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THE ROLE OF DISEASE-RESISTANT WHEAT GENOTYPES IN ENVIRONMENTAL PROTECTION AND SUSTAINABLE FOOD PRODUCTION

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РОЛЬ БОЛЕЗНЕУСТОЙЧИВЫХ ГЕНОТИПОВ ПШЕНИЦЫ В ОХРАНЕ ОКРУЖАЮЩЕЙ СРЕДЫ И УСТОЙЧИВОМ ПРОИЗВОДСТВЕ ПРОДОВОЛЬСТВИЯ

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Аннотация. Пшеница (*Triticum L.*) является одной из важнейших продовольственных культур мира и основным источником питания для значительной части населения планеты. По площади возделывания и общему объему производства она занимает ведущее место среди зерновых культур. Однако продуктивность и качество зерна пшеницы существенно снижаются под воздействием различных грибных, бактериальных и вирусных заболеваний. Представлены результаты оценки устойчивости к болезням 1467 местных и интродуцированных генотипов мягкой и твердой пшеницы различного географического происхождения. Исследования проводили в 2024-2025 гг. в условиях орошения в коллекционном питомнике Абшеронского вспомогательного опытного хозяйства Научно-исследовательского института земледелия. Экспериментальный материал включал 824 генотипа мягкой и 643 генотипа твердой пшеницы. Посев проводили вручную во второй и третьей декадах октября после бобовых культур. Каждый генотип высевали в двух повторениях на делянках площадью 1 м². Установлено, что ряд генотипов мягкой пшеницы проявлял устойчивость (R) одновременно к желтой и бурой ржавчине. К ним относились местные сорта Шафаг, Мархал, Гырмызы Гюль 1, Агалы, Мубариз и Акинчи, интродуцированные сорта Васса, Батко и Юна (Россия), а также ряд селекционных линий, полученных через международные селекционные программы Турции, CIMMYT и ICARDA. Среди генотипов твердой пшеницы устойчивостью к обеим болезням характеризовались местные сорта Тар-Тар, Вугар и Полад, сорта Мерам (Турция) и Карол Одесская (Украина), а также линии, интродуцированные из ICARDA. Выявленные устойчивые генотипы представляют ценный исходный материал для селекционных программ, направленных на создание новых сортов пшеницы с повышенной устойчивостью к болезням.

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Abstract. Wheat (*Triticum* L.) is one of the world's most important food crops and a major source of nutrition for a large proportion of the global population. It occupies a leading position among cereal crops in terms of both cultivated area and total production. However, wheat productivity and grain quality are substantially affected by a wide range of fungal, bacterial, and viral diseases. This study presents the results of an evaluation of disease resistance in 1467 local and introduced bread and durum wheat genotypes originating from different geographical regions. The study was conducted during the 2024 and 2025 growing seasons in a collection nursery under irrigated conditions at the Absheron Auxiliary Experimental Farm of the Research Institute of Crop Husbandry. The experimental material included 824 bread wheat and 643 durum wheat genotypes. Sowing was carried out manually during the second and third decades of October, following legumes as the preceding crop. Each genotype was sown in two replications on 1 m2 plots. Several bread wheat genotypes demonstrated resistance (R) to both stripe rust and leaf rust, including the local cultivars Shafaq, Marxal, Girmizi Gul 1, Aghali, Mubariz, and Akinci; the introduced cultivars Vassa, Batko, and Yuna (Russia); and several breeding lines introduced through international breeding programs involving Turkey, CIMMYT, and ICARDA. Among the durum wheat genotypes, the local cultivars Tartar, Vuqar, and Polad, as well as Meram (Turkey), Karol Odesskaya (Ukraine), and several ICARDA-introduced lines, also showed resistance (R) to both diseases. The identified resistant genotypes represent valuable genetic resources for use as parental material in wheat breeding programs aimed at developing cultivars with enhanced disease resistance.

Keywords: breeding, bread wheat, durum wheat, resistance, infection, stripe rust, leaf rust.

Ключевые слова: селекция, мягкая пшеница, твердая пшеница, устойчивость, инфекция, желтая ржавчина, бурая ржавчина.

