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EVALUATION OF DROUGHT TOLERANCE IN BREAD WINTER WHEAT VARIETIES OF FOREIGN SELECTION IN THE CENTRAL FOREST-STEPPE OF UKRAINE

M. V. Kharchenko, T. V. Yurchenko, S. V. Pykalo, V. P. Vasyliuk
The V.M. Remeslo Myronivka Institute of Wheat NAAS, 68 Tsentralna St., Tsentralne village, Obukhiv district, Kyiv region, 08853, Ukraine

Topicality. *Winter wheat is one of the main food crops in Ukraine and the world. The development of new varieties of bread winter wheat with a complex combination of valuable traits is currently relevant due to the possibility of stabilising the market for environmentally friendly food grains in Ukraine.* ***Purpose.*** *To determine the breeding value of fifteen winter bread wheat varieties of different ecological and geographical origin in terms of drought tolerance in the Central Forest-Steppe of Ukraine and to identify the sources of resistance to water scarcity.* ***Materials and Methods.*** *The studies were carried out at the V.5 M. Remeslo Myronivka Institute of Wheat NAAS of Ukraine in 2020–2022. The Podolianka variety was used as the standard. Fifteen bread winter wheat varieties of foreign selection were studied. An index approach was used to study the response of wheat samples to drought. Drought tolerance was assessed in the laboratory by germinating seeds in sucrose solutions at an osmotic pressure of 16 atm. and determining the intensity of electrolyte release from plant tissues under the impact of the stressor.* ***Results.*** *Over the years of research, meteorological conditions have differed significantly in terms of temperature and moisture availability both throughout the growing season and at certain stages of plant development. The yield of the wheat samples varied from 2.84 to 4.96 t/ha in a dry year and from 4.54 to 6.72 t/ha in an optimal year. The analysis of the data showed that the average yield in a dry year was 1.53 t/ha less than the optimal level. Assessment of drought tolerance by the method of seed germination in a sucrose solution revealed that among the tested varieties in 2021/22, three samples were highly tolerant, and the other 12 were medium tolerant. In 2020/21, all wheat samples were classified as medium tolerant. According to the intensity of electrolyte release from plant leaf tissues, all the studied wheat varieties showed high drought tolerance. The wheat varieties NE 06545, Aliya, Altigo, Vitor, MV Lepeny, Bodycek, Fotima were identified as sources of drought tolerance, based on a set of indices and laboratory assessment methods.* ***Conclusions.*** *The selected genotypes will serve as source breeding material for the development of new competitive varieties with valuable practical properties. Our research has made a contribution to the study of both theoretical and practical aspects of wheat drought tolerance.*

Key words: *bread winter wheat, variety, yield, drought tolerance, indices, sources of drought tolerance*

Introduction. According to UN forecasts, the world's population will continue to grow and reach 9.7 billion in 2050 [1]. The existence and development of mankind relies on a stable and diverse crop production and a healthy environment [2]. Bread winter wheat (*Triticum aestivum* L.) is one of the main food crops in Ukraine and the world. Demand for wheat is expected to grow steadily, which will be largely met by increasing yields [3–5].

Development of new highly adaptive varieties is one of the most affordable ways to increase the yield of any crop. However, varieties with high yield potential must be highly adaptable to environmental stressors [6, 7].

Wheat and its derivative products are a significant part of the human diet. This crop is quite susceptible to soil moisture scarcity [8]. Among the natural factors that have the most negative impact on all physiological processes of plant growth and development is water scarcity caused by drought [9]. In recent years,

Author information*:*

Mykhailo V. Kharchenko, *Candidate of Agricultural Sciences, Researcher of the Biotechnology, Genetics and Physiology Department, e-mail: michail.kharch@gmail.com, https://orcid.org/0000-0002-4005-2134*

Tetiana V. Yurchenko, *Candidate of Agricultural Sciences, Head of the Biotechnology, Genetics and Physiology Department, e-mail: t.yurchenko978@gmail.com, https://orcid.org/0000-0003-0164-4003*

Serhii V. Pykalo, *Candidate of Biological Sciences, Senior Researcher of the Biotechnology, Genetics and Physiology Department, e-mail: pykserg@ukr.net, http://orcid.org/0000-0002-3158-3830,*

