UDC 633.31:631.52:631.67
DOI https://doi.org/10.32848/agrar.innov.2023.19.22

ANALYSIS OF WINTER WHEAT VARIETIES FOR DROUGHT RESISTANCE IN THE CONDITIONS OF THE STEPPE OF UKRAINE (PART 1 – YEARS WITH SUFFICIENT MOISTURE)

KONOVALOVA V.M. – PhD (Doctor of Philosophy)
orcid.org/0000-0002-0655-9214
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine
TYSHCHENKO A.V. – Doctor of Agricultural Sciences
orcid.org/0000-0003-1918-6223
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine
BAZALII H.H. – Candidate of Agricultural Sciences, Senior Research
orcid.org/0000-0003-2842-0835
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine
FUNDIRAT K.S. – Candidate of Agricultural Sciences
orcid.org/0000-0001-8343-2535
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine
TYSHCHENKO O.D. – Candidate of Agricultural Sciences, Senior Research
orcid.org/0000-0002-8095-9195
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine
REZNICHENKO N.D. – Candidate of Agricultural Sciences
orcid.org/0000-0002-5741-6379
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine
KONOVALOV V.O.
orcid.org/0000-0002-1725-1557
Askanian State Agricultural Research Station of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine

Wheat (*Triticum aestivum* L.) is one of the most important crops in maintaining food security, which ensures the existence of a significant part of the world's population [9, 18]. Scientific forecasts indicate that with a significant increase in the population on Earth, the production of food products will not match this growth and, given the current dynamics, the food problem may turn into a deep international crisis. Scientists' calculations show that at the current rate of population growth, in the future, world grain production per person will decrease [10].

Currently, the annual gross production of wheat is increasing by about 0.9%, but this is much slower than the growth rate of the population and, accordingly, its quantity is insufficient to meet their needs [19, 35]. Therefore, humanity must find a solution to this problem, since the rate of population growth remains too high [15, 33].

Along with population growth, climate changes have been observed in recent decades, the so-called "global warming", as a result of which the temperature regime increases, dry periods become more frequent and their duration increases [23, 27, 32]. The increase in temperature in agricultural regions of the world significantly affects the amount of precipitation and its redistribution during the growing season, which leads to a significant decrease in wheat yield [5, 21, 26, 29]. Arid conditions are one of the main abiotic stress factors that cause serious problems worldwide and lead to a significant decrease in the yield of agricultural crops [3, 25, 31, 37]. However, the problem of water scarcity is not insurmountable. In fact, the negative effects of drought can be overcome by identifying and using drought-resistant cultivars [28, 30, 34].

The purpose of our research was the study and analysis of drought resistance of winter wheat varieties selected by the Institute of Climate-oriented Agriculture of the National Academy of Sciences of the Russian Academy of Sciences and the Selection and Genetics Institute of the National Center for Seed Science and Varietal Research of the National Academy of Sciences of the National Academy of Sciences in the conditions of the Southern Steppe of Ukraine.

Research materials and methods. The reaction of winter wheat varieties to different growing conditions was studied at the Askanian State Agricultural Research Station in the village of Tavrychanka, Kherson region (46°33'12"N; 33°49'13"E; 39 m above sea level) during 2015/16–2019/20. Research was conducted under different conditions of irrigation: with irrigation and without irrigation. Under conditions of natural moisture, the yield strongly depended on the amount of precipitation during the growing season, especially during the critical growing season

(April–May). Average temperatures and total precipitation for all experimental seasons are shown in Table 1 along with long-term average values (1961–2005). The seasons of 2016/2017 and 2018/19 were the most favorable for natural moisture conditions, as the precipitation that fell during the growing season contributed to the replenishment of moisture in the soil for normal plant growth and development. The intensity of drought in these years was 0.087 and 0.058, respectively. The 2017/18 and 2019/20 seasons were very dry, especially the critical growing season (April–May), in which air and soil drought were observed due to insufficient rainfall and high average daily temperature, and the drought intensity indices were equal to 0.345 and 0.321, respectively. Therefore, we calculated and analyzed the drought resistance indices of 18 varieties of winter wheat separately in dry years, wet years and for the five-year period (2015/16–2019/20), which included the year 2015/2016 with too much precipitation, which led to laying of crops and crop losses.

They studied 18 varieties of winter wheat, which are usually grown in the south of Ukraine and are listed in the State Register of Plant Varieties. Varieties were tested on plots with an area of 50 m^2 in three repetitions by the method of randomized repetitions (blocks), the sowing rate was adjusted to 4.5 million viable seeds per ha. Research was conducted according to generally accepted methods, the amount of fertilizers and chemical treatments was adjusted according to growing conditions and the presence of diseases and pests. The studied samples were sown in the first decade of October, and the harvest was done in July.

Statistical analysis. Analysis of the resistance of winter wheat varieties to stress was carried out using drought resistance indices: *MP* – the average yield [20], *D* – drought intensity [1], *SSI* – drought susceptibility index [8], *TOL* – drought tolerance index [20], *YSI* – crop stability index [2], *YI* – yield index [11, 16], *STI* – stress tolerance index [7], *GMP* – average geometric (proportional) yield [7, 13], *RDI* – index of relative resistance to drought [8], *DI* – drought resistance index [1, 14], *SSPI* – index of susceptibility to stress [17], *MSTI*, M_1STI, M_2STI – modified stress tolerance indices [6], *ATI* – index of abiotic tolerance [17], *HMP* – harmonic mean performance [4, 12, 13], *ISR* – stress resistance index [22, 24, 36].

A correlation analysis was conducted between grain yield and drought resistance indices to determine the best drought-resistant varieties and indices. Principal component analysis (PCA) was performed on the observations. Correlation, cluster analyses, and PCA were performed using Microsoft ® Excel 2016/XLSTAT © -Pro (Version 2016.02.28451, 2016, Addinsoft, Inc., Brooklyn, NY, USA), Statistica data analysis software system v.8. (Sta Stof Inc., North Melbourne, Australia) and SPSS 20.00 statistical software (SPSS/PC-20, SPSS Inc., Chicago, IL, USA).

Research results and their discussion. The obtained experimental data make it possible to distinguish varieties of winter wheat that significantly exceed the average variety in terms of productivity under irrigation: *Burhunka*, *Koshova*, *Askaniis'ka* and *Schedrist' odes'ka* with a yield of 7.87–8.49 t/ha, under stress conditions: *Burhunka*, *Koshova*, *Lira odes'ka* and *Tradytsiia odes'ka* 7.25–7.66 t/ha (Table 2).

A high index of the average yield of *MP* (7.59–7.69), which shows the potential yield of varieties under different growing conditions, was characterized by the varieties *Burhunka*, *Koshova*, *Lira odes'ka*, *Tradytsiia odes'ka* and *Schedrist' odes'ka*, but the varieties *Burhunka* and *Koshova* were high in both conditions, while *Lira odes'ka* and *Tradytsiia odes'ka* had the highest yield of all varieties under stress, *Schedrist' odes'ka* was characterized by the highest productivity under irrigation.

According to the indices of sensitivity to drought (*SSI*), tolerance to drought (*TOL*) and susceptibility to stress (*SSPI*), winter wheat varieties *Rosynka* and *Tradytsiia odes'ka* stood out, having the lowest values of the *SSI* index 0.22 and 0.09, the *TOL* index 0.10 and 0.05 and *SSPI* index 0.67 and 0.34, respectively.