Wheat (*Triticum* L.) is one of the world's most important staple food crops and a major source of nutrition for a large proportion of the global population. It occupies a leading position among cereal crops in terms of both cultivated area and total production. However, wheat productivity and grain quality are substantially affected by a wide range of fungal, bacterial, and viral diseases. Global climate change, intensive agricultural production systems, and the continuous evolution of pathogens are contributing to the increasing incidence and severity of wheat diseases in many wheat-growing regions. Among the most widespread and economically important diseases are stripe rust, leaf rust, powdery mildew, common bunt, and loose smut. Disease severity varies considerably depending on the genetic background of the wheat genotype and prevailing environmental conditions. Therefore, the development and cultivation of wheat cultivars with enhanced disease resistance are of considerable importance for reducing yield losses and ensuring sustainable agricultural production. Flour and flour-based products obtained from wheat processing constitute a major component of the human diet. More than two-thirds of wheat produced worldwide is used for food, while approximately one-fifth is used as animal feed [1].

The current rate of yield increase remains insufficient to meet the projected 70% increase in wheat demand by 2050. Wheat production is also increasingly threatened by emerging and more aggressive pests and diseases, diminishing water resources, limited arable land, and unstable weather conditions, particularly rising temperatures associated with climate change [2, 3].

The development of new wheat cultivars with high yield potential, superior grain quality, and resistance to various diseases and pests remains one of the major objectives of wheat breeding programs. One of the most effective approaches to achieving this objective is the efficient use of plant genetic resources through the comprehensive evaluation of locally adapted traditional and recently

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developed wheat populations, as well as introduced genotypes from different regions of the world. Assessing their agronomic performance and other economically important traits, together with their extensive use in hybridization, enables the selection of valuable parental materials for the development of new wheat cultivars with high grain yield, improved quality, and enhanced resistance to biotic and abiotic stress factors [4].

In addition, obtaining high yields from different cereal varieties remains one of the major challenges facing intensive agriculture. The development of new cultivars adapted to local environmental conditions and resistant to diseases and pests is one of the effective approaches to addressing this challenge [21].

There are three major rust diseases of wheat: stripe rust (*Puccinia striiformis* f. sp. *tritici*), leaf rust (*Puccinia triticina*), and stem rust (*Puccinia graminis*). Depending on the severity of infection, each of these diseases can significantly reduce grain yield and quality [5].

Diseases of global and regional significance are predominantly fungal and are caused by either biotrophic or necrotrophic pathogens. Recent estimates suggest that potential yield losses in wheat due to diseases range from 10-28% globally [6].

During severe epidemics, yield losses caused by rust diseases may reach 35-40%. Rust diseases, particularly stripe rust, are among the most widespread diseases affecting wheat worldwide. In Azerbaijan, stripe rust occurred as a widespread epidemic almost every year during the 2000s, resulting in substantial yield losses of 15-30% [7].

Stripe rust (*Puccinia striiformis* f. sp. *tritici*), leaf rust (*Puccinia triticina*), and stem rust (*Puccinia graminis* f. sp. *tritici*) are among the most destructive diseases limiting wheat production in Azerbaijan [8, 9].

The cultivation of wheat cultivars resistant to rust diseases, particularly in rainfed and arid regions where fungicides are not routinely applied, can significantly reduce the incidence and severity of rust infections. This approach is considered economically efficient and environmentally sustainable [10, 11].

Disease infection can reduce wheat grain yield and affect plant physiological processes. The conservation and effective use of disease- and pest-resistant germplasm are therefore essential for achieving high and stable yields. Newly acquired germplasm should be carefully evaluated for disease infection before being incorporated into working collections because the introduction of infected material may create favorable conditions for disease dissemination within collections [4, 7, 12].

Rust infection significantly reduces photosynthetic activity depending on disease severity. This may accelerate leaf senescence and plant maturity, resulting in reduced biomass accumulation and grain yield [13].

The use of plant genetic resources, including wild relatives, landraces, and breeding gene pools, has made a substantial contribution to wheat breeding for resistance to biotic and abiotic stresses while also improving nutritional value, end-use quality, and grain yield. In the Global South, post-Green Revolution genetic yield gains have generally been achieved with relatively limited additional inputs. As a result, agricultural production has increased and millions of hectares of natural ecosystems have been spared. It has been estimated that the cultivation of resistant wheat varieties has helped avoid more than one billion liters of fungicide use since 2000. Furthermore, the compound average annual growth rate in wheat production from 2014 to 2024 was 0.77%, with nearly 790 million tons harvested from 220 million hectares in the 2023/2024 marketing year [14, 15].

