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Environmental plasticity of short-stemmed winter bread wheat (*Triticum aestivum* L.) cultivars and resistance to yellow leaf blotch (*Pyrenophora tritici-repentis* (Died.) Drechsler) and brown (leaf) rust (*Puccinia recondita* f. sp. *tritici* Rob. et Desm.)

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In the context of variability of common pathogens of foliar diseases of winter bread wheat, evolvement of virulent and aggressive races, and periodic droughts, which with climate changes increasingly occur in the territory of Ukraine, prerequisites for in-depth research into adaptability of plant varieties and selection of the best gene pool for breeding arise. The paper presents results on the environmental plasticity of short-stemmed winter bread wheat cultivars, which were differentiated by resistance to yellow leaf blotch and brown (leaf) rust. New sources of high and stable group resistance to pathogenes of these diseases were identified: cv. 'Versiia odeska' (UKR) and cv. 'Mescal' (FRA). By genotypic effect (ε_i) and regression coefficient (R_i) for yield, the following genotypes showing the highest genetic potential for adaptability (sum of ranks = 2) to stressful conditions of cultivation in the eastern forest-steppe of Ukraine and yielding by 16% more than the check cultivar were identified among the short-stemmed cultivars under investigation: cv. 'Pokrovska' (ε_i = 1.92; R_i = 0.60) (UKR), cv. 'Versiia odeska' (ε_i = 1.21; R_i = 0.77) (UKR), cv. 'MIP Vidznaka' (ε_i = 1.05; R_i = 0.82) (UKR), cv. 'Mescal' (ε_i = 0.98; R_i = 0.65) (FRA), and cv. 'SY Wolf' (ε_i = 0.94; R_i = 0.69) (USA). It was found that the genotypic effect for yield ranged from -1.71 to 1.92 in the short-stemmed cultivars, and the regression coefficient - from 0.60 to 1.45, which largely affected the environmental plasticity: the sum of ranks for this parameter varied from 2 to 6. The percentage of accessions with high genotypic effects was 33.3%; the percentage of accessions with consistently stable yields was 41.7%. It was revealed that in short-stemmed winter bread wheat, resistance to brown rust and yellow leaf blotch was significantly negatively correlated with the sum of ranks of the genotypic effect and regression coefficient for yield ($r = -0.65$, $P < 0.01$ and $r = -0.58$, $P<0.01$, respectively). The selected sources of high group resistance to *Pyrenophora tritici-repentis* (Died.) Drechsler) and brown (leaf) rust (*Puccinia recondita* f. sp. *tritici* Rob. et Desm., with high yield potential and stability, are valuable starting materials for the breeding of new, highly promising winter bread wheat cultivars, which will be adaptable to stressful conditions of cultivation in the eastern forest-steppe of Ukraine.

Keywords: *winter bread wheat, epiphytoties, plasticity, stability, genotypic effect, adaptability, yield, source*

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Introduction

Enhancement of the genetic potentials of yield, quality, and adaptability of crops is among the main objectives of the agricultural sector of the Ukrainian economy. Increased gross collection of grain and stabilized grain production determine the level of farming intensification and the efficiency of agricultural development (Ilchuk et al., 2019). Studies of cultivars' environmental plasticity and selection among them of high-yielding sources adapted to certain growing conditions are necessary stages and a guarantee for breeding effectiveness in order to create highly adaptive genotypes for the corresponding ecological zone (Studnicki et al., 2019; Lavrynenko et al., 2020; Dhiwar et al., 2020).

The nutritional value and variety of technological uses of common wheat (*Triticum aestivum* L.) determine the importance of this crop in the agrarian sector and ensure the food security of Ukraine, which is a basis for the economic development of the country (Ilchuk et al., 2019). Scientists from different countries confirmed that the stress resistance of winter bread wheat cultivars to biotic and abiotic factors was crucial for the stabilization and development of agriculture (Morhun et al., 2014; Raza et al., 2019; Laugerotte et al., 2022).

Ukrainian researchers noted that in the face of abnormally high air temperatures and droughts observed on the territory of Ukraine during the last decades, water deficit issues are becoming increasingly important among the abiotic stressors (Kolupaev et al., 2023; Sydorenko, Chebotar, 2020). Because of them, metabolic processes in plants are disrupted, proteins are denatured and cleft, chemical composition and state of the cytoplasm change, and plants accumulate less organic matter. These phenomena quite often reduce yields of plant cultivars (Sydorenko, Chebotar, 2020).

Polish researchers M. Różewicz et al. (2021) pointed out that, among the biotic limiting factors, fungal diseases caused the greatest damage to spiked cereals, reducing their yields on average by 15–20%, and losses can reach 60% in epiphytotic cases (Różewicz et al., 2021). Ukrainian scientists hold a similar opinion, stressing that possible loss from fungal diseases can amount to 25–50% (Trybel, 2006; Retman, 2007). Different fungicides that are applied to suppress pathogens of foliar diseases pollute the environment and boost the genetic variability of pathogens, which evolve into new races (Kang et al., 2020; Li et al., 2020). Growing of plant cultivars that are resistant to pathogens of foliar diseases is a way to suppress phytoinfections and prevent epiphytoties. However, due to mutational, combinational, and population variabilities and spore migration in pathogen populations, new virulence genes that can overcome the protective effects of plants' resistance genes appear (Lisovyi, Lisova, 2017). Alternative plant protection, based on the introduction of new cultivars with reliable genetic protection against pathogens of foliar diseases, is becoming more and more relevant due to the undeniable economic and ecological advantages (Petrenkova et al., 2018; Kovalyshyna et al., 2018; Wu et al., 2021). The occurrence and spread of epiphytoties are mainly determined by genetic protection against pathogens (Kang et al., 2020), weather conditions during the growing period, crop rotation, and tillage method (Iwańska et al., 2019; Różewicz et. al., 2021).