Valerii P. Vasyliuk, *Postgraduate Student, e-mail: bioenergy.ua@ukr.net, https://orcid.org/0009-0008-5510-8867*

Ukraine has been experiencing intense droughts during the period of active plant growth, which inhibit plant growth and development and lead to a decrease in the assimilative leaf area, size of the stem, and reproductive organs, as well as a decrease in plant productivity and, in turn, yield [10]. Therefore, the development of new varieties of bread winter wheat with a complex combination of valuable economic traits is relevant today and has the potential to stabilise the market for environmentally safe food grain in Ukraine. Highly efficient cultivation of winter crops requires considering the specific weather conditions of a particular region and selecting varieties with high environmental plasticity.

The research is aimed at studying drought resistance of winter wheat varieties of different ecological and geographical origin in the central part of the Forest-Steppe of Ukraine and identifying sources of resistance to water scarcity using different research methods.

Materials and Methods. The research was conducted in the field conditions of the V. M. Remeslo Myronivka Institute of Wheat (MIP). The material for the study was 15 varieties of bread winter wheat of foreign selection: Aniya, Aliya, Derbes (Kazakhstan), Vitor, Balitus, Lukullus (Austria), MV Pengo, MV Lucia, MV Lepeny (Hungary), Altigo, Bodycek, Bordotka RAGT (France), Fotima, NE 06545, BC 01131-24 (Turkey). The Podolianka variety of bread winter wheat was used as a standard. Sowing was carried out from 5 to 10 October with a seeding rate of 250–300 seeds/m^2. The predecessor was black fallow. The plots were systematically arranged, with a registration area of 1 m^2, 15 cm row spacing, and 30 cm distance between plots. In the field, phenological observations and records were carried out in accordance with the generally accepted methodology [11]. Harvesting was carried out manually. The hydrothermal coefficient (HTC) was calculated to characterise the favourable environmental conditions and productivity formation according to the method of G. T. Selyaninov [12]. An index approach was used to study the response of varieties to drought [13]. The following indices were calculated: stress susceptibility index: $SSI = (1–Ys/Yp)/(1–\bar{Y}s/\bar{Y}p)$, tolerance index: $TOL = Yp–Ys$, mean productivity: $MP = (Yp+Ys)/2$, yield stability index: $YSI = Ys/Yp$, yield index: $YI = Ys/\bar{Y}s×100$, stress tolerance index: $STI = (Yp×Ys)/(\bar{Y}p)^2$, geometric mean productivity: $GMP = \sqrt{(Yp×Ys)}$, where Ys – yield under drought; Yp – yield under optimal conditions; $\bar{Y}s$ – yield mean of all varieties under drought; $\bar{Y}p$ – yield mean of all varieties under optimal conditions. Two contrasting years were chosen in the study: the dry year 2021/22 (HTC was 0.80, i.e., mild drought), and the optimal year 2020/21 (HTC was 1.03, i.e. sufficiently humid). Evaluation of cultivars for drought tolerance was carried out in the laboratory using two methods: germination of seeds in sucrose solutions at an osmotic pressure of 16 atm and by determining the intensity of electrolyte release from plant tissues under the influence of a stress factor [14]. The response of plants to water deficiency and temperature increase was studied at the VI stage of organogenesis (stem elongation) by determining the electrolyte release rate. The measurements of electrolyte release from the plant leaves after drying to a loss of 50 % of weight were used as an indicator of drought tolerance. The drought tolerance groups were divided into the following percentage of germi-nated seeds: highly resistant > 70 %, medium resistant 20–70 %, and low resistant < 20 %. According to the second method, the distribution was the opposite, the lower the relative intensity of electrolyte release from leaf tissues, the higher the level of drought resistance. Thus, the samples with a percentage of electrolyte release of less than 60 % were classified as highly resistant, 61–80 % as medium resistant, and 81–100 % as weakly resistant. The statistical significance of the differences between the data obtained was assessed using Fisher's criterion [15].

Results and Discussion. Winter wheat sowing in autumn 2020 took place under dry conditions. The rainfall was 21.3 mm in September, which is 35.3 mm less than the long-term average (Fig. 1).