According to the yield stability index (*YSI*), that is the ratio of yield under stress to yield under optimal conditions, with fluctuations from 0.81 to 0.99, five varieties with high indicators of the index stood out significantly: *Khersons'ka bezosta*, *Harantiia odes'ka* and *Lira odes'ka* – 0.97, *Rosynka* – 0.98, *Tradytsiia odes'ka* – 0.99.

According to the yield index (*YI*), the *Tradytsiia odes'ka* winter wheat variety was selected with an index of 110.73.

The stress tolerance index (*STI*) characterizes the ability of a genotype to form a stable level of productivity

Table 1

Weather conditions for research (2015–2020)

	1961–2005		**2015/2016**		**2016/2017**		**2017/2018**		**2018/2019**		**2019/2020**	
	T (°C)	**P (mm)**	**T (°C)**	**P (mm)**	**T (°C)**	**P (mm)**	**T (°C)**	**P (mm)**	**T (°C)**	**P (mm)**	**T (°C)**	**P (mm)**
October – December	4.8	98.0	6.0	81.2	3.4	42.0	5.9	75.0	5.5	53.4	7.4	67.9
January	-3.1	30.0	-3.1	59.9	-3.9	14.4	0.7	24.1	-0.3	33.8	1.0	18.3
February	-2.0	29.0	3.9	32.9	-0.9	22.0	0.1	47.0	1.1	10.6	2.2	59.6
March	2.2	26.0	6.1	20.3	6.6	10.2	1.5	35.1	5.5	5.7	7.5	3.5
April	9.6	28.0	12.4	50.5	8.5	81.8	12.9	2.7	10.3	38.9	9.5	7.5
May	15.6	38.0	15.9	95.7	15.5	25.8	19.5	13.0	17.4	72.4	14.9	42.4
June	20.0	46.0	21.5	76.2	21.7	8.0	22.4	23.0	24.5	14.1	22.2	59.3
January – June	7.1	197.0	9.5	335.5	7.9	162.2	9.5	144.9	9.8	175.5	9.6	190.6
October – June	6.0	295.0	7.8	416.7	5.7	204.2	7.7	219.9	7.7	228.9	8.5	258.5

Table 2

Grain yield of winter wheat varieties under irrigation and under natural moisture conditions and drought resistance indices (2017, 2019)

Variety	Designation	Yp	Ys	MP	SSI	TOL	YSI	YI	STI	GMP	RDI	DI	SSPI	M_1STI	M_2STI	MSTI	ATI	*HMP*	ISR
Anatoliia	G1	7.58	6.88	7.23	1.28	0.70	0.91	99.45	0.94	7.22	0.98	0.90	4.69	0.97	0.93	0.90	4.69	7.21	807
Burhunka	G2	7.92	7.25	7.59	1.17	0.67	0.92	104.80	1.03	7.58	0.99	0.96	4.49	1.17	1.13	1.32	4.71	7.57	1013
Konka	G3	7.33	6.88	7.11	0.85	0.45	0.94	99.45	0.91	7.10	1.01	0.93	3.02	0.88	0.90	0.79	2.97	7.10	1825
Kokhana	G4	7.66	6.82	7.24	1.52	0.84	0.89	98.59	0.94	7.23	0.96	0.88	5.63	0.99	0.91	0.91	5.63	7.22	567
Koshova	G5	7.91	7.32	7.62	1.03	0.59	0.93	105.81	1.04	7.61	1.00	0.98	3.96	1.17	1.17	1.37	4.17	7.60	1316
Mariia	G6	7.63	7.00	7.32	1.14	0.63	0.92	101.19	0.96	7.31	0.99	0.93	4.23	1.01	0.98	0.99	4.27	7.30	1027
Ledia	G7	6.62	6.04	6.33	1.21	0.58	0.91	87.31	0.72	6.32	0.98	0.80	3.89	0.57	0.55	0.31	3.40	6.32	787
Rosynka	G8	6.17	6.07	6.12	0.22	0.10	0.98	87.74	0.67	6.12	1.06	0.86	0.67	0.46	0.52	0.24	0.57	6.12	23108
Khersons'ka bezosta	G9	7.37	7.16	7.27	0.40	0.21	0.97	103.50	0.95	7.26	1.05	1.01	1.41	0.93	1.02	0.94	1.42	7.26	8819
Askaniis'ka	G10	7.87	7.07	7.47	1.41	0.80	0.90	102.20	1.00	7.46	0.97	0.92	5.37	1.12	1.05	1.17	5.54	7.45	684
Harantiia odes'ka	G11	7.22	6.99	7.11	0.44	0.23	0.97	101.04	0.91	7.10	1.04	0.98	1.54	0.85	0.93	0.79	1.52	7.10	6888
Zysk	G12	7.41	6.34	6.88	2.00	1.07	0.86	91.65	0.85	6.85	0.92	0.78	7.18	0.83	0.71	0.59	6.80	6.83	304
Lira odes'ka	G13	7.75	7.53	7.64	0.39	0.22	0.97	108.85	1.05	7.64	1.05	1.06	1.48	1.13	1.24	1.41	1.56	7.64	9344
Mudrist' odes'ka	G14	7.42	7.13	7.28	0.54	0.29	0.96	103.07	0.95	7.27	1.04	0.99	1.94	0.94	1.01	0.95	1.96	7.27	4668
Nyva odes'ka	G15	7.45	7.08	7.27	0.69	0.37	0.95	102.35	0.95	7.26	1.02	0.97	2.48	0.95	0.99	0.94	2.49	7.26	2870
Pylypivka	G16	6.69	6.43	6.56	0.54	0.26	0.96	92.95	0.77	6.56	1.04	0.89	1.74	0.62	0.67	0.42	1.58	6.56	4257
Tradytsiia odes'ka	G17	7.71	7.66	7.69	0.09	0.05	0.99	110.73	1.06	7.68	1.07	1.10	0.34	1.14	1.30	1.48	0.36	7.68	182137
Schedrist' odes'ka	G18	8.49	6.87	7.68	2.65	1.62	0.81	99.31	1.05	7.64	0.87	0.80	10.86	1.36	1.03	1.41	11.48	7.59	189
Medium grade		**7.46**	**6.92**	**7.19**	**0.98**	**0.54**	**0.93**	**100.00**	**0.93**	**7.18**	**1.00**	**0.93**	**3.61**	**0.95**	**0.95**	**0.94**	**3.62**	**7.17**	**13923**
V,%		7.22	6.50	6.35	67.35	72.42	4.95	6.50	12.21	6.33	5.16	9.39	72.40	24.11	22.92	40.33	74.88	6.28	304
$S\dot{x}_{absolute}$		0.13	0.11	0.11	0.15	0.09	0.01	1.53	0.03	0.11	0.01	0.02	0.62	0.05	0.05	0.09	0.64	0.11	9981
$S\dot{x}_{reletive}$		1.70	1.53	1.50	15.87	17.07	1.17	1.53	2.88	1.49	1.22	2.21	17.07	5.68	5.40	9.50	17.65	1.48	71
LSD_{01}		0.40	0.34	0.34	0.49	0.29	0.03	4.86	0.08	0.34	0.04	0.07	1.95	0.17	0.16	0.28	2.02	0.34	31642
LSD_{05}		0.29	0.24	0.25	0.35	0.21	0.02	3.51	0.06	0.25	0.03	0.05	1.41	0.12	0.12	0.20	1.46	0.24	22858

regardless of stress factors, and the harmonic productivity (*HMP*) shows the productivity of a specific genotype under stressful conditions relative to the average productivity of the studied genotypes under these conditions. According to these indices, the varieties *Burhunka* (1.03 and 7.57, respectively), *Koshova* (1.04 and 7.60, respectively), *Lira odes'ka* (1.05 and 7.64, respectively), *Tradytsiia odes'ka* (1.06 and 7.68, respectively) and *Schedrist' odes'ka* (1.05 and 7.59, respectively), which significantly exceeded the average grade indicator.