Among foliar diseases of winter bread wheat in Ukraine, yellow leaf blotch and brown rust, which are caused by *Pyrenophora tritici-repentis* (Died.) Drechsler and *Puccinia recondita* f. sp. *tritici* Rob. et Desm. (syn. *Puccinia triticina* Eriks.), respectively (Holosna, 2019; Horiainova et al., 2020). The causative agent of yellow leaf blotch, *P. tritici-repentis* (Died.) Drechsler, is a hemibiotrophic parasite that leads to preterm withering of leaves, formation of shriveled kernels, and a decline in the number of kernels per spike. By taxonomic status, it belongs to the class *Ascomycetes*, order *Pleosporales*, family *Pleosporacea*. *P. recondita* f. sp. *tritici* Rob. et Desm. belongs to the class *Basidiomycetes*, order *Uredinales*, family *Pucciniaceae*. By nutrition type, *P. recondita* f. sp. *tritici* Rob. et Desm. is an obligate parasite; it enhances transpiration, reduces assimilation surface, and disrupts photosynthesis, resulting in the formation of low-performance spikes (Retman, 2007; Pinchuk et al. 2018). Over 200 races of *P. recondita* f. sp. *tritici* Rob. et Desm. have been identified (Pinchuk et al. 2018); there are about 20 races of *P. tritici-repentis* (Died.) Drechsler (Shvets, 2016).

Selection of appropriate stress-resistant genotypes for the corresponding agro-ecological growing conditions allows for minimization of unwanted crop losses induced by limiting environmental factors (Studnicki et. al., 2019; Filip et al., 2021). The resistance of a genotype to environmental stressors characterizes its stability, while the ability to adapt and exist under changing environmental conditions, i.e. plasticity, enables effective using favorable factors of an environment within the limits of the genetic norm of reaction, (Litun, 1980; Zamlila et al., 2019; Dhiwar et al., 2020).

Pre-selection of sources combining high group resistance to pathogens, yield capacity, and desirable adaptability under certain agro-ecological growing conditions improves the effectiveness of breeding to create highly promising cultivars and leverage the gene pool of Ukrainian plants (Khomenko, Sandetska, 2018; Nazarenko et al., 2020).

Our purpose was to determine the environmental plasticity of short-stemmed winter bread wheat cultivars differentiated by resistance to yellow leaf blotch and brown rust via analyzing the ranks of the genotypic effect and regression coefficient for yield as well as to select high-yielding sources adapted to the eastern forest-steppe of Ukraine.

Materials and methods

Twenty-four (24) short-stemmed winter bread wheat (*Triticum aestivum* L.) cultivars from nine countries were studied: eight Ukrainian cultivars, four Hungarian cultivars, three French accessions, three accessions from the US, two German accessions, one Romanian accession, one accession from Tajikistan, one Czech accession, and one Croatian accession. The study was carried out in the Laboratory of Genetic Resources of Cereals, Grain Legumes, and Groats Crops of the National Center for Plant Genetic Resources of Ukraine (NCPGRU) at the Yuriev Plant Production Institute of NAAS (located in the Kharkivskyi District of the Kharkivska Oblast; the northeastern part of the left-bank forest-steppe of Ukraine) in 2019-2022. The experiments were conducted by the qualification examination techniques (Tkachyk, 2016). Post-fallow sowing was conducted with a SSFK-7 small seeder on plots of 5 m^2 in three replications within the optimal timeframe. The seeding rate was 4,500,000 seeds per 1 ha. In the spring, the plots were fertilized with ammonium nitrate (N_{40}). Cv. 'Bunchuk' was taken as the check cultivar and sown between every 20 accessions. The accessions were studied by S.O. Tkachyk's method (Tkachyk, 2016) and methods for assessing resistance of wheat cultivars to pests and pathogens (Trybel et al., 2010). The resistance to foliar diseases was evaluated on a 9–point scale, where 1 point corresponds to very low resistance (very strong damage, > 50%), 3 points – low resistance (strong damage, 26–50%), 5 points – medium resistance (moderate damage, 5–25%), 7 points - high resistance (weak damage, < 5%), 9 points – very high resistance (no damage, 0%). The environmental plasticity was determined as B.P. Hurieva, P.P. Litun, and I.A. Huriev (Huriev et al. 1981) recommended: this approach is based on evaluation of the genotypic effect (ε_i) as a degree of general adaptive capacity and the regression coefficient (R_i) as a degree of plasticity with the establishment of ranks. According to this approach, the higher genotypic effect is and the lower the regression coefficient is, the higher the rank is (1 – high, 2 – medium, 3 – low). Genotypes with a total number of ranks of 2–3 are of the greatest breeding value, as they combine the high potential of an investigated trait and its stable expression throughout the study period. To comprehensively evaluate the wetting modes in the study years, we used T.G. Selyaninov's hydrothermal coefficient (HTC) (Selyaninov, 1937), which was calculated by the following formula:

$$HTC = \sum \text{precipitation} / 0.1 \times \sum \text{temperatures above } 10\ °C.$$

The traditional scale is as follows: HTC < 0.4 – very arid; HTC = 0.4–0.5 – arid; HTC = 0.6–0.7 – moderately arid; HTC = 0.8–0.9 – wet; HTC = 1.0–1.5 – sufficiently wet; HTC > 1.5 – excessively wet.The Chaddock scale (Chaddock, 1952) was used to qualitatively assess the correlation coefficients and strength of relationships between the studied characteristics.