The air temperature from August to October exceeded the long-term average by 1.1–5.0 °C. In October and November 2020, the moisture deficiency was 23.7 mm and 10.6 mm, respectively. In August, September and October, the HTC was 0.12, 0.38 and 0.80, respectively.

The cessation of plant vegetation was noted on 11 November 2020, when the air temperature dropped below the biological minimum of +5 °C (with an average daily temperature of +4.4 °C). In general, the winter of 2020/21 was moderate, with average temperatures below the long-term average

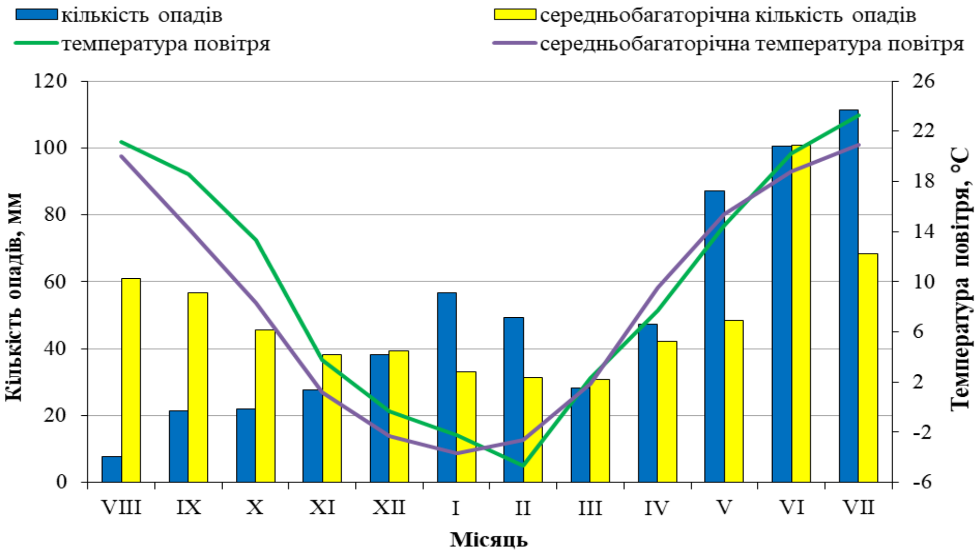

Fig. 1. Hydrothermal conditions during the growing season 2020/21.

only in February (-4.7 ºC). The maximum snow cover depth during the winter period was 32–35 cm. On 26 March 2021, the resumption of winter wheat vegetation was noted. In April, the average air temperature was 1.8°C below the long-term average, and in July it was 2.4 °C above it. In May, there was excessive moisture availability, and precipitation exceeded the norm by 38.6 mm. Thus, for the period from the resumption of vegetation to the end of July, the precipitation totalled 346.1 mm, or 134.8 % of the long-term average (256.7 mm). The maximum temperature (33.5 °C) was observed on 24 June. The hydrothermal coefficient was 0.16 in April, and 1.82, 1.66, 1.54 in May, June, and July, respectively.

In autumn 2021, winter wheat was sown under rather dry conditions. Thus, the precipitation totalled 18.7 mm in September, which is 37.9 mm less than the long-term average (Fig. 2).