Breeding new crop varieties with resistance to biotic stresses that undermine crop yields is equivalent to increasing the amount and quality of biological capital in agriculture. However, the effectiveness of resistance genes may decline as pathogens evolve mechanisms to overcome newly deployed host defenses. Consequently, maintaining the beneficial production and economic outcomes

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associated with disease resistance requires continuous investment in the development of new resistance sources. Analysis of observed and modeled data on stripe rust occurrence has demonstrated a significant increase in the geographical spread of the disease since 1960, with a large proportion of global wheat production potentially exposed to infection. Using probabilistic modeling, Beddow et al. estimated substantial annual wheat losses caused by stripe rust and demonstrated that sustained investment in the development of stripe-rust-resistant wheat varieties is economically justified [16].

Materials and methods

During 2024-2025, a total of 1467 local and introduced wheat genotypes of diverse geographical origins, including 824 bread wheat and 643 durum wheat genotypes, were evaluated in the collection nursery at the Absheron Auxiliary Experimental Farm of the Research Institute of Crop Husbandry. Legumes were used as preceding crops. Each genotype was sown manually in two replications on 1 m^2 plots.

After every 20 genotypes, the local bread wheat cultivar Murov 2 and the local durum wheat cultivar Barakatli 95, which are widely cultivated in the Republic of Azerbaijan, were included as standard cultivars for bread and durum wheat, respectively.

During the growing season, agrotechnical practices appropriate for the region were applied. At sowing, 200 kg ha^{-1} of a complex fertilizer was applied. In early spring, 250 kg ha^{-1} of ammonium nitrate (NH_4NO_3) was applied during the tillering stage. During the growing season, the genotypes were irrigated two to three times depending on the year.

The Absheron Auxiliary Experimental Farm is located on the Absheron Peninsula. The gray-brown soils prevalent in the area are relatively infertile and poorly supplied with essential plant nutrients [17].

Because Absheron soils readily drain excess water, they are generally well aerated. Their high porosity promotes rapid water evaporation, and agricultural crops cultivated under these conditions therefore require relatively frequent irrigation.

The Absheron Peninsula is located in the dry subtropical zone and is characterized by hot summers, sunny autumns, and mild winters. Strong northern (Khazri) and southern (Gilavar) winds frequently occur in the region. Wind speeds may occasionally reach 35-40 m s^{-1} or higher, contributing to unstable climatic conditions. Summers are generally hot, dry, and sunny, whereas winters are relatively mild. During the coldest months of the year (January-February), the average monthly temperature ranges from 0.9 to 6°C. During the hottest months (July-August), maximum temperatures may reach 38-39°C, while the average monthly temperature is approximately 25.9°C and the average minimum temperature is 18-20°C. The winter period is relatively warm and short.

In rare cases, air temperature may fall to 1.3-5.7°C. The number of frost days is generally low, ranging from 1 to 30 days per year and being absent in some years. The region is characterized by a high number of sunny days, strong northerly winds throughout the year, and low and uneven distribution of atmospheric precipitation. Low relative humidity, limited precipitation, and strong winds occurring on average for 60-90 days per year frequently cause soil and atmospheric drought. The average annual precipitation is approximately 220 mm, with recorded maximum and minimum values of 253.1 and 200.5 mm, respectively. Snow cover ranges from 3 to 120 mm per year, while relative air humidity generally varies between 60 and 80% [18].

During the research years, air temperature and precipitation were generally close to the long-term averages for the region. Rust disease reactions were evaluated using modified Cobb scales recommended by CIMMYT and ICARDA [19].

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Results and discussion

During the 2024 and 2025 growing seasons, the infection levels of local and introduced wheat genotypes of different geographical origins with stripe rust and leaf rust varied considerably.

In 2024, among the 414 bread wheat genotypes evaluated, 347 genotypes (83.8%) were resistant (R) to stripe rust, 3 genotypes (0.72%) showed moderate resistance (10-30MR), 7 genotypes (1.69%) were moderately susceptible (10-20MS), and 57 genotypes (13.8%) were susceptible (5-50S). Regarding leaf rust, 267 genotypes (64.5%) were resistant (R), 36 genotypes (8.7%) were moderately susceptible (5-40MS), and 111 genotypes (26.8%) were susceptible (5-50S).

In 2025, among the 410 bread wheat genotypes evaluated, 84 genotypes (20.5%) were resistant (R) to stripe rust, 5 genotypes (1.2%) exhibited moderate resistance (5-20MR), 26 genotypes (6.3%) were moderately susceptible (5-20MS), and 295 genotypes (72.0%) were susceptible (5-100S). No leaf rust infection was observed among the studied bread wheat samples in 2025 (Figure 1).

