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ADAPTIVE RESOURCE OF SOFT WINTER WHEAT GENOTYPES FOR UNSTABLE MOISTURE CONDITIONS

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Topicality. *The current plant breeding system should be considered a practical and effective tool to mitigate the adverse effects of climate change. An adaptive variety is ecologically flexible and capable of adapting to all environmental factors. Developing specific adaptive genotypes is feasible under conditions similar to those in which the variety will be cultivated. Targeted adaptation of cultivars to specific agro-ecological conditions allows them to maximize their genetic potential, enabling producers employing modern technologies to achieve high profitability from their implementation.* ***Purpose.*** *Comparison of varieties and hybrid combinations of winter wheat under changing growing conditions.* ***Materials and Methods.*** *During 2018–2023, a research of the adaptive resource of 10 hybrid combinations of soft winter wheat and standard varieties Yednist and Podolianka was conducted in the crop rotation of the Department of Breeding and Seed Production of the Dnipro State Agrarian and Economic University (DSAEU).* ***Results.*** *Yield differentiation was observed under uncontrolled weather conditions during the vegetation period. The maximum yield across the years was 9.12 t/ha in 2020, while the minimum yield was 4.18 t/ha in 2018. The average yield across varieties was 6.66 t/ha, with the maximum yield (9.10 t/ha) achieved by genotype 15-442 and the minimum (3.78 t/ha) – by genotype 15-309. The average yields in all environments for 2018-2023 did not completely reflect their adaptability, since the value of a specific trait is not inherited, and yield is a polygenic trait that indicates the rate of response of a particular variety sample.* ***Conclusions.*** *Yield variability is largely dependent on environmental conditions during a specific growing season with low significant effects of genotypes. The value of the average yield indicates the response rate of genotypes and their plasticity. Response of soft winter wheat cultivars in favourable years indicates productive potential, and in unfavourable years – adaptability or adaptive resource of genotypes to unstable moisture conditions. Under such conditions, the yield potential of soft winter wheat genotypes is maximally realised by the following: 15-383 – 8.37 t/ha, 15-259 – 8.15 t/ha, 15-442 – 9.10 t/ha, 15-145 – 8.22 t/ha, 15-291 – 8.78 t/ha, 15-393 – 8.70 t/ha, and the standard variety Yednist – 7.89 t/ha. Based on regression coefficients, genotypes were identified according to their environmental response: highly responsive genotypes included the standard Podolianka, 15-383, 15-705, 15-330, 15-256, 15-426, 15-309, and 15-442. Genotypes with low responsiveness included the standard variety Yednist, 15-291, and 15-145.*

Key words: *soft winter wheat, yield, stability, environment, adaptability*

Introduction. Today, the problem of ecological stability of modern intensive varieties of soft winter wheat (*Triticum aestivum* L.) in changing environmental conditions has become the most expressed. Overestimation of the potential productivity of such varieties leads to their significant variability in crop production, susceptibility to environmental changes. Breeding new varieties for specific soil and climate zones is not adaptively targeted enough. The goal of plant breeding is the development of high-yielding ecologically plastic varieties. Thus, ecological substantiation of breeding programmes, improvement of selection schemes, which remain empirical, are essential, and the main goal of adaptive breeding is to study and consider the interaction between genotype and environment [1–2].

This interaction is defined as a share of the phenotypic variability that results from the mismatch of genetic and non-genetic effects. When the varieties are tested under different weather conditions, the response rate of genotype to the environment varies. This interaction complicates the work of the breeder, especially in the initial steps of breeding, as selection in some conditions does not ensure the superiority of the variety in others [3].

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Domestic and foreign scientists have established that the genotype-environment interaction is a general biological phenomenon, which is statistically expressed in the additivity of genotype and environment effects [4–8].

The proposed biometric approaches for assessing the genotype-environment interaction during variety trials in different years, although they have real biological significance, but the information on phenotypic variance can be applied only to the group of genotypes under study.