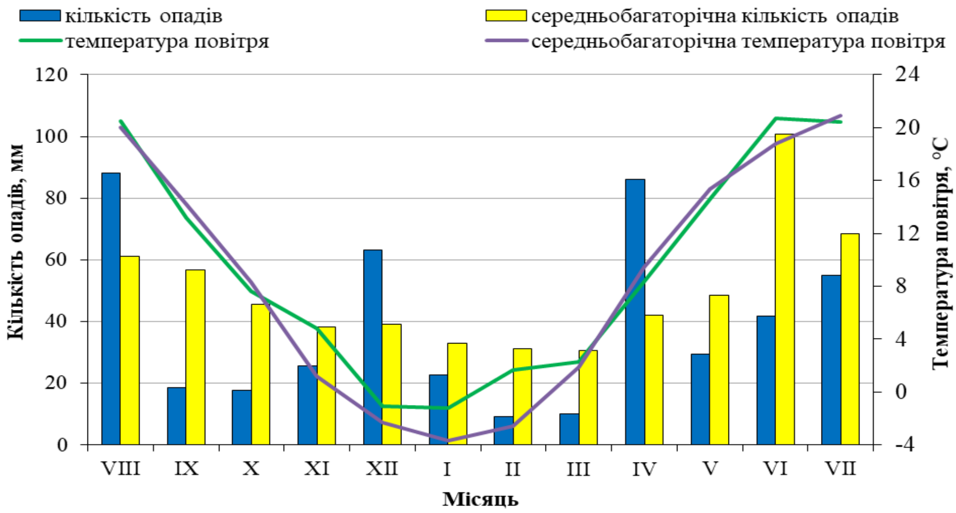

Fig. 2. Hydrothermal conditions during the growing season 2021/22.

The air temperature between August and October differed slightly from the long-term average. The moisture deficiency in October and November was 27.8 mm and 12.6 mm, respectively. The HTC was 1.39 in August and 0.16 in September.

On 9 November 2021, the air temperature dropped by +5 °C (with an average daily temperature of +4.1°C), and the first cessation of winter wheat growing season was observed. On 20 November, due to the change in weather conditions, winter crops resumed vegetation, and on 23 November, it finally ceased, which is 12 days later than last year.

The winter of 2021/22 was mild, with average monthly temperatures in January and February being 2.5 °C and 4.3 °C higher than the long-term average. The minimum air temperature for the winter period was -16.8 ºC. The maximum snow cover depth was 3–5 cm. The resumption of winter vegetation was noted on 21 March 2022. The average air temperature in April and May was 1.1 °C and 0.8 °C below the long-term average, respectively, and exceeded it by 1.9 °C in June. Excessive moisture availability was noted in April, when precipitation exceeded the long-term average by 43.9 mm. During the period from May to July, there was an acute deficiency of precipitation, especially in June (41.7 mm against the long-term average of 100.8 mm). HTC was 0.28 in April, and 0.65, 0.67, 0.87 in May, June, and July, respectively.

The results of the research directly depended on the weather conditions of the growing season. The drought tolerance indices of the cultivars were calculated using their yields, which were formed under optimal conditions and insufficient moisture availability. According to the data analysis, the yield loss was about 26.5 % under drought conditions compared to normal conditions. The yields of the cultivars varied from 2.84 to 4.96 t/ha in the dry year and from 4.54 to 6.72 t/ha in the optimal year (Fig. 3).

In a dry year, the highest yields were formed by varieties Altigo (4.96 t/ha), Vitor (4.87 t/ha), NE 06545 (4.77 t/ha) and Aliya (4.74 t/ha). However, their yields did not exceed the standard Podolianka variety, with a yield of 5.02 t/ha. In the optimal year, high yields were recorded for the varieties Altigo (6.72 t/ha) and Fotima (6.63 t/ha) compared to the standard.