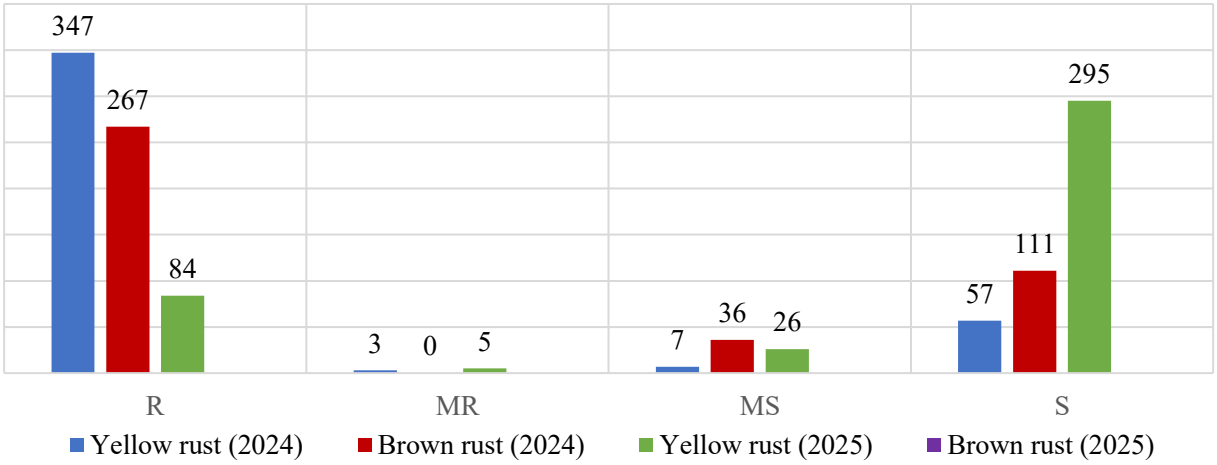


Figure 1. Disease reactions of bread wheat genotypes to stripe rust and leaf rust in 2024 and 2025: 0-immune; R-resistant; MR-moderately resistant; MS-moderately susceptible; S-susceptible

In 2024, among the 322 durum wheat genotypes evaluated, 302 genotypes (93.8%) were resistant (R) to stripe rust, 4 genotypes (1.2%) showed moderate susceptibility (5-10MS), and 16 genotypes (5.0%) were susceptible (5-30S). Regarding leaf rust, 240 genotypes (74.5%) were resistant (R), 2 genotypes (0.6%) exhibited moderate resistance (10-20MR), 25 genotypes (7.8%) were moderately susceptible (5-20MS), and 55 genotypes (17.1%) were susceptible (5-40S).

In 2025, among the 321 durum wheat genotypes evaluated, 152 genotypes (47.3%) were resistant (R) to stripe rust, 7 genotypes (2.2%) showed moderate resistance (10-20MR), 34 genotypes (10.6%) were moderately susceptible (5-20MS), and 128 genotypes (39.9%) were susceptible (5-50S). Regarding leaf rust, 40 genotypes (12.5%) showed no infection (0), whereas 281 genotypes (87.5%) were resistant (R) (Figure 2).

During the 2024 and 2025 growing seasons, the standard bread wheat cultivar Murov 2 showed a susceptible reaction to stripe rust, with infection scores ranging from 5S to 60S, and to leaf rust, with scores ranging from 5S to 20MS. Among the local bread wheat genotypes, Shafaq, Marxal, Girmizi Gul 1, Aghali, Mubariz, and Akinci, as well as the introduced cultivars Vassa, Batko, and Yuna (Russia), showed resistance (R) to both diseases. Several genotypes introduced through international breeding and research programs involving Turkey, CIMMYT, and ICARDA also showed resistance (R) to both diseases. These included P-5, N20, 21st IWWYT-IR (2017-2018); P-5, N21, 21st IWWYT-IR (2017-2018); P-1, N68, 26th FAWWON-SA (2018-2019); P-1, N81, 26th FAWWON-SA (2018-2019); P-2, N57, 21st IWWYT-SA (2018-2019); P-3, N29, 26th FAWWON-

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IR (2018-2019); P-1, N50, 27th FAWWON-SA (2019-2020); P-3, N55, 27th FAWWON-IR (2019-2020); and P-5, N7, 28th FAWWON-SA (2020-2021).