The concepts of stability and plasticity are interpreted differently in the scientific literature, which complicates the assessment of these parameters and their use in selection. Plasticity is the ability of a genotype to adapt to different environmental conditions, while stability is the absence of plasticity. Stability in the agronomic context does not mean general phenotypic stability under different environmental conditions, but refers to valuable economic traits, especially yield, grain quality, and the duration of the growing season. A number of assessment methods for environmental stability is based on regression analysis. If the regression coefficient is higher than 1, the variety is highly susceptible to environmental changes (below average stability), if it is close to 1, the variety is unstable to the environment, if the regression coefficient is lower than 1, the stability is above average, and in case of absolute phenotypic stability, the regression coefficient is zero. A variety with high overall adaptive capacity, maximum yield potential under the most favourable conditions and maximum phenotypic stability is considered ideal. Given modern cultivation technologies and the growth of potential yields of varieties, the harvest volume and quality largely depend on unregulated environmental factors, which contribute to 70–80 % of yield variability over the years, even under intensive cultivation technologies. It should be noted that the less favourable climatic conditions and higher potential productivity of varieties, the less their differences in the absolute value of limiting factors (such as air temperature, soil moisture, etc.) affect the yield of soft winter wheat [1, 9].

The priority of variety adaptability, especially under unfavourable growing conditions, is related to the fact that the potential yield can be realised only if it is ‘protected’ by resistance to both biotic and abiotic factors. Moreover, the adaptability of varieties under adverse climatic conditions plays a greater role in the realisation of their productivity.

Ecological plant breeding should be considered as a real and effective method for minimising the adverse effects of climate change. An adaptive variety is plastic, i.e. adapted to external environmental factors. Specific adaptive genotypes need to be developed in conditions similar to those in which the variety is planned to be grown. Adaptation of varieties to specific agro-ecological conditions ensures maximum realisation of their genetic potential, which allows producers to obtain high economic benefits from their implementation using modern technologies [9–10].

The linear relationship between yield and environmental conditions allows us to predict the behaviour of varieties with different rates of response to changing environmental conditions.

Research was aimed at comparing varieties and hybrid combinations of soft winter wheat under changing growing conditions.

Materials and Methods. The research was conducted on the experimental field of the Educational and Research Centre of Dnipro State Agrarian and Economic University for 2018–2023. The predecessor was black fallow. Agrotechnological practices corresponded to the cultivation technology of soft winter wheat. The research material was ten hybrid combinations and varieties-standards Yednist, Podolianka. The area of the registration plot was 10 m^2; the experiment was repeated three times. Sowing was carried out with a SN-16 seeder, harvesting with Sampo 130 harvester. Generally accepted domestic and foreign methods were used to characterise the genotype-environment interaction and differentiate varieties by yield. We determined the following indicators: d_k – environment effect; $\sigma^2(G\times E)_{ek}$ – variety– environment interaction; δ^2_{DCC} – differentiating capacity of environment, L_{ek} – linearity factor, S_{ek} – relative differentiating capacity of environment, K_{ek} – factor of compensation –destabilisation. The ecological plasticity was determined by the methodology of the Yuriev Crop Production Institute in accordance with the OSGE application package *Elite Systems gr*. [11–13].

Given the contrasting meteorological conditions during the years of research, the growing season 2017/2018 was optimal for the growth and development of winter soft wheat plants (Fig. 1, 2). The annual precipitation totalled 638 mm, which is 98 mm more than the long-term average. Precipitation in March was 99 mm above the long-term average.