Geometric mean yield (*GMP*) shows the yield of a specific genotype under stress conditions relative to the average yield of the studied genotypes under those conditions, but is calculated using a different formula than harmonic productivity (*HMP*). According to this index, the varieties *Lira odes'ka* (7.64), *Tradytsiia odes'ka* (7.68) and *Schedrist' odes'ka* (7.64) stood out.

Stress tolerance (*STI*), geometric mean yield (*GMP*) and harmonic productivity (*HMP*) indices are believed to be less sensitive to large differences between potential yield and yield under stress conditions.

According to the index of relative drought resistance (*RDI*), two varieties of winter wheat *Rosynka* and *Tradytsiia odes'ka* were selected with values of 1.06 and 1.07, respectively.

According to the drought resistance index (*DI*) with values of 1.06 and 1.10, two varieties, *Lira odes'ka* and *Tradytsiia odes'ka*, were selected.

According to the first modified indices of tolerance to stress (M_1STI) the variety *Schedrist' odes'ka* stood out – 1.36, according to the M_2STI the varieties *Lira odes'ka* – 1.24 and *Tradytsiia odes'ka* – 1.30, and according to the *MSTI* index – *Lira odes'ka* – 1.41, *Tradytsiia odes'ka* – 1.48 and *Schedrist' odes'ka* – 1.41.

According to the abiotic tolerance index (*ATI*) with values of 11.48, perhaps the most intensive variety was selected (yield under irrigation – 8.49 t/ha, under stress – 6.87 t/ha) *Schedrist' odes'ka*. On the other hand, the varieties with the smallest reduction in yield when moisture conditions worsen, *Rosynka* and *Tradytsiia odes'ka* have the lowest values of this indicator, 0.57 and 0.36, respectively. Although Moosavi et al. (2007) [17] claim that the greater this index, the higher the drought resistance.

According to the index of resistance to stress (*ISR*), which characterizes genotypes by resistance to stress not only by a smaller difference in yield under optimal and limiting conditions, but also takes into account high productivity under stress, two varieties were selected: *Rosynka* with the *ISR* index – 23108 and *Tradytsiia odes'ka*, whose *ISR* index is 182137.

According to the largest number of indices (14), the variety *Tradytsiia odes'ka* was singled out as the most drought-resistant, the variety *Lira odes'ka* was distinguished according to nine indices, and *Schedrist' odes'ka* according to seven indices. But can all the above indexes be used? The most valuable are those that have a higher dependence with yield under stress conditions than with yield under optimal conditions.

There is a high positive correlation r = 0.703 between yields under different conditions of wetting (irrigation and natural wetting). The yield of wheat varieties under both moisture conditions has a high positive correlation (r = 0.703–1.000) with the indices *MP*, *YI*, *STI*, *GMP*, M_1STI, M_2STI, *MSTI*, *HMP*. The yield under irrigation is characterized by an average positive correlation (r = 0.512–0.616) with the *SSI*, *TOL*, *SSPI*, *ATI* indices and an average negative r = -0.497 with the *YSI* and *RDI* indices, whereas there is no correlation with the yield under stress. Yield under stress had a high correlation (r = 0.851) with the *DI* index and medium (r = 0.381) – *ISR*, but low (r = 0.038–0.226) with yield under irrigation (Table 3).

According to the correlation analysis, two indices were distinguished: the drought resistance index (*DI*) and the stress resistance index *ISR*, according to which the winter wheat variety *Tradytsiia odes'ka* was characterized by the greatest drought resistance.

According to the results of the GGE biplot analysis, the winter wheat varieties *Lira odes'ka* (G13) and *Tradytsiia odes'ka* (G17), which are in the same quarter with the yield vector under stress (*Ys*) and are close to its peak, form a high yield under moisture stress conditions. Winter wheat varieties *Burhunka* (G2) and *Koshova* (G5), which are located on the axis between the vectors of environmental conditions, form a high yield under both moisture conditions. These varieties can be classified as moderately drought-resistant, which are well adapted to different moisture conditions (Fig. 1).

The variety of winter wheat *Schedrist' odes'ka* (G18), which is in one quarter of the yield vector under the best conditions of moisture (*Yp*) and is as close as possible to its peak, is characterized by high productivity under irrigation. This variety can be considered the most resistant to drought, that is, one that responds well to improving moisture conditions.

Rosynka winter wheat variety (G8), located in the third quarter and the most distant from the center, can be considered stable, but it is characterized by low productivity under both moisture conditions. The winter wheat variety *Ledia* (G7), located in the IV quarter and the most distant from the center, can be considered intensive, but it is characterized by low productivity under both moisture conditions.

Cluster analysis allows identification of winter wheat varieties based on genetically determined drought resistance. The advantage of the cluster analysis method is that its mathematical apparatus allows you to find and highlight the accumulation of objects (points) that actually exists in the feature space based on simultaneous grouping by a large number of features. The construction and analysis of dendrograms details information about the nature of the relationships between lines at the level of clusters and specifies the relationships between varieties within their boundaries. On the dendrogram, the numbers of the objects being merged and the distance at which the merger took place are indicated (Fig. 2).

The populations that formed two subclusters were the closest in terms of drought resistance indices: G2 – *Burhunka* and G6 – *Mariia* with a distance of 14.176, G1 – *Anatoliia* and G7 – *Ledia* with a distance of 23.437, with the addition of varieties G3 – *Konka*, G4 – *Kokhana*, G5 – *Koshova*, G10 – *Askaniis'ka*, G12 – *Zysk*, G15 –

Table 3

Matrix of correlations between grain yield of winter wheat varieties under irrigation and under natural moisture conditions and drought resistance indices (2017, 2019)

