Table 4. Area Under YLwRST Disease Progress Curve

Genotypes	Range of AUDPC
SRTN 2, SRTN 3, SRTN 4, SRTN 6, SRTN 13, SRTN 14, SRTN 18, SRTN 19, SRTN 21, SRTN 24, SRTN 25, SRTN 26, SRTN 27, SRTN 34, SRTN 35, SRTN 37, SRTN 38, SRTN 41, SRTN 42, SRTN 52, SRTN 54, SRTN 55, SRTN 56, SRTN 57, SRTN 58, SRTN 60, SRTN 67, SRTN 70, SRTN 71, SRTN 79, SRTN 80, YRTN 2, YRTN 12, YRTN 17, YRTN 24, YRTN 30, YRTN 50, YRTN 54, YRTN 56, YRTN 62, YRTN 63, YRTN 65, YRTN 73,	24-249

YRTN 74, YRTN 76, LRTN 3, LRTN 9, LRTN 17, LRTN 22, LRTN 27, LRTN 30, LRTN 32, LRTN 33, LRTN 34, LRTN 35, LRTN 36, LRTN 38, LRTN 40, LRTN 45, LRTN 59, LRTN 62, LRTN 66, LRTN 71, LRTN 76, LRTN 78, LRTN 79, NUWYT 5, NUWYT 8, NUWYT 9, NUWYT 10, NUWYT 12, NUWYT 13, NUWYT 20, NUWYT 23, NUWYT 29, NUWYT 30, NUWYT 33, NUWYT 39, NUWYT 41, NUWYT 42, NUWYT 46, NUWYT 47, NUWYT 48, NUWYT 52, NUWYT 54, NUWYT 57, NUWYT 59, NUWYT 65, NUWYT 70, NUWYT 75, NUWYT 76, NUWYT 77, NUWYT 79, CWV 2, CWV 3, CWV 8, CWV 26, CWV 36, CWV 41, CWV 69, CWV 71, CWV 74, CWV 75, CWV 76, CWV 85, CWV 100, CWV 112, CWV 123, CWV 124, CWV 133, CWV 135, CWV 137, CWV 138, CWV 139, CWV 140, CWV 141, CWV 143, CWV 147, CWV 156, CWV 161, CWV 166, CWV 167, CWV 170, CWV 171, CWV 172, CWV 175, CWV 177, CWV 180, CWV 183, CWV 184, CWV 185, CWV 187, CWV 188, CWV 190, CWV 192, CWV 195, CWV 197, CWV 198, CWV 201, CWV 205	
SRTN 28, SRTN 36, SRTN 40, SRTN 44, SRTN 45, SRTN 49, SRTN 50, SRTN 53, SRTN 59, SRTN 62, SRTN 64, SRTN 65, SRTN 81, YRTN 4, YRTN 14, YRTN 18, YRTN 19, YRTN 33, YRTN 34, YRTN 38, YRTN 41, YRTN 49, YRTN 53, YRTN 59, YRTN 60, YRTN 75, YRTN 77, YRTN 78, YRTN 79, LRTN 8, LRTN 11, LRTN 12, LRTN 25, LRTN 41, LRTN 46, LRTN 55, LRTN 58, LRTN 65, LRTN 70, LRTN 74, LRTN 80, NUWYT 1, NUWYT 2, NUWYT 3, NUWYT 6, NUWYT 11, NUWYT 14, NUWYT 22, NUWYT 24, NUWYT 34, NUWYT 35, NUWYT 38, NUWYT 40, NUWYT 45, NUWYT 51, NUWYT 53, NUWYT 58, NUWYT 60, NUWYT 67, NUWYT 71, CWV 25, CWV 37, CWV 38, CWV 53, CWV 77, CWV 79, CWV 88, CWV 92, CWV 99, CWV 111, CWV 113, CWV 128, CWV 132, CWV 150, CWV 153, CWV 154, CWV 155, CWV 157, CWV 162, CWV 163, CWV 173, CWV 193, CWV 202	250-475