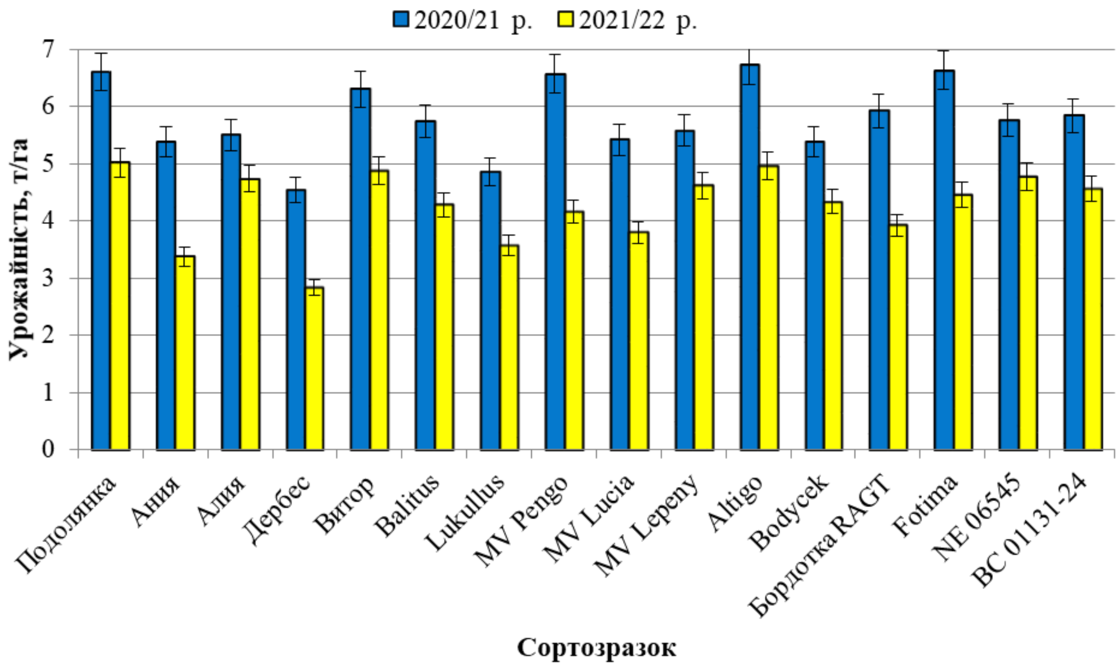

Fig. 3. Yields of winter wheat cultivars in dry (2021/22) and optimal (2020/21) years of research.

A number of indices were analysed to determine the level of drought tolerance of the cultivars (Table 1).

Thus, a lower drought susceptibility index (SSI) corresponds to a higher level of drought tolerance of the cultivar [13]. Among the studied cultivars, the lowest drought susceptibility index was found in Aliya, MV Lepeny, NE 06545 and Bodycek. The most susceptible cultivars were Derbes, Aniya, and MV Pengo. The different drought response of genotypes is evidenced by the range of variation of SSI from 0.52 to 1.42.

The drought tolerance index TOL shows the yield loss due to drought in absolute units [13]. Low values of this index indicate high drought tolerance of the cultivars. The range of variation of this index was from 0.76 to 2.41. It was found that the lowest yield losses caused by drought were observed in the cultivars Aliya, MV Lepeny, NE 06545, Bodycek, which had the lowest SSI values. MV Pengo, Fotima, Aniya, Bordotka RAGT cultivars had a much higher value of SSI, which in turn indicates greater yield losses under stressful conditions.

Table 1. Characteristics of winter wheat varieties by drought tolerance indices, for 2020/21, 2021/22 2020/2022

Cultivar	SSI	TOL	MP	YSI	YI	STI	GMP
Aniya	1.41	2.00	4.38	0.63	79	0.54	4.26
Aliya	0.52	0.76	5.12	0.86	111	0.78	5.11
Derbes	1.42	1.70	3.69	0.63	67	0.38	3.59
Vitor	0.86	1.43	5.59	0.77	114	0.91	5.54
Balitus	0.97	1.46	5.01	0.75	100	0.73	4.96
Lukullus	1.00	1.28	4.22	0.74	84	0.52	4.17
MV Pengo	1.39	2.41	5.37	0.63	97	0.81	5.23
MV Lucia	1.13	1.62	4.61	0.70	89	0.61	4.54
MV Lepeny	0.65	0.96	5.10	0.83	108	0.77	5.08
Altigo	0.99	1.76	5.84	0.74	116	0.99	5.77
Bodycek	0.73	1.04	4.86	0.81	102	0.69	4.83
Bordotka RAGT	1.28	2.00	4.92	0.66	92	0.69	4.82
Fotima	1.24	2.17	5.55	0.67	104	0.88	5.44
NE 06545	0.65	0.99	5.27	0.83	112	0.82	5.24
BC 01131-24	0.83	1.28	5.20	0.78	107	0.79	5.16
Podolianka (standard)	0.91	1.58	5.81	0.76	118	0.99	5.76

Notes. *SSI – stress susceptibility index; TOL – tolerance index; MP – mean productivity; YSI – yield stability index; YI – yield index; STI – stress tolerance index; GMP – geometric mean productivity.*

The mean productivity (MP) of a cultivar in dry and optimal conditions characterises its potential yield [13]. The range of variation of this index is from 3.69 to 5.84. The mean productivity (MP) of a cultivar in dry and optimal conditions characterises its potential yield [13]. The range of variation of this index is from 3.69 to 5.84. According to this index, the varieties that are able to form high yields under different weather conditions are Altigo, Vitor, Fotima, and MV Pengo. The lowest MP values in the cultivars Derbes, Lukullus, Ania indicate their susceptibility to stress factors.

