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ANALYSIS OF WINTER WHEAT VARIETIES FOR DROUGHT RESISTANCE IN THE CONDITIONS OF THE STEPPE OF UKRAINE (PART 3 – YEARS WITH DIFFERENT MOISTURE SUPPLY)

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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, 13, 21]. 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, 17].

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 [22, 40]. Therefore, humanity must find a solution to this problem, since the rate of population growth remains too high [14, 18, 37].

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 [25, 27, 31, 36]. 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, 24, 30, 33]. 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, 29, 35, 39, 42]. 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 [32, 34, 38].

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

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

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 [23], *D* – drought intensity [1], *SSI* – drought susceptibility index [8], *TOL* – drought tolerance index [23], *YSI* – crop stability index [2], *YI* – yield index [11, 19], *STI* – stress tolerance index [7], *GMP* – average geometric (proportional) yield [7, 15], *RDI* – index of relative resistance to drought [8], *DI* – drought resistance index [1, 16], *SSPI* – index of susceptibility to stress [20], *MSTI*, M_1STI, M_2STI – modified stress tolerance indices [6], *ATI* – index of abiotic tolerance [20], *HMP* – harmonic mean performance [4, 12, 15], *ISR* – stress resistance index [26, 28, 41].

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 winter wheat varieties that significantly exceed the average variety in terms of productivity under irrigation (*Yp*): *Mariia* and *Schedrist' odes'ka* with a yield of 7.41–7.53 t/ha, in stressful conditions (*Ys*): *Lira odes'ka* – 6.25 t/ha and the *Schedrist' odes'ka* – 6.12 t/ha (Table 2).

High index of mean yield (*MP*) 6.76 and 6.83, geometric mean yield (*GMP*) 6.74 and 6.79, harmonic productivity (*HMP*) 6.72 and 6.75 and the second modified stress tolerance index (M_2STI) 1.13 and 1.10 characterized the varieties *Lira odes'ka* and *Schedrist' odes'ka*.

According to drought sensitivity indices (*SSI*) 0.63 and 0.77, yield stability (*YSI*) 0.88 and 0.86, relative drought tolerance (*RDI*) 1.08 and 1.05 and stress tolerance (*ISR*) 371.80 and 317.50 *Rosynka* and *Lira odes'ka* winter wheat varieties stood out, respectively.

The drought tolerance index (*TOL*) and the stress propensity index (*SSPI*) are close in nature and show yield loss due to drought, the former in absolute units, the latter in percentage. *Rosynka* variety was characterized by the lowest value of these indices – 0.66 and 4.73, respectively. At the same time, the *Rosynka* variety formed a low yield under both growing conditions.

According to the yield index (*YI*), which is determined by the ratio of the yield of a variety under the influence of a stress factor to the average yield of studied genotypes under similar conditions, and the stress tolerance index (*STI*), which characterizes the genotype's ability to form a stable level of yield regardless of stress factors, varieties winter wheat *Koshova* were selected – 106.29 and 0.91,

Table 2

Grain yield of winter wheat varieties under irrigation and under natural moisture conditions and drought resistance indices (2016–2020)