SRTN 7, SRTN 9, SRTN 15, SRTN 16, SRTN 29, SRTN 30, SRTN 47, SRTN 61, SRTN 68, SRTN 78, SRTN 82, YRTN 1, YRTN 3, YRTN 8, YRTN 47, YRTN 48, YRTN 52, YRTN 55, YRTN 61, YRTN 66, YRTN 69, LRTN 6, LRTN 13, LRTN 16, LRTN 44, LRTN 49, LRTN 50, LRTN 53, LRTN 60, LRTN 64, LRTN 67, LRTN 72, LRTN 73, LRTN 75, LRTN 83, LRTN 84, NUWYT 15, NUWYT 17, NUWYT 21, NUWYT 49, NUWYT 55, NUWYT 64, NUWYT 66, NUWYT 68, CWV 5, CWV 21, CWV 45, CWV 57, CWV 72, CWV 78, CWV 81, CWV 86, CWV 117, CWV 125, CWV 131, CWV 136, CWV 145, CWV 158, CWV 160, CWV 165, CWV 169, CWV 174, CWV 181, CWV 200	476-701
SRTN 5, SRTN 12, SRTN 32, SRTN 33, SRTN 39, SRTN 43, SRTN 48, SRTN 63, SRTN 77, SRTN 83, SRTN 85, YRTN 5, YRTN 7, YRTN 28, YRTN 40, YRTN 58, YRTN 68, LRTN 14, LRTN 15, LRTN 47, LRTN 52, LRTN 68, LRTN 69, LRTN 81, NUWYT 25, NUWYT 44, NUWYT 50, CWV 17, CWV 20, CWV 22, CWV 27, CWV 28, CWV 30, CWV 35, CWV 39, CWV 43, CWV 49, CWV 52, CWV 59, CWV 61, CWV 63, CWV 67, CWV 68, CWV 82, CWV 89, CWV 94, CWV 95, CWV 97, CWV 101, CWV 103, CWV 106, CWV 116, CWV 118, CWV 127, CWV 164, CWV 194, CWV 206	702-927
SRTN 66, YRTN 26, YRTN 31, YRTN 36, YRTN 42, YRTN 43, YRTN 44, LRTN 5, LRTN 48, LRTN 51, LRTN 54, LRTN 85, NUWYT 28, NUWYT 37, NUWYT 63, NUWYT 80, CWV 13, CWV 14, CWV 15, CWV 16, CWV 18, CWV 34, CWV 46, CWV 73, CWV 104, CWV 105, CWV 110, CWV 119, CWV 142, CWV 144, CWV 159, CWV 189, CWV 204	928-1153
SRTN 1, SRTN 8, SRTN 10, SRTN 11, SRTN 17, SRTN 31, SRTN 51, SRTN 75, SRTN 76, YRTN 35, YRTN 45, YRTN 51, YRTN 67, LRTN 10, LRTN 18, LRTN 19, LRTN 21, LRTN 56, LRTN 57, LRTN 63, CWV 4, CWV 10, CWV 19, CWV 32, CWV 44, CWV 47, CWV 48, CWV 51, CWV 56, CWV 58, CWV 60, CWV 64, CWV 65, CWV 80, CWV 83, CWV 87, CWV 90, CWV 91, CWV 96, CWV 102, CWV 108, CWV 114, CWV 115, CWV 121, CWV 126, CWV 129, CWV 130, CWV 196	1154-1379
SRTN 20, SRTN 22, SRTN 84, YRTN 6, YRTN 13, YRTN 15, YRTN 16, YRTN 20, YRTN 23, YRTN 25, YRTN 57, YRTN 70, LRTN 1, LRTN 4, LRTN 7, LRTN 20, NUWYT 26, CWV 11, CWV 12, CWV 23, CWV 24, CWV 29, CWV 31, CWV 33, CWV 40, CWV 42, CWV 50, CWV 54, CWV 55, CWV 66, CWV 84, CWV 93, CWV 98, CWV 107, CWV 109, CWV 120, CWV 122, CWV 134, CWV 178, CWV 191	1380-1605