	Y_P	Ys	MP	SSI	TOL	YSI	YI	STI	GMP	RDI	DI	SSPI	M_1STI	M_2STI	MSTI	ATI	HMP	ISR
Y_P	1.000	0.703	0.936	0.512	0.570	-0.497	0.703	0.930	0.930	-0.497	0.226	0.570	0.983	0.802	0.900	0.616	0.921	0.038
Ys	0.703	1.000	0.908	-0.249	-0.184	0.266	1.000	0.914	0.915	0.264	0.851	-0.184	0.792	0.984	0.899	-0.127	0.924	0.381
MP	0.936	0.908	1.000	0.178	0.244	-0.160	0.908	1.000	1.000	-0.161	0.555	0.244	0.970	0.958	0.974	0.299	0.999	0.211
SSI	0.512	-0.249	0.178	1.000	0.995	-0.999	-0.249	0.163	0.161	-0.999	-0.718	0.995	0.375	-0.096	0.131	0.983	0.138	-0.414
TOL	0.570	-0.184	0.244	0.995	1.000	-0.994	-0.184	0.230	0.227	-0.992	-0.671	1.000	0.443	-0.028	0.204	0.997	0.204	-0.388
YSI	-0.497	0.266	-0.160	-0.999	-0.994	1.000	0.266	-0.146	-0.144	0.998	0.729	-0.994	-0.361	0.111	-0.118	-0.982	-0.121	0.401
YI	0.703	1.000	0.908	-0.249	-0.184	0.266	1.000	0.914	0.915	0.264	0.851	-0.183	0.792	0.984	0.899	-0.127	0.925	0.381
STI	0.930	0.914	1.000	0.163	0.230	-0.146	0.914	1.000	1.000	-0.147	0.567	0.230	0.969	0.964	0.978	0.285	0.999	0.224
GMP	0.930	0.915	1.000	0.161	0.227	-0.144	0.915	1.000	1.000	-0.145	0.568	0.228	0.966	0.963	0.974	0.283	1.000	0.214
RDI	-0.497	0.264	-0.161	-0.999	-0.992	0.998	0.264	-0.147	-0.145	1.000	0.728	-0.992	-0.359	0.111	-0.115	-0.979	-0.122	0.404
DI	0.226	0.851	0.555	-0.718	-0.671	0.729	0.851	0.567	0.568	0.728	1.000	-0.670	0.363	0.757	0.573	-0.625	0.588	0.504
SSPI	0.570	-0.184	0.244	0.995	1.000	-0.994	-0.183	0.230	0.228	-0.992	-0.670	1.000	0.444	-0.027	0.205	0.997	0.205	-0.387
M_1STI	0.983	0.792	0.970	0.375	0.443	-0.361	0.792	0.969	0.966	-0.359	0.363	0.444	1.000	0.881	0.962	0.498	0.960	0.140
M_2STI	0.802	0.984	0.958	-0.096	-0.028	0.111	0.984	0.964	0.963	0.111	0.757	-0.027	0.881	1.000	0.962	0.030	0.968	0.366
MSTI	0.900	0.899	0.974	0.131	0.204	-0.118	0.899	0.978	0.974	-0.115	0.573	0.205	0.962	0.962	1.000	0.264	0.973	0.306
ATI	0.616	-0.127	0.299	0.983	0.997	-0.982	-0.127	0.285	0.283	-0.979	-0.625	0.997	0.498	0.030	0.264	1.000	0.260	-0.374
HMP	0.921	0.924	0.999	0.138	0.204	-0.121	0.925	0.999	1.000	-0.122	0.588	0.205	0.960	0.968	0.973	0.260	1.000	0.221
ISR	0.038	0.381	0.211	-0.414	-0.388	0.401	0.381	0.224	0.214	0.404	0.504	-0.387	0.140	0.366	0.306	-0.374	0.221	1.000

** – Confidence interval (%): 95*

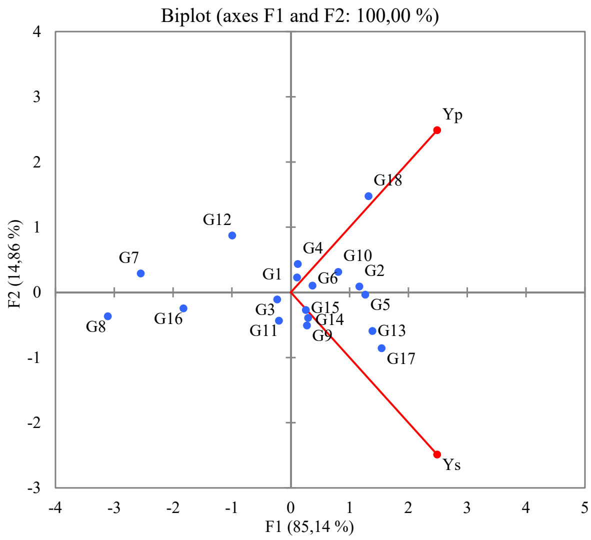

Fig. 1. Genotype-environment interaction of winter wheat varieties and environments (biplot analysis method). The lines show the eigenvectors of the leading factor loads for the environments:
● – humidification conditions; ● – varieties

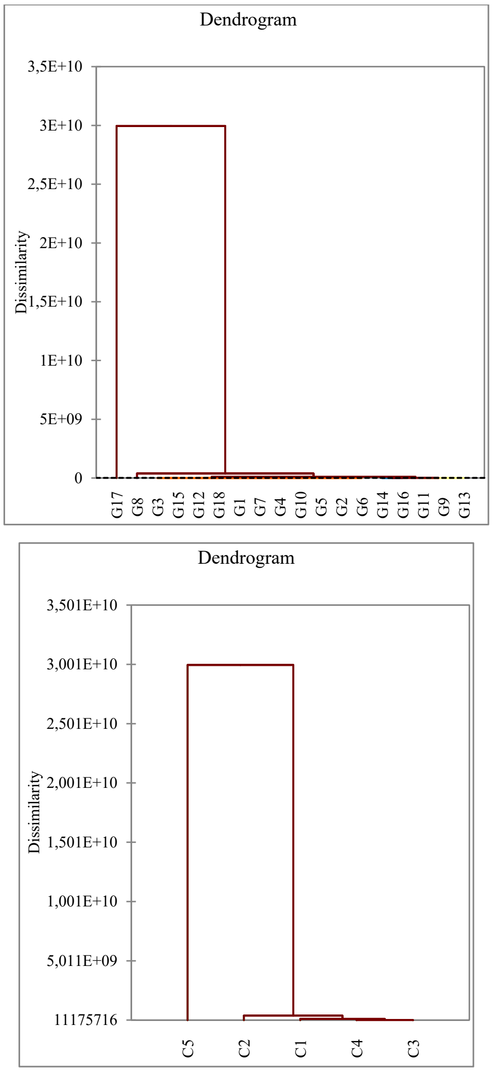

Fig. 2. Clustering dendrogram of eighteen winter wheat varieties according to drought resistance

Table 4

Clustering of eighteen varieties of winter wheat according to drought resistance by the method of k-means and agglomerative hierarchical cluster analysis

Variety	Designation	k-means clustering		Agglomerative hierarchical clustering
		Cluster	Distance to the center of the cluster	Cluster
Anatoliia	G1	1	63.056	1
Burhunka	G2	1	269.450	1
Konka	G3	2	522.472	1
Kokhana	G4	1	176.560	1
Koshova	G5	1	572.067	1
Mariia	G6	1	283.076	1
Ledia	G7	1	44.852	1
Rosynka	G8	3	7144.515	2
Khersons'ka bezosta	G9	3	7144.515	3
Askaniis'ka	G10	1	59.573	1
Harantiia odes'ka	G11	4	598.720	3
Zysk	G12	1	439.696	1
Lira odes'ka	G13	4	3055.119	3
Mudrist' odes'ka	G14	4	1621.641	4
Nyva odes'ka	G15	2	522.472	1
Pylypivka	G16	4	2032.208	4
Tradytsiia odes'ka	G17	5	0.000	5
Schedrist' odes'ka	G18	1	555.059	1

Nyva odes'ka and G18 – *Schedrist' odes'ka* grouped into 1 cluster at a distance of 4211357. G11 – *Harantiia odes'ka*, G9 – *Khersons'ka bezosta* and G13 – *Lira odes'ka* grouped into 3 at a distance of 3207866. Varieties G14 – *Mudrist' odes'ka* and G16 – *Pylypivka* were grouped into cluster 4 at a distance of 84328. Genetic divergence regarding drought resistance was shown by variety G8 – *Rosynka* – cluster 2, and especially variety G17 – *Tradytsiia odes'ka* – cluster 5. In total, five clusters were formed: in the first cluster included eleven most drought-resistant varieties at a distance of 4211357, the second cluster included one variety G8 – *Rosynka*, the third cluster included three drought-resistant varieties at a distance of 3207866, the fourth cluster included at a distance of 84328 two varieties of medium drought resistance, and the fifth cluster included one variety G17 – *Tradytsiia odes'ka* (Table 4).