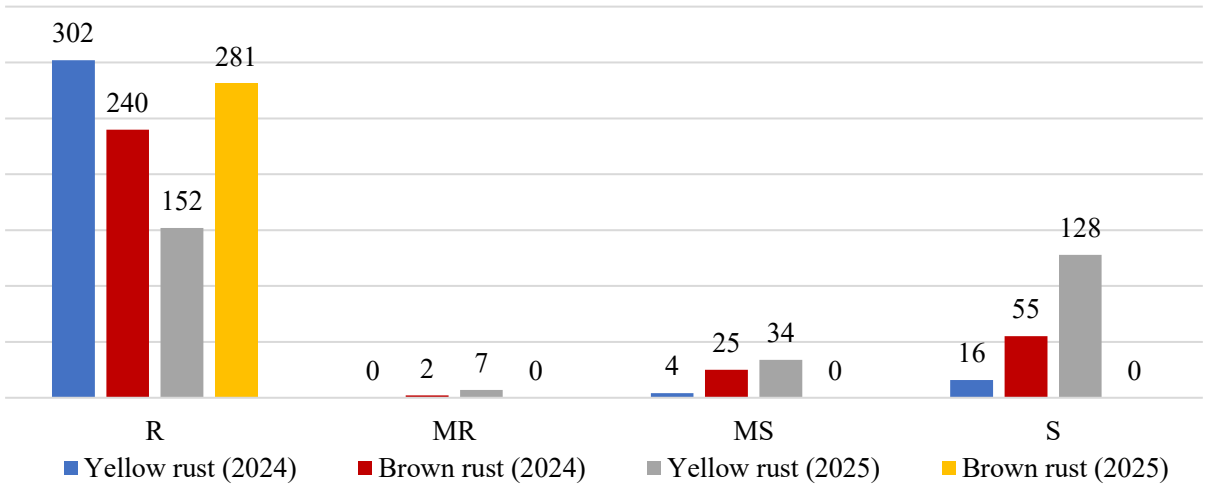


Figure 2. Disease reactions of durum wheat genotypes to stripe rust and leaf rust in 2024 and 2025: *0-immune; R-resistant; MR-moderately resistant; MS-moderately susceptible; S-susceptible*

Among the local genotypes, Pirshahin showed disease reactions ranging from 20S to 40S for stripe rust and from 10S to 30S for leaf rust. Saba showed 15S-60S infection for stripe rust and 20MS-10S infection for leaf rust. Vostok (Russia) showed 10S-60S infection for stripe rust and 20MS-10S infection for leaf rust. The introduced genotype P-2, N62, 21st IWWYT-SA (2018-2019) (T-C-I) exhibited 30S-60S infection for stripe rust and 20S-50S for leaf rust, whereas P-3, N89, 26th FAWWON-IR (2018-2019) (T-C-I) showed 20S-80S infection for stripe rust and 5S-50S for leaf rust. These genotypes were among those more severely affected by the diseases.

Table

RESISTANCE OF SELECTED BREAD AND DURUM
WHEAT GENOTYPES TO STRIPE RUST AND LEAF RUST DURING 2024 and 2025

Genotypes	*Origin*	*Years*			
		2024	*2025*	*2024*	*2025*
		stripe rust		*Leaf rust*	
Disease-resistant bread wheat genotypes					
Murov 2 (standard)	Azerbaijan	5MS-10S	5S-20S	20MS-5S	R
Shafaq	Azerbaijan	R	R	R	R
Marxal	Azerbaijan	R	R	R	R
Girmizi Gul 1	Azerbaijan	R	R	R	R
Aghali	Azerbaijan	R	R	R	R
Mubariz	Azerbaijan	R	R	R	R
Akinci	Azerbaijan	R	R	R	R
Vassa	Russia	R	R	R	R
Batko	Russia	R	R	R	R
Yuna	Russia	R	R	R	R
P-5, N20, 21st IWWYT-IR, 2017-2018	T-C-I	R	R	R	R
P-5, N21, 21st IWWYT-IR, 2017-2018	T-C-I	R	R	R	R
P-1, N68, 26th FAWWON-SA, 2018-2019	T-C-I	R	R	R	R