To achieve the goal, we used the following research methods: general scientific (analysis and synthesis) – for differentiation and generalization of the results, field - for evaluation of the accessions' resistance to fungal pathogens and yield capacity, ANOVA – for determination of the environmental plasticity for yield and significance of differences. Experimental data were statistically processed by calculus of variations, analysis of variance, and correlation and regression analyses in MS Excel 2007 and Statistica 6.0.

Results and discussion

Having analyzed the weather during the growing periods in 2019–2022, we can conclude that different values of the hydrothermal coefficient (HTC) contributed to differentiation of the winter bread wheat accessions by resistance to yellow leaf blotch and brown rust as well as by yield. The autumn in 2021 was very dry (HTC = 0.36); the 2020 autumn was dry (HTC = 0.46), and the 2019 autumn was rather wet (HTC = 1.46). The meteorological conditions during the spring-summer vegetation differed significantly in terms of wetting and temperature: the 2022 spring was dry (HTC = 0.59); the 2021 spring was sufficiently wet (HTC = 1.46); and the 2020 spring was water-logged (HTC = 2.05). The summer months in 2020 (HTC = 1.27) and 2022 (HTC = 1.17) were sufficiently wet, while the 2021 summer was moderately dry (HTC = 0.64). 2020 and 2021 were favorable years for the selection of sources of resistance to yellow leaf blotch (*P. tritici-repentis* (Died.) Drechsler) and brown rust *(P. recondita* f. sp. *tritici* Rob. et Desm.). 2020 and 2022 were the most favorable years for high yields. In 2021, the yields were mostly lower. Water deficit and high

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temperature in July 2021 (HTC = 0.09) led to windburn of grain, negatively affecting the yields of the vast majority of the winter bread wheat under investigation.

Thus, the weather during the growing periods made it possible to differentiate the winter bread wheat accessions by resistance to yellow leaf blotch and brown rust as well as by yield, to determine the environmental plasticity of these parameters, and to identify high-yielding sources that are adapted to the eastern forest-steppe of Ukraine.

In 2019–2022, the variation series of resistance to *P. tritici-repentis* (Died.) Drechsler and *P. recondita* f. sp. *tritici* Rob. et Desm. in the tested winter bread wheat cultivars ranged from 1 point to 9 points. As a result of the study, nine sources of high resistance to *P. tritici-repentis* (Died.) Drechsler (7–9 points) were selected, i.e. 37.5% of the total number of studied accessions. They are the following cultivars: 'Versiia odeska' (UKR), 'Pokrovska' (UKR), 'MIP Vidznaka' (UKR), 'Perspektyva odeska' (UKR), 'Doskonalist odeska' (UKR), 'Amurg' (ROU), 'MV Kaplar' (HUN), 'Mescal (FRA)', and 'SY Wolf' (USA), while the check cv. 'Bunchuk' showed a 4–point resistance (Fig. 1).

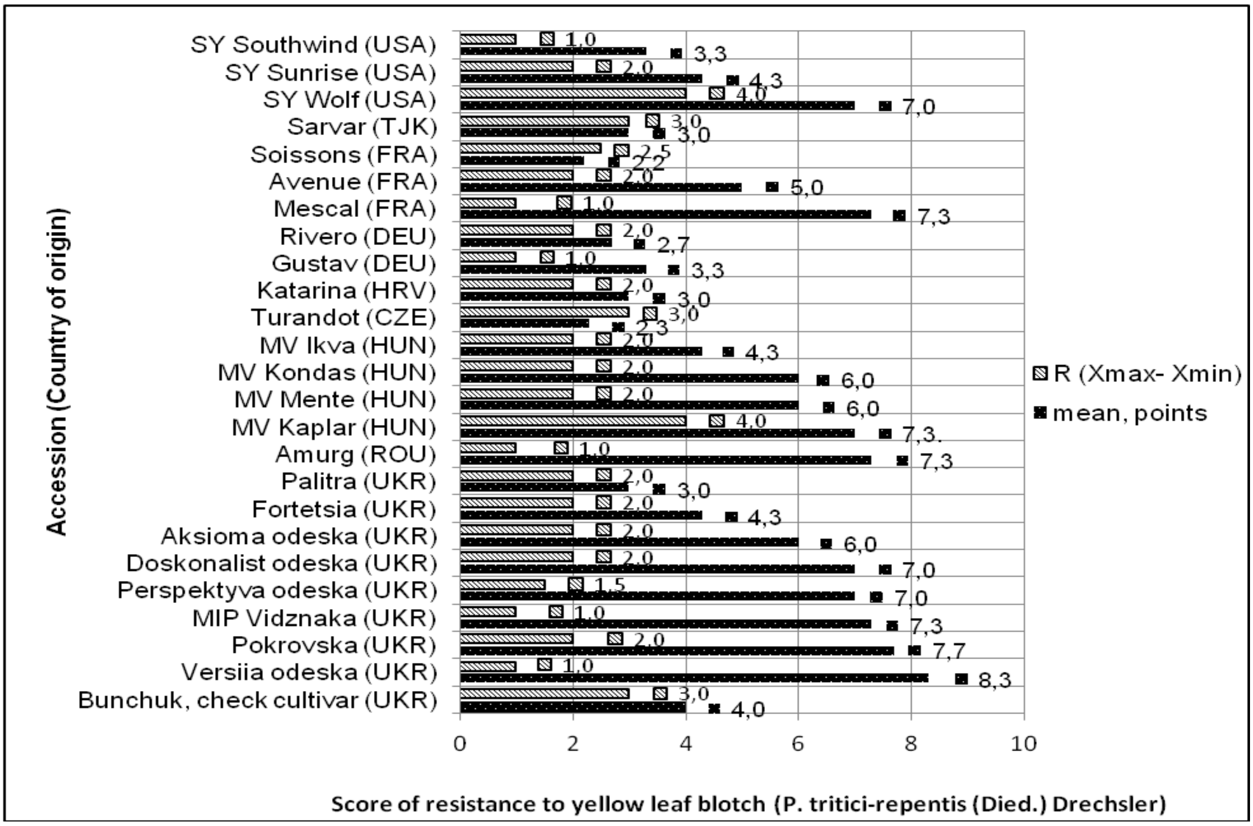

Fig. 1. Resistance of the short-stemmed winter bread wheat genotypes to the causative agent yellow leaf blotch (*P. tritici-repentis* (Died.) Drechsler), 2019–2022