A cluster analysis of winter wheat varieties was also carried out using the k-means method. This method differs in that before starting, you need to choose the number of clusters yourself. Based on the agglomerative hierarchical cluster analysis described above, we proposed five clusters.

Cluster 1 included nine non-drought resistant varieties, compared to the agglomerative hierarchical cluster analysis, the exceptions are varieties G3 – *Konka* and G15 – *Nyva odes'ka*, which were included in the second cluster. The smallest distance to the center of the cluster was observed in the G7 – *Ledia* variety at the level of 44.852, whereas the largest 572.067 was observed in the G5 – *Koshova* variety.

Cluster 2 included two slightly more drought-resistant varieties. Cluster 3 includes two drought-resistant varieties, but they have low productivity. The fourth cluster included four varieties of medium resistance to drought with the smallest distance of 598.720 to the center of the cluster in the variety G11 – *Harantiia odes'ka*, and the largest – 3055.119 in G13 – *Lira odes'ka*.

The fifth cluster included the most drought-resistant variety G17 – *Tradytsiia odes'ka*.

Conclusions. Two indices were singled out: the drought resistance index (*DI*) and the *ISR* stress resistance index, which most fully characterize the resistance of winter wheat varieties to drought. Based on the data analysis, such years should be excluded if you analyze the resistance of plants to drought in two environments (irrigation and natural moisture). If the analysis is carried out under conditions of natural moisture, then years with sufficient moisture are considered optimal, and dry years are considered stressful or limited.

According to the indices of drought resistance and biplot analysis, the most drought-resistant selected varieties are *Tradytsiia odes'ka* and *Lira odes'ka*. The *Schedrist' odes'ka* variety stood out as the most resistant to drought.

Using cluster analysis, eighteen winter wheat cultivars were divided into five clusters: drought-resistant, medium-resistant, non-resistant, and two clusters of one cultivar each, distinguished by genetic divergence.

BIBLIOGRAPHY:

1. Blum A. Plant breeding for stress environments. CRC Press, Boca Raton, Florida, USA. 1988
2. Bouslama M., Schapaugh W.T. Stress tolerance in soybean. Part 1: evaluation of three screening techniques for heat and drought tolerance. *Crop Science*. 1984. Vol. 24, № 5. P. 933–937. doi:10.2135/cropsci1984.0011183X002400050026x

3. Ceglar A., Toreti A., Lecerf R., Van der Velde M., Dentener F. Impact of meteorological drivers on regional inter-annual crop yield variability in France. *Agric. For. Meteorol*. 2016, Vol. 216, 58–67. https://doi.org/10.1016/j.agrformet.2015.10.004
4. Chakherchaman, S.A., Mostafaei H., Imanparast L. and Eivazian M.R. Evaluation of drought tolerance in lentil advanced genotypes in Ardabil region. *Journal of Food Agriculture and Environment*. 2009. Vol. 7. P. 283-288
5. Chawade A., Armonienė R., Berg G., Brazauskas G., Frostgård G., Geleta M., Gorash A., Henriksson T., Himanen K., Ingver A. A transnational and holistic breeding approach is needed for sustainable wheat production in the Baltic Sea region. *Physiol. Plant*. 2018, Vol. 164, 442–451. https://doi.org/10.1111/ppl.12726
6. Farshadfar E, Sutka J. Multivariate analysis of drought tolerance in wheat substitution lines. *Cereal Res Commun*. 2002. Vol. 31. P. 33–40. https://www.jstor.org/stable/23787201
7. Fernandez C.J. Effective selection criteria for assessing plant stress tolerance. Proceeding of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress. Aug. 13–16. Shanhua, Taiwan, 1992. P. 257–270.
8. Fisher R.A., Maurer R. Drought resistance in spring wheat cultivars. 1. Grain yield responses. *Australian Journal of Agricultural Research*. 1978. Vol. 29, № 5. P. 897–912. doi.org/10.1071/AR9780897
9. Franco F.A., Marchioro V.S., Montecelli T.D.N., Schuster I., Polo M., Souza, L.V., Lima F.J.A., Evangelista A., Santos D.A., Grave E.L. CD 1303 – Short stature, high productive potential and industrial quality. *Crop Breeding and Applied Biotechnology*. 2018, Vol. 18, 123–125. https://doi.org/10.1590/1984-70332018v18n1c15
10. Galetto S.L., Bini A.R., Haliski A., Scharr D.A., Borszowskei P.R., Caires E.F. Nitrogen fertilization in top dressing for wheat crop in succession to soybean under a no-till system. *Bragantia*. 2017, Vol. 76, 282-291. https://doi.org/10.1590/1678-4499.095
11. Gavuzzi P., Rizza F., Palumbo M. et al. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journals of Plant Science*. 1997. Vol. 77, № 4. P. 523–531.
12. Jafari A., Paknejad F., Jami Al-Ahmadi M. Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. *Inter J Plant Prod*. 2009. Vol. 3, Issue 4. P. 33–38.
13. Kristin A.S., Serna R.R., Perez F.I., Enriquez B.C., Gallegos J.A.A., Vallejo P.R., Wassimi N., Kelley J.D. Improving common bean performance under drought stress. *CropSci*. 1997. Vol. 37. P. 43–50.
14. Lan J. Comparison of evaluating methods for agronomic drought resistance in crops. *Acta Agriculturae Boreali-occidentalis Sinica*. 1998. Vol. 7. P. 85–87.
15. Lavrynenko Yu.O. Breeding heritage and its role in stabilizing production of corn grain in Ukraine. Natural sciences and modern technological solutions: knowledge integration in the XXI century: collective monograph. Lviv-Torun: Liha-Pres, 2019. P. 103–119. https://doi.org/10.36059/978-966-397-154-4/103-119
16. Lin C.S., Binns M.R. A superiority measure of cultivar performance for cultivar × location data. *Can. J. PlantSci*. 1988. Vol. 68. P. 193–198. https://doi.org/10.4141/cjps88-018
17. Moosavi S.S., Yazdi-Samadi B., Naghavi M.R., Zali A.A., Dashti H., Pourshahbazi A. Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *Desert*. 2008. Vol. 12, Issue 2. P. 165–178.
18. Oliveira Й.C.D., Pinto-Maglio C.A.F. Cytomolecular characterization of cultivars and landraces of wheat tolerant and sensitive to aluminum toxicity. *Bragantia*. 2017, Vol. 76: 456–469. https://doi.org/10.1590/1678-4499.2016.278
19. Ray D.K., Mueller N.D., West P.C., Foley J.A. Yield trends are insufficient to double global crop production by 2050. *PLoS ONE*. 2013, Vol. 8, E66428. https://doi.org/10.1371/journal.pone.0066428
20. Rosielle A.A., Hamblin J. Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Science*. 1981. Vol. 21, № 6. P. 943–946. doi:10.2135/cropsci1981.0011183X002100060033x
21. Team B.A. Second assessment of climate change for the Baltic Sea basin. In Regional Climate Studies; Springer: Berlin/Heidelberg, Germany, 2015, Vol. 6, pp. 131–144.
22. Tyshchenko A.V., Tyshchenko O.D., Konovalova V.M., Fundirat K.S., Piliarska O.O. Methods of determining the drought resistance of plants. *Scientific Collection «InterConf+»*, 33(155): with the Proceedings of the 1st International Scientific and Practical Conference «Modern Knowledge: Research and Discoveries» (May 19-20, 2023; Vancouver, Canada) by the SPC «InterConf». A.T. International, 2023. P. 343–361. https://doi.org/10.51582/interconf.19-20.05.2023.030 ISSN 2709-4685
23. Tyshchenko O., Tyshchenko A., Piliarska O., Kuts H., Lykhovyd P. Evaluation of drought tolerance in alfalfa *(Medicago sativa)* genotypes in the conditions of osmotic stress. *AgroLife Scientific Journal*. 2020. Vol. 9, No. 2, P. 353-358. ISSN 2285-5718
24. Vozhehova R., Tyshchenko A., Tyshchenko O., Dymov O., Piliarska O., Lykhovyd P. Evaluation of breeding indices for drought tolerance in alfalfa (*Medicago*) genotypes. *Scientific Papers. Series A. Agronomy*. 2021. Vol. LXIV, No. 2. P. 435–444.
25. Yuyi Zhou, Rui He, Yuling Guo, Keke Liu, Guanmin Huang, Chuanxi Peng, Yiguo Liu, Mingcai Zhang, Zhaohu Li & Liusheng Duan. A novel ABA functional analogue B2 enhances drought tolerance in wheat. *Scientific Reports*. 2019. Vol. 9:2887. https://doi.org/10.1038/s41598-019-39013-8
26. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Димов О.М., Люта Ю.О. Особливості прояву адаптивних ознак у селекційних популяцій люцерни при вирощуванні на насіння. *Вісник СумНАУ. Серія «Агрономія і біологія»*. 2021. Випуск 2(44), С. 3–11. https://doi.org/10.32845/agrobio.2021.2.1
27. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Димов О.М., Пілярська О.О. Оцінювання посухостійкості селекційного матеріалу люцерни за показниками водного режиму в умовах Півдня України. *Plant Varieties Studying and protection*. 2021, Vol. 17, No 1. С. 21–29. https://doi.org/10.21498/2518-1017.17.1.2021.228204
28. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Пілярська О.О., Гальченко Н.М. Оцінка посухостійкості популяцій люцерни кормового використання в рік сівби за математичними індексами. *Аграрні інновації*.