The yield stability index (YSI) characterises the ratio of yield under stress to yield under optimal conditions [13]. The range of variation of this index was from 0.63 to 0.86. The highest value of YSI was found in the cultivars Aliya, MV Lepeny, NE 06545, Bodycek, and the lowest value in the cultivars Aniya, Derbes, MV Pengo.

The yield index (YI) describes the yield percentage of a particular cultivar under dry conditions to the average yield of the studied cultivars under drought conditions [13]. The range of variation of this index was from 67 to 116. According to this index, Altigo, Vitor, NE 06545, Alyia were the most productive cultivars under drought conditions, while Derbes, Ania and Lukullus were the least productive ones.

Stress tolerance index (STI) was developed for identifying the cultivars with stable yield and stress tolerance potential [13]. The range of variation for this index was from 0.38 to 0.99. A stable high yield was observed in Altigo, Vitor, Fotima, NE 06545The varieties Derbes, Lukullus and Aniya were sensitive to drought, which affected the yields in the years of study. The range of variation of the geometric mean yield (GMP) in the dry and optimal conditions was from 3.59 to 5.77. The cultivars with the highest and lowest values of this index were the same as those with the STI.

The method of seed sprouting on sucrose solution at 16 atm to determine the level of drought resistance showed that three wheat cultivars were highly resistant , and the rest 12 were moderately resistant in 2021/22 (Table 2). However, according to the Fisher criterion, four samples had resistance at the level of the standard Podolianka variety as follows: Fotima (76 %), Altigo (73 %), Bodycek (70 %), BC 01131-24 (67 %).

It should be noted that in 2020/21, all samples were classified as moderately resistant. Two varieties Altigo (64 %) and Fotima (63 %) were identified at the level of the standard. According to the research, the seeds obtained under optimal conditions in 2020/21 had a slightly lower percentage of germinated seeds under stress compa-

Table 2. Level of relative drought tolerance of winter wheat cultivars, for 2020/21, 2021/22, 2020/2022

Cultivar	Number of germinated seeds (% ± Sp), P = 16 atm		Relative indicator of the intensity of electrolyte release from leaf tissues, %	
Aniya	2020/21	2021/22	2020/21	2021/22
Aliya	44±5.0	52±5.0	28.2	26.5
Derbes	56±5.1	65±4.9	34.6	41.9
Vitor	54±5.1	57±5.1	35.5	36.9
Balitus	37±4.9	34±4.8	38.7	40.8
Lukullus	54±5.1	52±5.1	40.7	40.6
MV Pengo	41±5.1	45±5.1	32.7	23.9
MV Lucia	39±5.0	42±5.0	37.8	42.0
MV Lepeny	40±4.9	49±5.1	30.1	42.5
Altigo	35±4.8	44±5.0	28.2	38.5
Bodycek	64±5.0*	73±4.5*	44.0	41.8
Bordotka RAGT	61±5.0	70±4.6*	32.8	34.9
Fotima	41±5.1	43±5.0	42.1	40.0
NE 06545	63±4.9*	76±4.3*	42.2	45.7
BC 01131-24	52±5.0	59±5.0	30.7	39.7
Podolianka (standard)	53±5.0	67±4.7*	25.0	30.5
	72±4.5	74±4.4	44.0	46.2

***Notes**: *not significantly different from the standard (according to Fisher's criterion),*
***significantly higher than the standard.*

red to seeds obtained under drought conditions in 2021/22.