In the studied sample, the following accessions were characterized by 4– to 6–point resistance to yellow leaf blotch: cvs. 'Aksioma odeska' (UKR), 'Fortretsia' (UKR), 'MV Mente' (HUN), 'MV Kondas' (HUN), 'MV Ikva' (HUN), 'Avenue' (FRA), and 'SY Sunrise' (USA); their share was 29.2%. Eight cultivars (33.3%) showed low resistance to *P. tritici-repentis* (Died.) Drechsler: cvs. 'Palitra' (UKR), 'Turandot' (CZE), 'Gustav' (DEU), 'Rivero' (DEU), 'Soissons' (FRA), 'Sarvar' (TJK), and 'SY Southwind' (USA).

From the coefficient of variation (CV, %), it was seen that the resistance to yellow leaf blotch ranged from 6.9% to 65.5%. Having analyzed the variation series, we determined that cvs. 'Versiia odeska' (UKR), 'Pokrovska' (UKR), 'MIP Vidznaka' (UKR), 'Amurg' (ROU), and 'Mescal' (FRA) were little variable (CV ≤ 10.0%); their share was 20.8%. Eight accessions (33.3%) were characterized by medium variability (CV = 11.0%–20.0%): cvs. 'Perspektyva odeska' (UKR), 'Doskonalist odeska' (UKR), 'Aksioma odeska' (UKR), 'MV Mente' (HUN), 'MV Kondas' (HUN), 'Gustav' (DEU), 'Avenue' (FRA), and 'SY Southwind' (USA). The following cultivars were distinguished by high variability (CV > 20.0%) of resistance to *P. tritici-repentis*

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(Died.) Drechsler: 'Fortetsia' (UKR), 'Palitra' (UKR), 'MV Ikva' (HUN), 'MV Kaplar' (HUN), 'Turandot' (CZE), 'Katarina' (HRV), 'Rivero' (DEU), 'Soissons' (FRA), 'Sarvar' (TJK), 'SY Sunrise' (USA), and 'SY Wolf' (USA). It was found that the percentage of accessions with significant variability of resistance yellow leaf blotch was 45.8%. The variability of resistance to yellow leaf blotch in cv. 'Bunchuk' (check cultivar) was considerable (CV = 43.3%).

High resistance to brown rust (7–9 points) was noted for nine genotypes; their share was 37.5% of the total number of tested accessions. These were the following cultivars: 'Perspektyva odeska' (UKR), 'Fortetsia' (UKR), 'Pokrovska' (UKR), 'Versiia odeska' (UKR), 'MV Kondas' (HUN), 'Gustav' (DEU), 'Rivero' (DEU), 'Mescal' (FRA), and 'Avenue' (FRA). The check cultivar, 'Bunchuk', showed resistance of 6 points (Fig. 2).