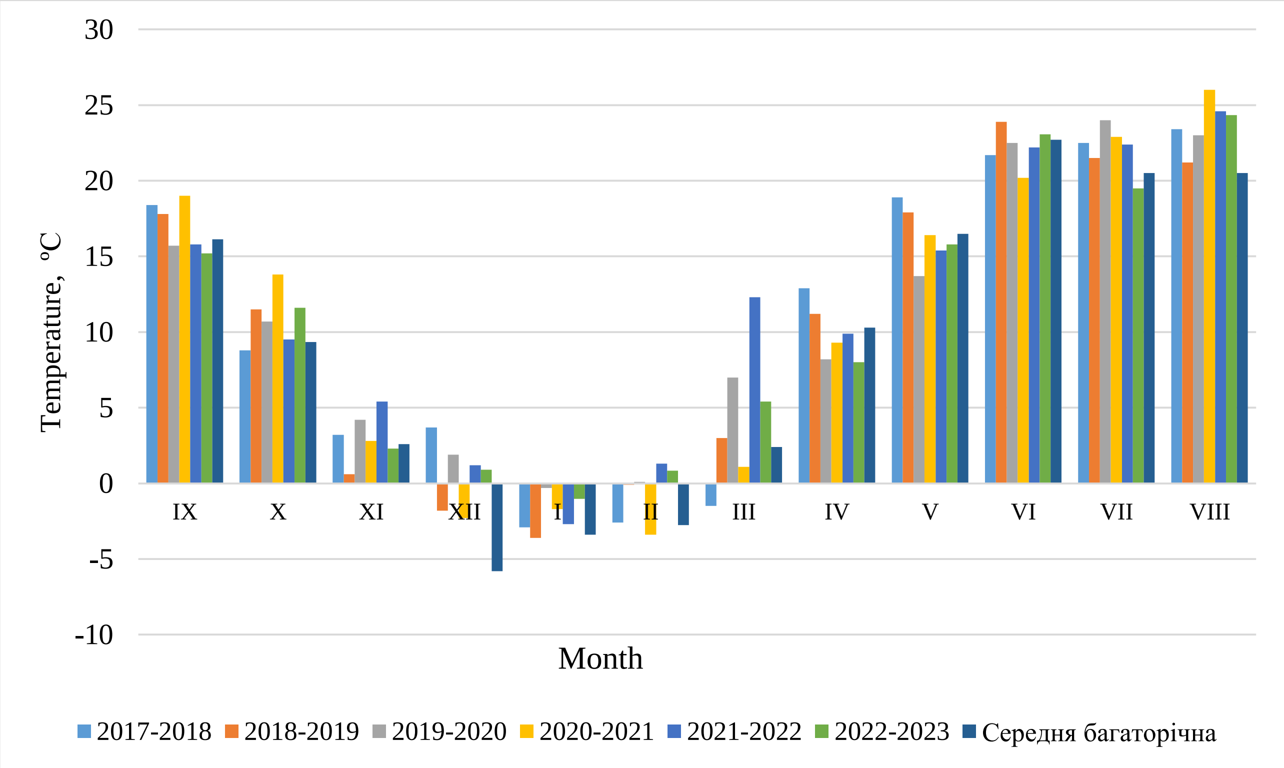

Fig. 1. Air temperature average for years of research, °C, (2018–2023).