The electrolyte release rate from leaf tissues of growing plants during dehydration shows a change in the colloidal-osmotic properties of the cytoplasm, especially in the increase of its permeability, and has a feedback with drought tolerance [14]. According to the analysis of electrolyte release from the leaves of bread wheat plants under stress, high drought resistance of all studied varieties was found. The lowest relative value of the electrolyte release rate from leaf tissues in 2020/21 and 2021/22 was observed in the cultivars: BC 01131-24 (25.0 and 30.5 %), Aniya (28.2 and 26.5 %), MV Lepeny (28.2 and 38.5 %), Lukullus (32.7 and 23.9 %), which indicates a high drought tolerance of these samples at this stage of organogenesis.

The cultivars were evaluated in the laboratory using two methods at different stages of development, the material was studied in detail and a complete characterisation of the drought tolerance of the cultivars was obtained. It was found that the cultivars under study at the initial stages of development are more sensitive to soil moisture deficiency than at the stem elongation stage.

Conclusions. The meteorological conditions of 2020/21 and 2021/22 differed significantly in terms of temperature and moisture availability both during the growing season and in individual stages of plant development. The sources of drought tolerance of winter wheat NE 06545, Aliya, Altigo, Vitor, MV Lepeny, Bodycek, Fotima were identified using a set of indices and laboratory assessment methods. These genotypes can be used as source breeding material for the development of new competitive varieties with valuable practical properties. The presented results of the study will contribute to the more efficient use of the tested wheat cultivars both in crop production and in breeding practice. They have contributed to the study of both theoretical and practical aspects of drought tolerance in wheat and will serve as elements of breeding programs.

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Миронівський інститут пшениці імені В. М. Ремесла НААН, с. Центральне, Обухівський р-н, Київська обл., 08853, Україна

Актуальність. Озима пшениця є однією з основних продовольчих культур в Україні і світі. Створення нових сортів пшениці м’якої озимої з комплексним поєднанням ознак та їх високими значеннями на сьогодні є актуальним та має перспективу стабілізувати ринок екологічно-безпечного продовольчого зерна в Україні. **Мета.** Встановити селекційну цінність 15 сортозразків пшениці м’якої озимої різного еколого-географічного походження за посухостійкістю в умовах центральної частини Лісостепу України та виділити джерела стійкості до водного дефіциту. **Матеріали і методи.** Дослідження проводили в Миронівському інституті пшениці імені В. М. Ремесла НААН України. За стандарт використовували сорт Подолянка. Досліджували 15 сортозразків пшениці м’якої іноземної селекції. Для вивчення зразків за реакцією на посуху застосовано індексний підхід. Оцінку посухостійкості у лабораторних умовах проводили шляхом пророщування насіння на розчинах сахарози за осмотичного тиску 16 атм та визначення інтенсивності виходу електролітів з рослинних тканин за дії стресора. **Результати.** Метеорологічні умови років досліджень значно відрізнялись за температурним режимом та вологозабезпеченістю як в цілому за вегетаційний період, так і за окремими фазами розвитку рослин. Урожайність зразків варіювала від 2,84 до 4,96 т/га у посушливому та від 4,54 до 6,72 т/га – в оптимальному роках. Аналіз отриманих даних показав, що середній рівень урожайності в посушливому році на 1,53 т/га був нижчий порівняно з оптимальним. При визначенні рівня посухостійкості методом пророщування насіння на розчині сахарози виявлено, що серед досліджуваних сортозразків у 2021/22 р. до групи високостійких ввійшли три зразки, решта 12 – до середньостійких. У 2020/21 р. всі зразки були віднесені до групи середньостійких. За показником інтенсивності виходу електролітів з тканин листків рослин у всіх досліджуваних сортозразків виявлено високу стійкість до посухи. За використання комплексу індексів та лабораторних методів оцінювання виділено джерела посухостійкості пшениці NE 06545, Алия, Altigo, Витор, MV Lepeny, Bodycek, Fotima. **Висновки.** Виділені генотипи можуть слугувати як вихідний селекційний матеріал при створенні нових конкурентоспроможних сортів з цінними практичними властивостями. Отримані результати є певним внеском у вивчення як теоретичних, так і практичних аспектів посухостійкості пшениці та можуть застосовуватися як елементи селекційних програм.

Ключові слова: *пшениця м'яка озима, сорт, урожайність, посухостійкість, індекси, джерела посухостійкості*