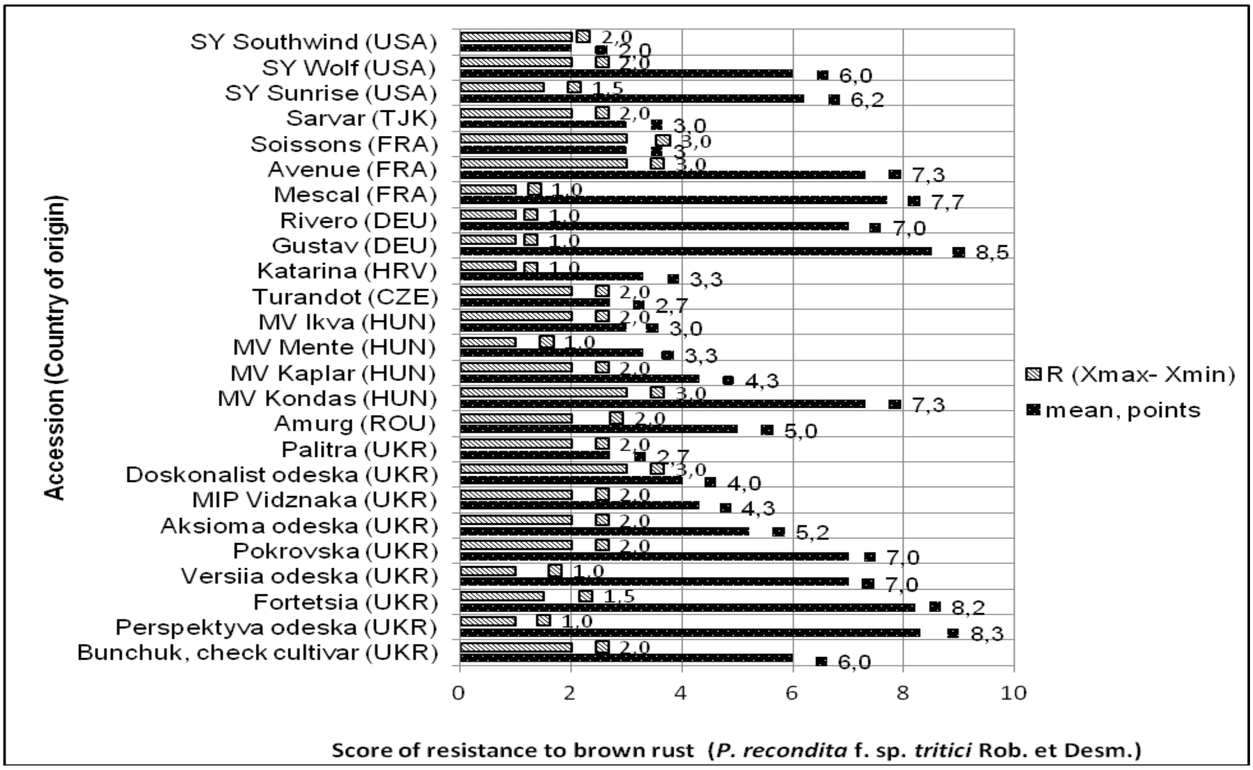

Fig. 2. Resistance of the short-stemmed winter bread wheat genotypes to the causative agent of brown rust (*P. recondita* f. sp. *tritici* Rob. et Desm.), 2019–2022

The following accessions were characterized by medium resistance (4–6 points): cvs. 'Aksioma odeska' (UKR), 'MIP Vidznaka' (UKR), 'Doskonalist odeska' (UKR), 'Amurg' (ROU), 'MV Kaplar' (HUN), 'SY Sunrise' (USA), and 'SY Wolf' (USA); their share was 29.2%.

Low resistance to *P. recondita* f. sp. *tritici* Rob. et Desm. was noted in cvs. 'Palitra' (UKR), 'MV Mente' (HUN), 'MV Ikva' (HUN), 'Turandot' (CZE), 'Katarina' (HRV), 'Soissons' (FRA), 'Sarvar' (TJK), and 'SY Southwind' (USA); their share was 33.3%.

According to the coefficient of variation (CV, %), the variability of resistance to brown rust ranged from 5.9% to 57.7%. Having analyzed the variation series, we determined that cvs. 'Fortetsia' (UKR), 'Versiia odeska' (UKR), 'Perspektyva odeska' (UKR), 'Gustav' (DEU), 'Rivero' (DEU), and 'Mescal (FRA)' were little variable (CV ≤10.0 %); their share was 25.0%. Six cultivars (25.0%) showed medium variability (CV = 11.0% – 20.0%) of resistance to brown rust: cvs. 'Pokrovska' (UKR), 'Amurg' (ROU), 'MV Mente' (HUN), 'Katarina' (HRV), 'SY Sunrise' (USA), and 'SY Wolf' (USA). A high variability (CV > 20.0%) was noted in the following cultivars: 'Doskonalist odeska' (UKR), 'Palitra' (UKR), 'MIP Vidznaka' (UKR), 'Aksioma odeska' (UKR), 'MV Ikva' (HUN), 'MV Kaplar' (HUN), 'MV Kondas' (HUN), 'Soissons' (FRA), 'Avenue' (FRA), 'Sarvar' (TJK), and 'SY Southwind' (USA).

It was determined that the percentage of accessions with considerable variability in resistance to brown rust was 45.8%. The variability of resistance to *P. recondita* f. sp. *tritici* Rob. et Desm in cv. 'Bunchuk' (check cultivar) was medium (CV = 16.7%).

As a result of the analysis, little-variable sources of high and stable resistance to the causative agents of yellow leaf blotch and brown rust were identified in the studied group of short-stemmed winter bread wheat genotypes. They were cv. 'Versiia odeska' (UKR) and cv. 'Mescal' (FRA).

To determine the environmental plasticity of the short-stemmed winter bread wheat genotypes differentiated by resistance to yellow leaf blotch and brown rust, the tested sample was evaluated by the genotypic effect ranks and coefficient of regression for yield.

In 2019 - 2022, sources of high yield (plus > 16% to the yield from the check cultivar) were selected from the short-stemmed winter bread wheat genotypes of different eco-geographical origins. These sources included cvs. 'Pokrovska' (UKR), 'Doskonalist odeska' (UKR), 'Versiia odeska' (UKR), 'MIP Vidznaka' (UKR), 'Amurg' (ROU), 'MV Ikva' (HUN), 'Mescal' (FRA), and 'SY Wolf' (USA). The check cultivar, 'Bunchuk' (UKR), yieldd 5.18 t/ha.

Table 1. Environmental plasticity of the short-stemmed winter bread wheat genotypes differentiated by resistance to *P. tritici-repentis* (Died.) Drechsler, *P. recondita* f. sp. *tritici* Rob. et Desm. and yield, 2019–2022