2022. № 13. С. 190–198. DOI https://doi.org/10.32848/agrar.innov.2022.13.28

29. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Пілярська О.О., Фундират К.С., Коновалова В.М. Особливості прояву адаптивних ознак у популяцій люцерни за кормового використання. *Аграрні інновації*. 2022. № 14. С. 135–144. DOI https://doi.org/10.32848/agrar.innov.2022.14.20
30. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Пілярська О.О., Фундират К.С., Гальченко Н.М. Оцінка посухостійкості популяцій люцерни за насіннєвого використання в рік сівби. *Аграрні інновації*. 2022. № 15. С. 89–96. DOI https://doi.org/10.32848/agrar.innov.2022.15.14
31. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Пілярська О.О., Фундират К.С., Коновалова В.М. Визначення посухостійкості популяцій люцерни насіннєвого використання за математичними індексами. *Вісник аграрної науки*. 2023. № 1 (838). С. 40–48. https://doi.org/10.31073/agrovisnyk202301-05
32. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Пілярська О.О., Фундират К.С., Коновалова В.М. Насіннєва продуктивність популяцій люцерни другого року життя та особливості прояву у них адаптивних ознак. *Аграрні інновації*. 2022. № 16. С. 94–103. https://doi.org/10.32848/agrar.innov.2022.16.15
33. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Пілярська О.О., Фундират К.С., Коновалова В.М. Формування стійкості рослин насіннєвої люцерни в умовах різного екологічного градієнта. *Вісник аграрної науки.* 2023. № 3 (840). С. 53–62. https://doi.org/10.31073/agrovisnyk202303-08
34. Вожегова Р.А., Тищенко А.В., Тищенко О.Д., Пілярська О.О., Фундират К.С., Коновалова В.М. Посухостійкість популяцій люцерни другого року за кормового використання. *Аграрні інновації*. 2023. № 17. С. 25–36. https://doi.org/10.32848/agrar.innov.2023.17.4
35. Лавриненко Ю.О., Вожегова Р.А., Базалій Г.Г., Усик Л.О., Жупина А.Ю. Вплив зрошення на продуктивність різних сортотипів озимої пшениці в умовах Південного Степу України. *Наукові доповіді НУБіП України*. 2019. № 3 (79). http://dx.doi.org/10.31548/dopovidi2019.03.014
36. Тищенко А.В., Тищенко О.Д., Люта Ю.О. Оцінка генотипів люцерни за насіннєвою продуктивністю на посухостійкість. *Таврійський науковий вісник*. Херсон: ВД «Гельветика», 2021. № 120. С. 155–168. https://doi.org/10.32851/2226-0099.2021.120.21
37. Тищенко А.В., Тищенко О.Д., Люта Ю.О., Пілярська О.О. Адаптивна здатність – важлива ознака в селекції рослин. *Зрошуване землеробство*. 2021. № 75, С. 101–109. https://doi.org/10.32848/0135-2369.2021.75.19

REFERENCES:

1. Blum, A. (1988). Plant breeding for stress environments. CRC Press, Boca Raton, Florida, USA. ISBN 9781351075718.
2. Bouslama, M. & Schapaugh, W.T. (1984). Stress tolerance in soybean. Part 1: evaluation of three screening techniques for heat and drought tolerance. *Crop Science*, *24*(5), 933–937. doi:10.2135/cropsci1984.0011183X002400050026x
3. Ceglar, A. et al. (2016). Impact of meteorological drivers on regional inter-annual crop yield variability in France. *Agric. For. Meteorol*. 216, 58–67. https://doi.org/10.1016/j.agrformet.2015.10.004
4. Chakherchaman, S.A., Mostafaei H., Imanparast L., & Eivazian, M.R. (2009). Evaluation of drought tolerance in lentil advanced genotypes in Ardabil region. *Journal of food, agriculture & environment (JFAE), 7,* 283–288.
5. Chawade, A. et al. (2018). A transnational and holistic breeding approach is needed for sustainable wheat production in the Baltic Sea region. *Physiol. Plant*. 164, 442–451. https://doi.org/10.1111/ppl.12726
6. Farshadfar, E., & Sutka, J. (2002). Multivariate analysis of drought tolerance in wheat substitution lines. *Cereal Res Commun.* Vol. 31. P. 33–40. https://www.jstor.org/stable/23787201
7. Fernandez, C. J. (1992). Effective selection criteria for assessing plant stress tolerance. *Proceeding of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress*. Aug. 13–16. Shanhua, Taiwan, P. 257–270.
8. Fisher, R. A., & Maurer, R. (1978). Drought resistance in spring wheat cultivars. 1. Grain yield responses. *Australian Journal of Agricultural Research.* Vol. 29, № 5. P. 897–912. doi.org/10.1071/AR9780897
9. Franco, F.A. et al. (2018). CD 1303 – Short stature, high productive potential and industrial quality. *Crop Breeding and Applied Biotechnology*. 18, 123–125. https://doi.org/10.1590/1984-70332018v18n1c15
10. Galetto, S.L. et al. (2017). Nitrogen fertilization in top dressing for wheat crop in succession to soybean under a no-till system. *Bragantia*. 76, 282–291. https://doi.org/10.1590/1678-4499.095
11. Gavuzzi, P. et fl. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journals of Plant Science*. Vol. 77. № 4. P. 523–531.
12. Jafari, A., Farzad, P., & Jami Al-Ahmadi, M. (2009). Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. *International Journal of Plant Production, 3*(4), 33–38.
13. Kristin, A.S. et al. (1997). Improving common bean performance under drought stress. *CropSci*. 37, P. 43–50.
14. Lan, J. (1998). Comparison of evaluating methods for agronomic drought resistance in crops. *Acta Agriculturae Boreali-occidentalis Sinica*. Vol. 7. P. 85–87.
15. Lavrynenko Yu.O. (2019). Breeding heritage and its role in stabilizing production of corn grain in Ukraine. Natural sciences and modern technological solutions: knowledge integration in the XXI century: collective monograph. Lviv-Torun: Liha-Pres, 103–119. https://doi.org/10.36059/978-966-397-154-4/103-119
16. Lin, C.S., & Binns, M.R. (1988). A superiority measure of cultivar performance for cultivar × location data. *Can. J. PlantSci*. 68, P. 193–198. https://doi.org/10.4141/cjps88-018
17. Moosavi, S.S. et al. (2008). Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *Desert*., 12(2), 165–178.
18. Oliveira, Й.С.D. & Pinto-Maglio, C.A.F. (2017). Cytomolecular characterization of cultivars and landraces of wheat tolerant and sensitive to aluminum toxicity. *Bragantia*. 76: 456–469. https://doi.org/10.1590/1678-4499.2016.278

19. Ray, D.K., Mueller, N.D., West, P.C. & Foley, J.A. (2013). Yield trends are insufficient to double global crop production by 2050. *PLoS ONE*. 8, E66428. https://doi.org/10.1371/journal.pone.0066428
20. Rosielle, A. A., & Hamblin, J. (1981). Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Science*, 21(6), 943–946. doi:10.2135/cropsci1981.0011183X002100060033x
21. Team, B.A. (2015). Second assessment of climate change for the Baltic Sea basin. In Regional Climate Studies; Springer: Berlin/Heidelberg, Germany, 6, 131–144.
22. Tyshchenko A.V. et al. (2023). Methods of determining the drought resistance of plants. *Scientific Collection "InterConf+", 33(155): with the Proceedings of the 1st International Scientific and Practical Conference "Modern Knowledge: Research and Discoveries" by the SPC "InterConf"*. (pp. 343-361) A.T. International. Vancouver, Canada. https://doi.org/10.51582/interconf.19-20.05.2023.030 ISSN 2709-4685
23. Tyshchenko, O. et al. (2020). Evaluation of drought tolerance in alfalfa *(Medicago sativa)* genotypes in the conditions of osmotic stress. *AgroLife Scientific Journal*, 9(2), 353–358. ISSN 2285-5718
24. Vozhehova, R. et al. (2021). Evaluation of breeding indices for drought tolerance in alfalfa (*Medicago*) genotypes. *Scientific Papers. Series A. Agronomy*, LXIV(2), 435–444.
25. Yuyi, Z. et al. (2019). A novel ABA functional analogue B2 enhances drought tolerance in wheat. *Scientific Reports*. 9:2887. https://doi.org/10.1038/s41598-019-39013-8
26. Vozhehova, R. A. et al. (2021). Osoblyvosti proiavu adaptyvnykh oznak u selektsiinykh populiatsii liutserny pry vyroshchuvanni na nasinnia. [Features of manifestation of adaptive traits in breeding populations of alfalfa when grown from seed]. *Visnyk SumNAU. Seriia "Ahronomiia i biolohiia" – Bulletin of SumNAU. Agronomy and Biology Series*. 2(44). 3–11. https://doi.org/10.32845/ agrobio.2021.2.1 [in Ukrainian].
27. Vozhehova, R.A. et al. (2021). Otsiniuvannia posukhostiikosti selektsiinoho materialu liutserny za pokaznykamy vodnoho rezhymu v umovakh Pivdnia Ukrainy [Evaluation of drought tolerance of alfalfa breeding material based on water regime indicators in Southern Ukraine.]. *Plant Varieties Studying and protection*, 17(1), 21–29. https://doi.org/10.21498/2518-1017.17.1.2021.228204. [in Ukrainian].
28. Vozhehova, R.A. et al. (2022). Otsinka posukhostiikosti populiatsii liutserny kormovoho vykorystannia v rik sivby za matematychnymy indeksamy [Assessment of drought resistance of fodder alfalfa populations in the year of sowing by mathematical indices]. *Ahrarni innovatsii – Agrarian Innovations*, 13, 190–198. DOI https://doi.org/10.32848/agrar.innov.2022.13.28. [in Ukrainian].
29. Vozhehova, R.A. et al. (2022). Osoblyvosti proiavu adaptyvnykh oznak u populiatsii liutserny za kormovoho vykorystannia [Peculiarities of the manifestation of adaptive traits in alfalfa populations under fodder use]. *Ahrarni innovatsii – Agrarian Innovations*, 14, 135–144. https://doi.org/10.32848/agrar.innov.2022.14.20. [in Ukrainian].
30. Vozhehova, R.A. et al. (2022). Otsinka posukhostiikosti populiatsii liutserny za nasinnievoho vykorystannia v rik sivby [Assessment of drought resistance of alfalfa populations for seed use in the year of sowing]. *Ahrarni innovatsii – Agrarian Innovations*, 15, 89–96. https://doi.org/10.32848/agrar.innov.2022.15.14. [in Ukrainian].
31. Vozhehova, R.A. et al. (2023). Vyznachennia posukhostiikosti populiatsii liutserny nasinnievoho vykorystannia za matematychnymy indeksamy [Determination of drought resistance of alfalfa populations for seed use by mathematical indices]. *Visnyk ahrarnoi nauky – Bulletin of Agricultural Science*, 1(838), 40–48. https://doi.org/10.31073/agrovisnyk202301-05. [in Ukrainian].
32. Vozhehova, R.A. et al. (2022). Nasinnieva produktyvnist populiatsii liutserny druhoho roku zhyttia ta osoblyvosti proiavu u nykh adaptyvnykh oznak [Seed productivity of alfalfa populations in the second year of life and the peculiarities of the manifestation of adaptive traits in them]. *Ahrarni innovatsii – Agrarian Innovations*, 16, 94–103. https://doi.org/10.32848/agrar.innov.2022.16.15 [in Ukrainian].
33. Vozhehova, R.A. et al. (2023). Formuvannia stiikosti roslyn nasinnievoi liutserny v umovakh riznoho ekolohichnoho hradiienta [Formation of resistance of seed alfalfa plants in conditions of different environmental gradients]. *Visnyk ahrarnoi nauky – Bulletin of Agricultural Science*, 3(840), 53–62. https://doi.org/10.31073/agrovisnyk202303-08 [in Ukrainian].
34. Vozhehova, R.A. et al. (2023). Posukhostiikist populiatsii liutserny druhoho roku za kormovoho vykorystannia [Drought resistance of second-year alfalfa populations for fodder use]. *Ahrarni innovatsii – Agrarian Innovations*, 17, 25–36. https://doi.org/10.32848/agrar.innov.2023.17.4 [in Ukrainian].
35. Lavrynenko, Yu.O. et al. (2019). Vplyv zroshennia na produktyvnist riznykh sortotypiv ozymoi pshenytsi v umovakh Pivdennoho Stepu Ukrainy [The influence of irrigation on the productivity of different varieties of winter wheat in the conditions of the Southern Steppe of Ukraine]. *Naukovi dopovidi NUBiP Ukrainy – Scientific reports of NULES of Ukraine*. 3(79). http://dx.doi.org/10.31548/dopovidi2019.03.014 [in Ukrainian].
36. Tyshchenko, A.V., Tyshchenko, O.D. & Lyuta, Yu.O. (2021). Otsinka henotypiv liutserny za nasinnievoiu produktyvnistiu na posukhostiikist. [Evaluation of alfalfa genotypes by seed productivity for drought resistance]. *Tavriiskyi naukovyi visnyk. Kherson: VD "Helvetyka" – Taurian Scientific Bulletin. Kherson: Helvetica*. 120. 155–168. https://doi.org/10.32851/2226-0099.2021.120.21. [in Ukrainian].
37. Tyshchenko, A.V., Tyshchenko, O.D., Liuta, Yu.O. & Piliarska, O.O. (2021). Adaptyvna zdatnist – vazhlyva oznaka v selektsii roslyn [Adaptability is an important feature in plant selection]. *Zroshuvane zemlerobstvo – Irrigated farming*, 75, 101–109. https://doi.org/10.32848/0135-2369.2021.75.19. [in Ukrainian].