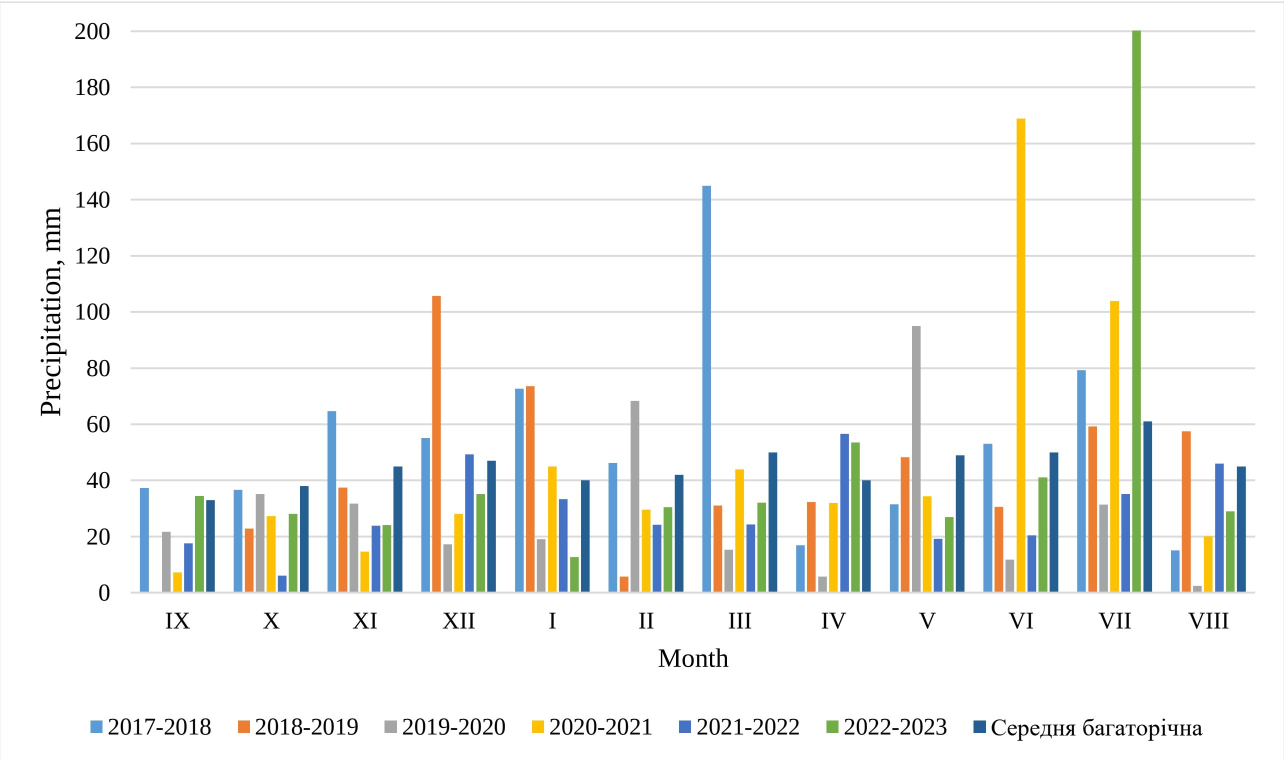

Fig. 2. Monthly precipitation for years of research, mm, (2018–2023).

The 2018/2019 growing season of soft winter wheat was heterogeneous in terms of weather conditions, which significantly affected the development of the crop and the formation of the harvest. The spring was early and warm, which contributed to the rapid growth resumption of wheat. The summer was dry and hot, which resulted in faster grain ripening. Precipitation was insufficient to provide plants with moisture during the critical development stages - heading and grain filling. In 2019/2020, the growing season was characterised by dry conditions. In autumn, the effective temperature sum was 384.0 °C, total precipitation was 35.3 mm, in spring and summer – 1433.4 °C and 151.4 mm, and for the entire growing season – 1817.4 °C and 186.7 mm, respectively. In 2020/2021, the pre-sowing and post-sowing periods were characterised by drought, with favourable hydrothermal conditions in October and November, which subsequently had a positive impact on overwintering. Following the spring growth resumption of soft winter wheat, favourable weather conditions prevailed for plant growth and development. The average temperature in April was 9.3 °C, and in May it was 16.4 °C, which is close to the long-term average. The total precipitation for the period was 64.3 mm. Heavy precipitations in June and July had a negative impact on plant growth and development. The total precipitation for this period was 271 mm (161 mm above the long-term average). The average air temperature in June was 20.2°C (2.5°C less than the long-term average), and in July it was 22.9 °C (2.4 °C above the long-term average). In 2021/2022, weather conditions during the sowing period were cool and dry. In September, the average monthly air temperature was 15.8°C, which is 0.3°C less than the long-term average, the effective temperature sum was 410.3°C, and the total precipitation was 17.6 mm (15.4 mm less than the long-term average).

The winter period was favourable in terms of hydrothermal conditions for winter wheat overwintering. The prolonged cool spring had a negative impact on the development of crops. During the spring growing season, the conditions for winter wheat were optimal for its growth and development. In May, the average monthly air temperature was 15.4°C, the effective temperature sum was 464.6°C, and the total precipitation was 66.7 mm (9.7 mm above the long-term average). In June, the average monthly air temperature was 22.2 °C, and the total precipitation was 20.4 mm (28.6 mm less than the long-term average).

Results and Discussion. The selection of a variety should be determined by the limiting factors of its growing environment and the material condition of production. The selection criterion should be the specific adaptation of the genotype to stressful conditions and, especially, to the local type of drought (Table 1).

Over the years of research, the highest yields were achieved by hybrid combinations 15-360 (9.12 t/ha), 15-442 (9.10 t/ha) and the standard variety Podolianka (9.07 t/ha). The most productive year was 2020, with a yield of 9.12 t/ha. The difference between the maximum and minimum yields – the range of variation (R) characterises the stability in yields of a particular genotype. The lower value of variation and, consequently, higher adaptability was observed in hybrid combinations HK 15-145 R – 2.95, HK 15-256 – 3.33, HK 15-383 – 3.24 and the standard variety Podolianka – 3.20.

Analysis of variance shows a significant share of environmental conditions (85.7 %) in the variability (Table 2). Genotypes, hybrid combinations and their interaction with the environment had significantly lower, but significant effects of 1.6 % and 12.7 %, respectively.