Accession	Country of origin	Yield, t/ha			Genotypic effect		Coefficient of regression (degree of plasticity)		Environmental plasticity, sum of ranks
		max	*min*	*X*	ε_i	Rank	R_i	Rank	
Bunchuk[1)]	UKR	7.00	4.10	5.18	-0.13	2	1.32	3	5
Pokrovska	UKR	7.50	6.70	7.23	1.92	1	0.60	1	2
Doskonalist odeska	UKR	7.80	5.50	6.61	1.30	1	1.29	3	4
Versiia odeska	UKR	7.15	5.85	6.52	1.21	1	0.77	1	2
MIP Vidznaka	UKR	6.75	5.62	6.36	1.05	1	0.82	1	2
Fortetsia	UKR	6.45	4.50	5.73	0.42	2	1.38	3	5
Palitra	UKR	6.50	4.42	5.52	0.21	2	1.27	3	5
Perspektyva odeska	UKR	5.20	4.20	4.83	-0.48	3	0.70	1	4
Aksioma odeska	UKR	5.70	4.00	4.67	-0.64	3	0.69	1	4
Amurg	ROU	7.22	5.20	6.47	1.16	1	1.43	3	4
MV Ikva	HUN	6.80	5.40	6.26	0.95	1	0.97	2	3
MV Kaplar	HUN	6.85	4.73	5.73	0.42	2	1.17	3	5
MV Mente	HUN	5.47	3.80	4.54	-0.77	3	0.79	1	4
MV Kondas	HUN	5.32	3.20	4.24	-1.07	3	1.12	3	6
Turandot	CZE	4.75	2.50	3.81	-1.50	3	1.45	3	6
Katarina	HRV	4.50	2.70	3.60	-1.71	3	0.97	2	5
Gustav	DEU	6.24	4.85	5.56	0.25	2	0.82	1	3
Rivero	DEU	5.80	4.35	5.16	-0.15	2	0.93	2	4
Mescal	FRA	6.61	5.71	6.29	0.98	1	0.65	1	2
Avenue	FRA	5.70	3.30	4.47	-0.84	3	1.25	3	6
Soissons	FRA	4.80	2.80	3.80	-1.51	3	1.08	2	5
Sarvar	TJK	5.65	3.50	4.55	-0.76	3	1.13	3	6
SY Wolf	USA	6.85	5.65	6.25	0.94	1	0.69	1	2
SY Sunrise	USA	6.53	4.43	5.17	-0.14	2	0.78	1	3
SY Southwind	USA	4.70	3.40	4.23	-1.08	3	0.94	2	5
$LSD_{0.05}$		–	–	0.43	–	–	–	–	–
min		4.50	2.50	3.60	-1.71	1	0.60	1	2
max		7.80	6.70	7.23	1.92	3	1.45	3	6
med		6.15	4.42	5.31	0.00	–	1.00	–	–

Note: [1)] check cultivar.

Among the short-stemmed genotypes under investigation, high values of the genotypic effect (rank 1) for yield were noted for eight cultivars, accounting for 33.3%. These genotypes were cvs. 'Pokrovska'

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(UKR), 'Doskonalist odeska' (UKR), 'Versiia odeska' (UKR), 'MIP Vidznaka' (UKR), 'Amurg' (ROU), 'MV Ikva' (HUN), 'Mescal' (FRA), and 'SY Wolf' (USA) (Table 1).

A medium genotypic effect (rank 2) was intrinsic to cvs. 'Fortetsia' (UKR), 'Palitra' (UKR), 'MV Kaplar' (HUN), 'Gustav' (DEU), 'Rivero' (DEU), and 'SY Sunrise' (USA), which accounted for 25.0%. A low genotypic effect (rank 3) was characteristic of ten cultivars (41.7%), viz: 'Perspektyva odeska' (UKR), 'Aksioma odeska' (UKR), 'MV Mente' (HUN), 'MV Kondas' (HUN), 'Turandot' (CZE), 'Katarina' (HRV), 'Avenue' (FRA), 'Soissons' (FRA), 'Sarvar' (TJK), and 'SY Southwind' (USA). The check cultivar, 'Bunchuk' (UKR), showed a medium genotypic effect on yield (rank 2). We demonstrated that the genotypic effect (ε_i) on yield in the tested group of short-stemmed cultivars differentiated by resistance to yellow leaf blotch and brown rust ranged from -1.71 to 1.92.

There were ten (41.7%) homeostatic accessions with high stability of yield (rank 1). The following accessions were noticeable for this genotypic feature: cvs. 'Pokrovska' (UKR), 'Versiia odeska' (UKR), 'MIP Vidznaka' (UKR), 'Perspektyva odeska' (UKR), 'Aksioma odeska' (UKR), 'MV Mente' (HUN), 'Gustav' (DEU), 'Mescal' (FRA), 'SY Wolf' (USA), and 'SY Sunrise' (USA). Five cultivars (20.8%) were classed as moderately sensitive to variable growing conditions in terms of yield (rank 2): cvs. 'MV Ikva' (HUN), 'Katarina' (HRV), 'Rivero' (DEU), 'Soissons' (FRA), and 'SY Southwind' (USA).

According to the degree of plasticity (R_i), there were nine (37.5%) intensive, i.e., sensitive to improved or worsened conditions of cultivation, genotypes (rank 3). They included cvs. 'Doskonalist odeska' (UKR), 'Fortetsia' (UKR), 'Palitra' (UKR), 'Amurg' (ROU), 'MV Kaplar' (HUN), 'MV Kondas' (HUN), 'Turandot' (CZE), 'Avenue' (FRA), and 'Sarvar' (TJK). According to the degree of plasticity, cv. 'Bunchuk' (check cultivar) was characterized by high sensitivity to changing conditions of cultivation (rank 3).

Having investigated the environmental plasticity of the short-stemmed winter bread wheat genotypes differentiated by resistance to yellow leaf blotch and brown rust and having analyzed the sum of ranks of the genotypic effect (ε_i) and the regression coefficient (R_i) for yield in the studied sample, we identified five cultivars (20.8%) with the highest genetic potential for adaptability to stressful growing conditions in the eastern forest-steppe of Ukraine and, accordingly, with the greatest breeding value, as evidenced by the lowest sum of ranks (sum of ranks = 2), viz: cvs. 'Pokrovska' (ε_i = 1.92; R_i = 0.60) (UKR), 'Versiia odeska' (ε_i = 1.21; R_i = 0.77) (UKR), 'MIP Vidznaka' (ε_i = 1.05; R_i = 0.82) (UKR), 'Mescal' (ε_i = 0.98; R_i = 0.65) (FRA), and 'SY Wolf' (ε_i = 0.94; R_i = 0.69) (USA).