Коновалова В.М., Тищенко А.В., Базалій Г.Г., Фундират К.С., Тищенко О.Д., Резніченко Н.Д., Коновалов В.О. Аналіз сортів озимої пшениці на посухостійкість в умовах Степу України (ч. 1 – роки з достатнім зволоженням).

Метою наших досліджень було вивчення та аналіз посухостійкості сортів озимої пшениці селекції Інституту кліматично орієнтованого сільського господарства НААН та Селекційно-генетичного інституту Національного центру насіннєзнавства та сортовивчення НААН в умовах Південного Степу України. **Матеріали і методи досліджень.** Реакцію 18 сортів озимої пшениці на різні умови вирощування вивчали на Асканійській державній сільськогосподарській дослідницькій станції у с. Тавричанка, Херсонська область (46°33'12''N; 33°49'13''E; 39 м над рівнем моря) протягом 2015/16–2019/20 рр. Дослідження проводилися за різних умов зволоження: при зрошенні та без зрошення. Аналіз стійкості сортів озимої пшениці до стресу проводили за допомогою 17 індексів посухостійкості. **Результати дослідження та їх обговорення.** Найбільшу урожайність при зрошенні 7,87–8,49 т/га було отримано у сортів озимої пшениці *Бургунка*, *Кошова*, *Асканійська* і *Щедрість одеська*, в стресових умовах: *Бургунка*, *Кошова*, *Ліра одеська* і *Традиція одеська* 7,25–7,66 т/га. За більшою кількістю індексів (14), як найбільш посухостійкий, був виділений сорт *Традиція одеська*, сорт *Ліра одеська* виділився за дев'ятьма індексами, а *Щедрість одеська* за сімома. За кореляційним аналізом було виділено два індекси: індекс посухостійкості (*DI*) та індекс стійкості до стресу *ISR*, де урожайність при стресі характеризувалася високою кореляцією (r = 0,851) з індексом *DI* та середньою (r = 0,381) – *ISR*, натомість низькою (r = 0,038–0,226) з врожайністю при зрошенні. **Висновки.** Виділено два індекси: індекс посухостійкості (*DI*) та індекс стійкості до стресу *ISR*, що найбільш повно характеризують стійкість сортів озимої пшениці до посухи. За індексами посухостійкості та біплот-аналізом, як найбільш посухостійкі виділені сорти *Традиція одеська* та *Ліра одеська*. Сорт *Щедрість одеська* виділився як найбільш нестійкий до посухи.

Ключові слова: озима пшениця, сорт, зрошення, природнє зволоження, урожайність, посухостійкість, індекси посухостійкості, біплот-аналіз, кластерний аналіз.

Konovalova V.M., Tyshchenko A.V., Bazalii H.H., Fundirat K.S., Tyshchenko O.D., Reznichenko N.D., Konovalov V.O. **Analysis of winter wheat varieties for drought resistance in the conditions of the Steppe of Ukraine (part 1 – years with sufficient moisture)**

The purpose of our research was the study and analysis of drought resistance of winter wheat varieties selected by the Institute of Climate-oriented Agriculture of the National Academy of Sciences of the Russian Academy of Sciences and the Selection and Genetics Institute of the National Center for Seed Science and Varietal Research of the National Academy of Sciences of the National Academy of Sciences in the conditions of the Southern Steppe of Ukraine. **Materials and methods of research.** The reaction of 18 varieties of winter wheat to different growing conditions was studied at the Askania State Agricultural Research Station in the village of Tavrychanka, Kherson region (46°33'12"N; 33°49'13"E; 39 m above sea level) during 2015/16–2019/20. Research was conducted under different conditions of irrigation: with irrigation and without irrigation. Analysis of the resistance of winter wheat varieties to stress was carried out using 17 indices of drought resistance. **Research results and their discussion.** The highest yield under irrigation of 7.87–8.49 t/ha was obtained from winter wheat varieties *Burgunka*, *Koshova*, *Askaniyska* and *Shchedrist Odeska*, under stress conditions: *Burgunka*, *Koshova*, *Lyra Odeska* and *Traditsia Odeska* 7.25–7.66 t /Ha. According to the largest number of indices (14), the variety *Traditsia Odeska* was singled out as the most drought-resistant, the variety *Lyra Odeska* was distinguished according to nine indices, and *Shchedrist Odeska* according to seven indices. According to the correlation analysis, two indices were distinguished: the drought resistance index (*DI*) and the stress resistance index *ISR*, where yield under stress was characterized by a high correlation (r = 0.851) with the *DI* index and a medium (r = 0.381) – *ISR*, on the other hand, a low correlation (r = 0.038–0.226) with yield under irrigation. **Conclusions.** Two indices were singled out: the drought resistance index (*DI*) and the *ISR* stress resistance index, which most fully characterize the resistance of winter wheat varieties to drought. According to the indices of drought resistance and biplot analysis, the most drought-resistant selected varieties are *Traditsia Odeska* and *Lyra Odeska*. The *Shchedrist Odeska* variety stood out as the most resistant to drought.

Key words: winter wheat, variety, irrigation, natural moisture, productivity, drought resistance, drought resistance indices, biplot analysis, cluster analysis.