It was found that environments and genotypes had different values of statistical parameters during the studies, which contributed to the ranking and selection of promising winter wheat lines.

Indicators of environmental effects allow determining adaptability in specific environments, i.e., yields can be stable with the manifestation of genetic characteristics in the presented set of hybrid combinations and varieties-standards Yednist and Podolianka. For additionnal information, we determined the effects and interaction of factors, as well as the response of the varieties (Table 3).

The set of interaction effects of the factors characterises their variability. The best growing season conditions were observed in 2019, 2020 and 2023 (the effects of factor B were 0.81, 1.96 and 0.39, respectively).

In adaptive plant breeding, there are not enough values of the quantitative yield trait component for a complete and objective characterisation of hybrid combinations. Therefore, constant evaluation of the trait response in the genotype-environment interaction is crucial.

In the studies performed, differentiation of yields was observed in uncontrolled weather

Table 1. Yields of varieties and hybrid combinations, t/ha, 2018–2023

Variety, hybrid combination	Reference name	Years						Σ	x̄	max	min	R
		2018	2019	2020	2021	2022	2023					
Yednist (standard)		4.83	7.40	7.88	4.68	6.20	7.31	38.3	6.38	7.88	4.68	3.20
Podolianka (standard)		4.99	7.50	9.07	5.23	5.93	7.43	40.15	6.69	9.07	4.88	4.08
Yednist / Smuhlianka	HK 15-383	5.13	7.00	8.37	6.00	6.30	7.00	39.60	6.60	8.37	5.13	3.24
Podolianka / Zemliachka	HK 15-305	4.18	7.30	8.63	5.96	6.39	7.31	39.77	6.62	8.63	4.18	4.45
Yednist / HK 25	HK 15-360	4.40	7.70	9.12	6.50	7.07	6.96	41.75	6.95	9.12	4.40	4.72
Yednist / Korysna	HK 15-256	5.43	7.30	8.15	4.82	6.20	6.92	38.82	6.47	8.15	4.82	3.33
Yednist / Zolotokolosa	HK 15-426	4.61	7.50	8.70	4.92	6.76	7.01	39.50	6.58	8.70	4.61	4.09
Hoduvalnytsia / Yednist	HK 15-309	3.78	7.40	8.86	5.03	6.36	7.34	38.77	6.46	8.86	3.78	5.08
HK 25 / Spivanka	HK 15-442	4.66	7.80	9.40	5.73	6.76	7.33	41.38	6.89	9.10	5.73	3.37
HK 25 / Spivanka	HK 15-145	5.87	7.60	8.22	6.26	6.36	6.74	40.45	6.74	8.22	5.27	2.95
Podolianka / Zemliachka	HK 15-291	5.23	7.58	8.78	6.21	6.81	6.71	41.32	6.89	8.78	5.23	3.55
Podolianka / Zemliachka	HK 15-393	4.83	7.70	8.70	5.72	6.56	6.70	40.21	6.70	8.70	4.83	3.87
LSD_{05}, t/ha		0.41	0.52	0.51	0.43	0.53	0.35					
Σ		57.39	89.72	103.58	67.06	77.70	84.76	480.13	79.97			
x̄		4.78	7.47	8.63	5.58	6.47	7.06	40.00	6.66			
max		5.43	7.80	9.12	6.50	7.07	7.43					
min		4.18	7.40	7.88	4.92	5.93	6.70					
R		1.25	0.40	1.24	1.58	1.14	0.73					

Table 2. Proportion of factors influencing yield variability, 2018–2023

Factor	Mean square	Proportion of impact
Varieties (A)	75.87	1.6
Environment (B)	8732.53	85.7
Interaction (A x B)	35.41	12.7
Deviation P ≤ 0.05	4.81	