Variety	Designation	*Yp*	*Ys*	*MP*	*SSI*	*TOL*	*YSI*	*YI*	*STI*	*GMP*	*RDI*	*DI*	*SSPI*	*M_1STI*	*M_2STI*	*MSTI*	*ATI*	*HMP*	*ISR*
Anatoliia	G1	6.84	5.73	6.29	0.88	1.11	0.84	100.66	0.81	6.26	1.03	0.84	7.96	0.78	0.82	0.63	5.67	6.24	217.58
Burhunka	G2	6.96	5.79	6.38	0.92	1.17	0.83	101.72	0.83	6.35	1.02	0.85	8.39	0.83	0.86	0.71	6.07	6.32	204.89
Konka	G3	6.88	5.79	6.34	0.86	1.09	0.84	101.72	0.82	6.31	1.03	0.86	7.82	0.80	0.85	0.68	5.62	6.29	230.68
Kokhana	G4	7.24	5.94	6.59	0.98	1.30	0.82	104.35	0.89	6.56	1.00	0.86	9.32	0.95	0.96	0.92	6.96	6.53	184.24
Koshova	G5	7.33	6.05	6.69	0.95	1.28	0.83	106.29	0.91	6.66	1.01	0.88	9.18	1.01	1.03	1.04	6.96	6.63	198.40
Mariia	G6	7.41	5.77	6.59	1.21	1.64	0.78	101.37	0.88	6.54	0.95	0.79	11.76	0.99	0.90	0.90	8.76	6.49	117.79
Ledia	G7	6.18	5.14	5.66	0.92	1.04	0.83	90.30	0.65	5.64	1.02	0.75	7.46	0.51	0.53	0.27	4.79	5.61	181.50
Rosynka	G8	5.68	5.02	5.35	0.63	0.66	0.88	88.19	0.59	5.34	1.08	0.78	4.73	0.39	0.46	0.18	2.88	5.33	371.80
Khersons'ka bezosta	G9	6.70	5.57	6.14	0.92	1.13	0.83	97.85	0.77	6.11	1.02	0.81	8.11	0.71	0.74	0.52	5.64	6.08	195.82
Askaniis'ka	G10	7.29	5.91	6.60	1.03	1.38	0.81	103.83	0.89	6.56	0.99	0.84	9.90	0.97	0.96	0.93	7.40	6.53	164.92
Harantiia odes'ka	G11	6.93	5.26	6.10	1.31	1.67	0.76	92.41	0.75	6.04	0.93	0.70	11.98	0.74	0.64	0.48	8.23	5.98	90.58
Zysk	G12	7.08	5.61	6.35	1.13	1.47	0.79	98.56	0.82	6.30	0.97	0.78	10.54	0.84	0.79	0.67	7.57	6.26	130.14
Lira odes'ka	G13	7.27	6.25	6.76	0.77	1.02	0.86	109.80	0.94	6.74	1.05	0.94	7.32	1.02	1.13	1.15	5.61	6.72	317.50
Mudrist' odes'ka	G14	7.30	5.61	6.46	1.26	1.69	0.77	98.56	0.84	6.40	0.94	0.76	12.12	0.92	0.82	0.76	8.83	6.34	104.67
Nyva odes'ka	G15	7.22	5.67	6.45	1.17	1.55	0.79	99.61	0.84	6.40	0.96	0.78	11.12	0.90	0.84	0.76	8.10	6.35	123.03
Pylypivka	G16	6.46	5.31	5.89	0.97	1.15	0.82	93.29	0.71	5.86	1.01	0.77	8.25	0.61	0.61	0.37	5.50	5.83	167.56
Tradytsiia odes'ka	G17	7.17	5.92	6.55	0.95	1.25	0.83	104.00	0.87	6.52	1.01	0.86	8.97	0.92	0.94	0.87	6.65	6.49	194.78
Schedrist' odes'ka	G18	7.53	6.12	6.83	1.02	1.41	0.81	107.52	0.95	6.79	1.00	0.87	10.11	1.11	1.10	1.21	7.82	6.75	174.54
Medium grade		**6.97**	**5.69**	**6.33**	**0.99**	**1.28**	**0.82**	**100.00**	**0.82**	**6.30**	**1.00**	**0.82**	**9.17**	**0.83**	**0.83**	**0.72**	**6.61**	**6.26**	**187.25**
V, %		6.76	5.92	6.11	17.32	20.90	3.76	5.92	11.74	6.07	3.89	7.15	20.89	22.50	22.12	39.52	23.25	6.05	37.51
$S\dot{x}_{absolute}$		0.11	0.08	0.09	0.04	0.06	0.01	1.39	0.02	0.09	0.01	0.01	0.45	0.04	0.04	0.07	0.36	0.09	16.55
$S\dot{x}_{reletive}$		1.59	1.39	1.44	4.08	4.93	0.89	1.39	2.77	1.43	0.92	1.69	4.92	5.30	5.21	9.32	5.48	1.43	8.84
LSD_{01}		0.35	0.25	0.29	0.13	0.20	0.02	4.42	0.07	0.29	0.03	0.04	1.43	0.14	0.14	0.21	1.15	0.28	52.48
LSD_{05}		0.25	0.18	0.21	0.09	0.14	0.02	3.19	0.05	0.21	0.02	0.03	1.03	0.10	0.10	0.15	0.83	0.20	37.91

Lira odes'ka – 109.80 and 0.94 and *Schedrist' odes'ka* with an indicator of 107.52 and 0.95.

According to the drought resistance index (*DI*) with a value of 0.94, the variety *Lira odes'ka* was selected, which significantly exceeded the average variety indicator.

According to the first modified index of stress tolerance (M_1STI), the variety *Schedrist' odes'ka* stood out – 1.11, and according to the full modified stress tolerance index (*MSTI*) the varieties *Lira odes'ka* – 1.15 and *Schedrist' odes'ka* – 1.21.

According to the most indices (12), the variety *Lira odes'ka* was singled out as the most drought-resistant, the variety *Schedrist' odes'ka* was distinguished according to eight indices, and the variety *Rosynka* – according to seven.