Scientists have different opinions about the possibility of combining relatively high and stable yield with resistance to environmental stressors in one genotype. Some scientists claim that there are no winter bread wheat cultivars that are capable of combining high resistance to stress factors, in particular drought, with high and stable yield (Zviahin et al., 2008). However, T. Yurchenko et al. (2020) point out that the negative correlation between stress resistance and yield is not absolute and, therefore, there are prospects for an optimal combination of these traits in one genotype (Yurchenko et al., 2020). It is noteworthy that British scientists managed to identify four modern British winter bread wheat cultivars ('Gladiator', 'Humber', 'Mercato', and 'Zebedee'), which combined a high yield potential with its stable manifestation (Pennacchi et al., 2019).

A lot of scientists, both Ukrainian and foreign ones, think that, when one breeds for increased yield only, the adaptive potentials of cultivars decrease over time, and therefore, genotypes' potential yields and parameters of adaptive capacity should be routinely monitored to improve existing cultivars (Lavrynenko et al., 2020; Dhiwar et al., 2020).

Our results indicate that the *T. aestivum* L. genotypes with high group resistance to pathogens have significant advantages in terms of adaptability compared to accessions with individual or low resistance to phytopathogens (Petrenkova et al., 2018; Khomenko, Sandetska, 2018). Thus, cvs. 'Versiia Odeska' (UKR) and 'Mescal' (FRA), which were noticeable for high and stable resistance to *P. tritici-repentis* (Died.) Drechsler and *P. recondita* f. sp. *tritici* Rob. et Desm., were included in the group of the most high-yielding and adapted genotypes.

Accessions 'MV Ikva' (ε_i = 0.95; R_i = 0.97) (HUN), 'Gustav' (ε_i = 0.25; R_i = 0.82) (DEU), and 'SY Sunrise' (ε_i = -0.14; R_i = 0.78) (USA) were somewhat inferior (sum of ranks = 3) to cvs. 'Versiia Odeska' (UKR) and 'Mescal' (FRA). Six cultivars (25%) were ranged in group 3, based on potential for adaptability and relative practical value for production (sum of ranks = 4): cvs. 'Doskonalist odeska' (ε_i = 1.30; R_i = 1.29) (UKR), 'Perspektyva odeska' (ε_i = -0.48; R_i = 0.70) (UKR), 'Aksioma odeska' (ε_i = -0.64; R_i = 0.69) (UKR), 'Amurg' (ε_i = 1.16; R_i = 1.43) (ROU), 'MV Mente' (ε_i = -0.77; R_i = 0.79) (HUN), and 'Rivero' (ε_i = -0.15; R_i = 0.93) (DEU). The sum of ranks of 5 was scored by cvs. 'Fortetsia' (ε_i = 0.42; R_i = 1.38) (UKR), 'Palitra' (ε_i = 0.21; R_i = 1.27) (UKR), 'MV Kaplar' (ε_i = 0.42; R_i = 1.17) (HUN), 'Katarina' (ε_i = -1.71; R_i = 0.97) (HRV),

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'Soissons' ($ε_i$ = -1.54; R_i = 1.08) (FRA), and 'SY Southwind' ($ε_i$ = -1.08; R_i = 0.94) (USA), which made up 25%. Four foreign cultivars (16.7%) had the lowest adaptability potential by genotypic effect and degree of plasticity (sum of ranks = 6), viz: cvs. 'MV Kondas' ($ε_i$ = -1.07; R_i = 1.12) (HUN), 'Turandot' ($ε_i$ = -1.50; R_i = 1.45) (CZE), 'Avenue' ($ε_i$ = -0.84; R_i = 1.25) (FRA), and 'Sarvar' ($ε_i$ = -0.76; R_i = 1.13) (TJK). Cv. 'Bunchuk' (check cultivar) ($ε_i$ = -0.13; R_i = 1.32) (UKR) had a sum of ranks of 5 for environmental plasticity.

The selected high-yielding short-stemmed genotypes with high adaptive potentials are valuable starting materials to breed new promising winter bread wheat cultivars, which will be adapted to the stressful conditions of growing in the eastern forest-steppe of Ukraine.

Having analyzed relationships between the investigated traits, we established that resistance to the causitive agents of brown rust and yellow leaf blotch was significantly negatively correlated with the sum of ranks of the genotypic effect and degree of yield plasticity (r = -0.65 and r = -0.58, respectively) in the short-stemmed winter bread wheat genotypes. At the same time, the variability of resistance to the causative agents of brown rust and yellow leaf blotch was significantly positively correlated with the sum of ranks of the genotypic effect and yield plasticity degree (r = 0.59 and r = 0.52, respectively). The significance of the relationships was 99% ($P < 0.01$) (Table 2).

Table 2. Correlations (r) of the sum of ranks of the genotypic effect and degree of yield plasticity with resistance to the causitive agents of yellow leaf blotch and brown rust and the variability of these phytopathogens in the short-stemmed winter bread wheat genotypes, 2019–2022

Trait		Sum of ranks of the genotypic effect ($ε_i$) and degree of plasticity (R_i) of yield, t/ha
Score of resistance to pathogens, points	Yellow leaf blotch	-0.58 [1)]
	Brown rust	-0.65 [1)]
Variability of resistance to pathogens (CV), %	Yellow leaf blotch	0.52 [1)]
	Brown rust	0.59 [1)]

Note: [1)] – P < 0,01.