Table 3. Factor effects and genotype-environment interaction

Variety, hybrid combination	Effect of factor A	Effect of interaction AB						Regression coefficient b_i
		years						
		2018	2019	2020	2021	2022	2023	
Yednist (standard)	-0.28	0.05	-0.07	-0.75	-0.90	-0.27	0.25	0.96
Podolianka (standard)	0.03	0.21	003	0.44	-0.35	-0.54	0.37	1.09
HK 15-383	-0.06	0.35	-0.47	-0.26	0.42	-0.17	-0.06	1.23
HK 15-305	-0.04	-0.60	-0.17	0.00	0.38	-0.08	0.25	1.08
HK 15-360	0.30	-0.36	0.23	0.49	0.92	0.60	-0.10	1.08
HK 15-256	-0.19	0.65	-0.17	-0.48	-0.76	-0.27	-0.14	1.09
HK 15-426	-0.02	-0.17	0.03	0.07	-0.66	0.29	-0.05	1.23
HK 15-309	-0.20	-1.00	-0.07	0.23	-0.55	-0.11	0.28	1.38
HK 15-442	0.23	-0.12	0.33	0.77	0.15	0.29-	0.27	1.20
HK 15-145	0.08	1.09	0.13	-0.41	0.68	0.11	-0.33	0.75
HK 15-291	0.23	0.45	0.11	0.15	0.63	0.34	-0.35	0.86
HK 15-393	0.04	0.05	-0.27	0.07	0.14	0.09	-0.36	1.00
Effect of factor B		-1.88	0.81	1.96	-1.08	-0.19	0.39	

conditions of the growing season. By year, the maximum average yield of soft winter wheat was 9.12 t/ha in 2020, and the minimum yield was 4.18 t/ha in 2018. With an average yield of 6.66 t/ha, the maximum yield was 9.10 t/ha for genotype 15-442, and the minimum yield was 3.78 t/ha for genotype 15-309. In 2018–2023, the average yield in all environments does not fully demonstrate the adaptability of genotypes, but indicates the response rate of particular cultivars.

The response of genotypes to growing conditions in favourable years indicates the potential for productivity, and in unfavourable years – their adaptability to insufficient and unstable moisture conditions. Under such conditions, maximum yield potential was realised by the genotypes: 15-383 – 8.37 t/ha, 15-259 – 8.15 t/ha, 15-442 – 9.10 t/ha, 15-145 – 8.22 t/ha, 15-291 – 8.78 t/ha, 15-393 – 8.70 t/ha, and the standard variety Yednist – 7.89 t/ha.

The regression coefficient (b_i) of the yield of soft winter wheat cultivars shows the response to changes in growing conditions, with a value higher or lower than 1 or equal to it. According to this indicator, the wheat cultivars were divided into three groups: 1) low plasticity of cultivars ($b_i > 1$), which respond significantly to environmental conditions – standard variety Podolianka (1.09), 15-383 (1.23), 15-305 (1.08), 15-360 (1.08), 15-256 (1.09), 15-426 (1.23), 15-309 (1.38), 15-442 (1.20); 2) homeostatic cultivars ($b_i < 1$) have a weak reaction to changes in environmental conditions and the best adaptation to adverse conditions – variety-standard Yednist (bi = 0.96), 15-291 (bi = 0.86), 15-145 (bi = 0.75); 3) medium plasticity ($b_i = 1$) – hybrid combination 15-393.

All environments are intended to simulate a diversity of unpredictable and predictable growing conditions in the region for which the selection is being made, as well as to provide an opportunity to analyse and optimise its parameters. Ecological and genetic information on the genotype-environment interaction increases the quality and efficiency of crop breeding (Table 4).

In 2019, the highest differentiating capacity of environment was 0.48 with a high compensation coefficient of 2.28, which characterises the environment as analysing, i.e. it helps to identify the best genotypes. The linearity factors were 0.71 in 2018, 0.27 in 2021, and 0.24 in 2022, indicating a suppressive effect of the environment that levels the yield trait of soft win-

Table 4. Environmental parameters as background for evaluation of soft winter wheat genotypes

Year	d_k	δ^2_{DCC}	L_{ek}	S_{ek}	K_{ek}
	1	3	4	5	6
2018	-0.81	0.12	0.71	9.87	0.46
2019	0.93	0.48	0.26	11.75	2.28
2020	6.22	0.71	0.29	14.43	1.36
2021	-0.28	0.43	0.27	14.13	2.17
2022	-0.37	0.28	0.24	11.63	1.36
2023	1.51	0.21	0.19	7.15	1.03

Note: d_k – environment effect; δ^2_{DCC} – differentiating capacity of the environment; L_{ek} – linearity factor; S_{ek} – relative differentiating capacity of the environment; K_{ek} – compensation-destabilisation factor.

ter wheat. The conditions of 2020 and 2023 with low compensation coefficients of 1.36 and 1.03, respectively, when no yield variability was observed, were determined as a stabilising environment.