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Genotypes	Origin	Years			
		2024	2025	2024	2025
		stripe rust		Leaf rust	
P-1, N81, 26th FAWWON-SA, 2018-2019	T-C-I	R	R	R	R
P-2, N57, 21st IWWYT-SA, 2018-2019	T-C-I	R	R	R	R
P-3, N29, 26th FAWWON-IR, 2018-2019	T-C-I	R	R	R	R
P-1, N50, 27th FAWWON-SA, 2019-2020	T-C-I	R	R	R	R
P-3, N55, 27th FAWWON-IR, 2019-2020	T-C-I	R	R	R	R
P-5, N7, 28th FAWWON-SA, 2020-2021	T-C-I	R	R	R	R
Disease-susceptible bread wheat genotypes					
Pirshahin	Azerbaijan	20S	30S	40S	10S
Saba	Azerbaijan	15S	20MS	60S	10S
Vostok	Russia	10S	20MS	60S	10S
P-2, N62, 21st IWWYT-SA, 2018-2019	T-C-I	30S	50S	60S	20S
P-3, N89, 26th FAWWON-IR, 2018-2019	T-C-I	20S	50S	80S	5S
Disease-resistant durum wheat genotypes					
Barakatli 95 (standard)	Azerbaijan	R	R	R	R
Tartar	Azerbaijan	R	R	R	R
Vuqar	Azerbaijan	R	R	R	R
Polad	Azerbaijan	R	R	R	R
Meram	Turkey	R	R	R	R
Karol Odesskaya	Ukraine	R	R	R	R
P-11, N10, 39th IDON, 2015-2016	ICARDA	R	R	R	R
P-10, N37, 39th IDON, 2015-2016	ICARDA	R	R	R	R
P-11, N12, 41st IDON, 2017-2018	ICARDA	R	R	R	R
P-11, N13, 41st IDON, 2017-2018	ICARDA	R	R	R	R
Disease-susceptible durum wheat genotypes					
ST/2016/65	Azerbaijan	40S	10S	70S	10S
(Mirbashir 50 x Karabakh) x Karabakh	Azerbaijan	10S	20MR	50S	10S
P-10, N93, 39th IDON, 2015-2016	ICARDA	30S	20S	40S	5S

Note: 0 - immune; R -resistant; MR - moderately resistant; MS - moderately susceptible; S -susceptible. T-C-I-Turkey, CIMMYT, and ICARDA

During 2024 and 2025, the standard durum wheat cultivar Barakatli 95 showed resistance (R) to both stripe rust and leaf rust. Among the locally originated genotypes, Tartar, Vuqar, and Polad, as well as the introduced cultivars Meram (Turkey) and Karol Odesskaya (Ukraine), showed resistance (R) to both diseases. The ICARDA-introduced genotypes P-11, N10, 39th IDON (2015-2016); P-10, N37, 39th IDON (2015-2016); P-11, N12, 41st IDON (2017-2018); and P-11, N13, 41st IDON (2017-2018) also showed resistance (R) to both diseases. Among the local genotypes, ST/2016/65 showed infection levels of 40-70S for stripe rust and 10S for leaf rust; (Mirbashir 50 × Karabakh) × Karabakh showed 10-50S infection for stripe rust and 20MR-10S for leaf rust; and the introduced genotype P-10, N93, 39th IDON (2015-2016) (ICARDA) exhibited 30-40S infection for stripe rust and 5-20S for leaf rust. These and other genotypes were more severely affected by the diseases.

Conclusions

During the 2024 and 2025 growing seasons, bread wheat genotypes generally exhibited a higher level of infection with rust diseases than durum wheat genotypes. A substantial increase in the number of bread wheat genotypes susceptible to stripe rust was observed in 2025 compared with 2024,

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increasing from 57 to 295 genotypes. Several local bread wheat genotypes demonstrated combined resistance to stripe rust and leaf rust, including Shafaq, Marxal, Girmizi Gul 1, Aghali, Mubariz, and Akinci, as well as the Russian cultivars Vassa, Batko, and Yuna. Among durum wheat, the local cultivars Tartar, Vuqar, and Polad, together with Meram (Turkey), Karol Odesskaya (Ukraine), and several ICARDA-introduced genotypes, also demonstrated resistance to both diseases. The identified resistant genotypes represent valuable genetic resources for wheat breeding [20]. Their incorporation into hybridization programs may contribute to the development of new cultivars with enhanced and potentially durable resistance to rust diseases. The use of disease-resistant genetic resources can also reduce dependence on fungicide applications, thereby contributing to environmentally sustainable wheat production.

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