DISCUSSION

Wheat, a staple food crop not only in Pakistan but also for a large population worldwide, is severely affected by various WHRSTs. YLwRST is the most serious disease threatening wheat production (Zelba *et al.*, 2024). The best strategy to tackle WHRSTs is through growing resistant varieties albeit there are other techniques besides that. A typical strategy adopted for assessing

varieties' resilience is screening and it is also the most suitable method for examining the genotypic and phenotypic profile of varieties against WHRSTs (Shewaye and Mohammed, 2021). In the present study, five hundred thirty-three genotypes of wheat were sown and their responses and severity against YLwRST was examined. Three readings of YLwRST severity and DR, with a gap of seven days each, were taken. The present experiment

revealed that some varieties were either immune or resistant to YLwRST, while some showed different ranges of DS. Thus it is appraised that the resistance against WHRSTs functions in a complex way, some genotypes show resilience to one type of rust while some depict resilience to other type of WHRST. This could be linked with contemporary development of novel pathogenic races rust pathogens and difference in prevalence and dispersion patterns of such races of aforesaid pathogens (Mapuranga *et al.*, 2022).

Out of the 533 genotypes under study, 68 were immune to YLwRST. This could be associated with a couple of reasons. One could be the uneven spread of disease inoculum in the field. The second could be the presence of a single or a combination of resistant genes, against YLwRST in those varieties (Ali *et al.*, 2024). The YLwRST screening results showed that 96 genotypes were resistant. The moderately susceptible and moderately resistant lines were 173 and 139 respectively. Fifty-seven genotypes were found to be susceptible to YLwRST. The results of the present investigation are in accordance with the previous studies. The genotypes under study were also scored based on their AUDPC values. The observed range of AUDPC was 24-1600. The maximum and minimum AUDPC value was shown by SRTN 22 and YRTN 62 respectively.

Saleem *et al.* (2022) screened 168 lines, identifying 52 as resistant and 8 as immune to YLwRST. Another experiment screened the wheat germplasm consisting of 152 lines. They propounded that 31 lines were resistant to YLwRST, while other lines showed moderately susceptible or moderately resistant responses to YLwRST (Rehman *et al.*, 2019). Another study underwent an experiment to check the resistivity of 8 varieties previously known as resistant to YLwRST. They found that only two genotypes still showed auspicious resilience against YLwRST. Three varieties showed symptoms of *PStT* infection, apprising that the YLwRST is more strengthened in breaking the resistant genes in resistant varieties. These outcomes of aforesaid study also resembled with the findings of current study (Pathak and Khadka, 2014).

These results of the present study divulged that the genotypes were more susceptible to YLwRST. There could be various factors influencing the aforesaid phenomenon and such factors include accelerated rate of *PStT* evolution resulting in novel virulent races of *PStT*. The pathogen of YLwRST has better adaption to the

environmental conditions as compared to other pathogenic fungi causing WHRSTs. The complexity in the host-pathogen interaction of *PStT* could also be a potential factor towards providing ability to *PStT* in causing a more aggressive infection as compared to other fungi causing WHRSTs (Dobon *et al.*, 2016; Bouvet *et al.*, 2022).

CONCLUSION

It is appraised from the present research, that a continuous monitoring and screening of wheat germplasm is necessary to detect any shift in the patterns of resistance and virulence in wheat and rust pathogens respectively. The wheat varieties having a combination of genes must be sown in the field as they provide enhanced resilience to YLwRST. The present study, however, highlights the paramount necessity of WHRST-resistant breeding programs in semi-arid areas. The genotypes that showed resistance against the rusts under study can be further utilized to perform additional studies regarding the identification of specific genes that conferred resistance against YLwRST. Thus can be used by breeders to develop resistant wheat varieties that decrease the threat of these destructive rust diseases, improving global food security.

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