According to the obtained environmental parameters, we characterise the conditions of 2018, 2021 and 2022 as levelling, 2020 and 2023 as stabilising, and 2019 as analysing.

Conclusions

1. Variability of soft winter wheat yield significantly depends on environmental conditions in a particular period of growing season with low significant effects of genotypes.

2. Varieties and hybrid combinations should be continuously evaluated to determine their adaptive potential.

3. Average yields indicate the response rate of genotypes on environment and their plasticity.

4. Response of genotypes to the environment in favourable years indicates their productive potential, and in unfavourable years - adaptability to insufficient and unstable moisture conditions. Under favourable conditions, soft winter wheat genotypes maximise their productive potential: 15-383 – 8.37 t/ha, 15-259 – 8.15 t/ha, 15-442 – 9.10 t/ha, 15-145 – 8.22 t/ha, 15-291 – 8.78 t/ha, 15-393 – 8.70 t/ha, and the standard variety Yednist – 7.89 t/ha.

5. According to the regression coefficient of the genotypes' response to changing conditions, the following soft winter wheat genotypes were identified: significant response to the environment was observed in the standard variety Podolianka and hybrid combinations: 15-383, 15-705, 15-330, 15-256, 15-426, 15-309, 15-442, weak response – standard variety Yednist and hybrid combinations 15-291, 15-145.

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Актуальність. Сучасну систему селекції рослин слід розглядати в якості реального та ефективного засобу, що дає змогу мінімізувати несприятливі наслідки зміни клімату. Адаптивний сорт екологічно пластичний, пристосований до біотичних та абіотичних чинників. Створити специфічні адаптивні генотипи можливо в умовах, подібних до тих, у яких сорт вирощуватимуть. Адресна адаптація сортів до конкретних агроекологічних умов, де вони максимально реалізують свій генетичний потенціал, а виробничники, які застосовують сучасні технології, зможуть отримувати високі прибутки від їх впровадження. **Мета.** Порівняння сортів і гібридних комбінацій пшениці м'якої озимої в мінливих умовах вегетації. **Матеріали і методи.** В дослідженнях, проведених у сівозміні кафедри селекції і насінництва ДДАЕУ впродовж 2018–2023 рр., визначали адаптивний ресурс 10 гібридних комбінацій пшениці м'якої озимої та сорти-стандарти Єдність і Подолянка. **Результати.** Спостерігається диференціація врожайності пшениці м'якої озимої в нерегульованих погодних умовах вегетації. За роками досліджень максимальна врожайність відмічена у 2020 р. – 9,12 т/га, мінімальна – 4,18 т/га – у 2018 р. За середньої врожайності по сортах (6,66 т/га) максимальна отримана у генотипу 15-442 – 9,10 т/га, а мінімальна – у генотипу 15-309 – 3,78 т/га. Показники середньої врожайності в усіх середовищах за 2018–2023 рр. не повною мірою відображають їх адаптивність, тому що успадковується не величина конкретної ознаки, а врожайність – це полігенна ознака, яка вказує норму реакції конкретного сортозразка. **Висновки.** Мінливість урожайності значною мірою залежить від умов середовища в конкретний період вегетації при низьких достовірних ефектах генотипів. Величина середньої урожайності відображає норму реакції генотипів та вказує на їх пластичність. Реакція сортозразків пшениці м'якої озимої у сприятливі роки свідчить про продуктивний потенціал, а в несприятливі – про їх пристосованість або адаптивний ресурс генотипів до умов нестійкого зволоження. За таких умов максимально реалізують урожайний потенціал генотипи пшениці м'якої озимої: 15-383 – 8,37 т/га, 15-259 – 8,15 т/га, 15-442 – 9,10 т/га, 15-145 – 8,22 т/га, 15-291 – 8,78 т/га, 15-393 – 8,70 т/га, а також сорт-стандарт Єдність – 7,89 т/га. За значенням коефіцієнта регресії виділено генотипи за реакцією на середовище: значно реагують сорт-стандарт Подолянка,15-383, 15-705, 15-330, 15-256, 15-426, 15-309 і 15-442, слабка реакція – сорт-стандарт Єдність, 15-291, 15-145.

Ключові слова: *пшениця м'яка озима, врожайність, стабільність, середовище, адаптивність*