Thus, among biotic factors as environmental stressors, the pathogens *Pyrenophora tritici-repentis* (Died.) Drechsler and *Puccinia recondita* f. sp. *tritici* Rob. et Desm. negatively and significantly affected the potential and stability of yield in the group of short-stemmed winter bread wheat genotypes. This fact means that sources of group resistance to the specified phytopathogens are mandatory to involve in breeding to create genotypes adapted to the eastern forest-steppe of Ukraine.

Conclusions

According to the sum of ranks of the genotypic effect ($ε_i$) and the regression coefficient (R_i) for yield in the short-stemmed cultivars differentiated by resistance to yellow leaf blotch and brown rust, genotypes with the highest genetic potential of adaptability to the stressful conditions of cultivation in the eastern forest-steppe of Ukraine were identified, as evidenced by the lowest sum of ranks (sum of ranks = 2). These cultivars yielded by > 16% more than the chek cultivar, viz: cvs. 'Pokrovska' ($ε_i$ = 1.92; R_i = 0.60) (UKR), 'Versiia odeska' ($ε_i$ = 1.21; R_i = 0.77) (UKR), 'MIP Vidznaka' ($ε_i$ = 1.05; R_i = 0.82) (UKR), 'Mescal' ($ε_i$ = 0.98; R_i = 0.65) (FRA), and 'SY Wolf' ($ε_i$ = 0.94; Ri = 0.69) (USA).

Due to this study, we detected new sources of high and stable group resistance to the causative agents of yellow leaf blotch and brown rust: cv. 'Versiia odeska' (UKR) and cv. 'Mescal' (FRA). It was established that in the short-stemmed cultivars differentiated by resistance to *P. tritici-repentis* (Died.) Drechsler and *P. recondita* f. sp. *tritici* Rob. et Desm, the genotypic effect ($ε_i$) on yield ranged from -1.71 to 1.92 and the coefficient of regression (R_i) ranged from 0.60 to 1.45, largely affecting the environmental plasticity, the sum of ranks for which varied from 2 to 6. The percentage of accessions with high genotypic effects was 33.3%; the percentage of accessions with high stability of yield was 41.7%. It was found that in the short-stemmed winter bread wheat genotypes the resistance to the causative agents of brown rust and yellow leaf blotch was significantly negatively correlated with the sum of ranks of the genotypic effect and degree of yield plasticity (r = -0.65, P<0.01 and r = - 0.58, P<0.01, respectively).

The selected sources of high group resistance to yellow leaf blotch and brown rust, high potential and stability of yield are valuable starting materials for the breeding of new highly promising winter bread cultivars wheat that will be adaptable to growing in the eastern forest-steppe of Ukraine.

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Екологічна пластичність короткостеблих сортів пшениці м'якої озимої (*Triticum aestivum* L.) та стійкість до збудників піренофорозу (*Pyrenophora tritici-repentis* (Died.) Drechsler) і бурої листкової іржі (*Puccinia recondita* f. sp. *tritici* Rob. et Desm.)

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У зв'язку з мінливістю поширених збудників листкових хвороб пшениці м'якої озимої, утворенням вірулентних та агресивних рас, а також з періодичними посухами, які зі змінами клімату все частіше спостерігаються на території України, виникають передумови для поглибленого вивчення адаптивних властивостей сортів рослин та виділення серед них кращого генофонду для селекції. У роботі представлені результати визначення екологічної пластичності в короткостеблих сортів пшениці м'якої озимої, диференційованих за стійкістю до збудників піренофорозу та бурої листкової іржі. Виділено нові джерела високої та стабільної групової стійкості до збудників піренофорозу та бурої листкової іржі – Версія одеська (UKR) та Mescal (FRA). За сумою рангів генотипового ефекту (ε_i) та коефіцієнту регресії (R_i) врожайності серед короткостеблих сортів, визначено генотипи, які відзначаються найвищим генетичним потенціалом адаптивності (сума рангів 2) до стресових умов вирощування в східній частині Лісостепу України, формуючи при цьому урожайність понад 16 % до стандарту, а саме: Покровська (ε_i = 1,92; R_i = 0,60), Версія одеська (ε_i = 1,21; R_i = 0,77), МІП Відзнака (ε_i = 1,05; R_i = 0,82) (UKR); Mescal (ε_i = 0,98; R_i = 0,65) (FRA) та SY Wolf (ε_i = 0,94; R_i = 0,69) (USA). Встановлено, що у короткостеблих сортів генотиповий ефект врожайністі був у межах від -1,71 до 1,92, а коефіцієнт регресії – від 0,60 до 1,45, що значною мірою позначалося на рівні екологічної пластичності, діапазон суми рангів якої варіював при цьому від 2 до 6. Частка зразків з високими значеннями генотипового ефекту при цьому складала 33,3 %, а з високою стабільністю реалізації урожайності – 41,7 %. Встановлено, що у короткостеблих генотипів пшениці м'якої озимої стійкість до збудників бурої листкової іржі та піренофорозу на значному негативному рівні корелюють із сумою рангів генотипового ефекту і коефіцієнту регресії врожайністі – r = -0,65, P < 0,01 та r = -0,58, P < 0,01 відповідно. Виділені джерела високих рівнів групової стійкості до збудників піренофорозу та бурої листкової іржі, високого потенціалу та стабільності урожайності є цінним вихідним матеріалом для створення нових та високоперспективних сортів пшениці м'якої озимої адаптивних до стресових умов вирощування у східній частині Лісостепу України

Ключові слова: *пшениця м'яка озима, епіфітотії, пластичність, стабільність, генотиповий ефект, адаптивність, урожайність, джерело*

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