There is a high positive correlation r = 0.832 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 = 0.832–1.000) with the indices *MP*, *YI*, *STI*, *GMP*, M_1STI, M_2STI, *MSTI*, *HMP*. Yield under irrigation is characterized by a high positive correlation (r = 0.715) with the *TOL* and *SSPI* indices, an average positive correlation (r = 0.542) with the *SSI* index, and an average negative r = (-0.499–-0.549) with the *YSI*, *RDI*, and *ISR* indices on the other hand, there is no dependence with productivity under stress (r = -0.013–0.207). The *ATI* index had a high positive correlation (r = 0.832) with yield under irrigation and a moderate positive correlation (r = 0.386) with yield under stress. The yield under stress had a high correlation (r = 0.852) with the *DI* index and a medium correlation (r = 0.420) with the yield under irrigation (Table 3).

According to the correlation analysis, one index was selected: the drought resistance index (*DI*), according to which the winter wheat variety *Lira odes'ka* was characterized by the greatest drought resistance. In this part, we analyzed and saw how years with sufficient moisture significantly affected the determination of drought resistance of varieties and lead to errors in the analysis. Therefore, it is necessary to exclude these years when analyzing the drought resistance of plants, if you analyze the resistance of plants to drought in two environments (irrigation and natural humidification). 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 results of GGE biplot analysis, winter wheat varieties *Kokhana* (G4), *Askaniis'ka* (G10) and *Schedrist' odes'ka* (G18), located between the vectors of environmental conditions on the axis, can be characterized as moderately drought-tolerant (Fig. 1).

Winter wheat varieties *Mariia* (G6), *Mudrist' odes'ka* (G14) and *Nyva odes'ka* (G15), which are in the same quarter with the yield vector under irrigation (*Yp*) and are as close as possible to its peak, are characterized by high productivity under optimal conditions. These varieties can be classified as varieties that are not resistant to drought.

The variety winter wheat *Rosynka* (G8), which is located in the third quarter and is as far from the center as possible, is characterized by the smallest decrease in yield due to deterioration of moisture conditions, but it also has low productivity under both conditions. The winter wheat variety *Harantiia odes'ka* (G11), which is located in the IV quarter and is as far from the center as possible, is characterized by one of the greatest increases in yield when moisture conditions are improved, but it also has low productivity under both conditions.

The variety of winter wheat *Lira odes'ka* (G13), located in one quarter of the yield vector under natural moisture conditions (*Ys*) and as close as possible to its peak, is characterized by high productivity under stress. This variety can be considered the most resistant to drought.

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. Construction and analysis of dendrograms details information about the nature of relationships between lineages at the cluster level and specifies relationships between populations 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 varieties that formed the subcluster were the closest in terms of drought resistance indices: G5 – *Koshova* and G17 – Odesa tradition were united at a distance of 9, with the further addition of the variety G9 – *Khersons'ka bezosta* at a distance of 38 and G2 – *Burhunka* at a distance of 56 and completed the grouping into 1 cluster at a distance of 881, a subcluster of varieties G1 – *Anatoliia* and G3 – *Konka*, united at a distance of 86. The varieties G4 – *Kokhana* and G18 – *Schedrist' odes'ka* united at a distance of 53, at a distance of 178 they were joined by the variety G7 – *Ledia* and supplemented grouping of cluster 2 at a distance of 236 subcluster with varieties G10 – *Askaniis'ka* and G16 – *Pylypivka*, united at a distance of 64. Cluster 3 grouped 5 varieties at a distance of 837. Varieties G6 – *Mariia* and G15 – *Nyva odes'ka* united at a distance of 16, at a distance of 67 they were joined by the variety G12 – *Zysk* and complemented the grouping of cluster 3 at a distance of 119 by a subcluster with the varieties G11 – *Harantiia odes'ka* and G14 – *Mudrist' odes'ka*. Varieties G8 – *Rosynka* and G13 – *Lira odes'ka* united in cluster 5 at a distance of 1721 (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 four clusters.

Cluster 1 included five varieties of medium resistance to drought, compared to the agglomerative hierarchical cluster analysis, the exception is the variety G5 – *Koshova*, which was included in the second cluster. The smallest distance to the center of the cluster was observed in the G2 – *Burhunka* population at the level of 3.903, while the largest was 21.943 in the G3 – variety *Konka* (Table 4).

Cluster 2 includes the four most drought-resistant varieties. If compared with the agglomerative hierarchical clus-

Table 3

Matrix of correlations between grain yield of winter wheat varieties under irrigation and under natural moisture conditions and drought resistance indices (2016–2020)

	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**	0.832	0.971	0.542	0.715	-0.512	0.832	0.953	0.963	-0.549	0.420	0.715	0.979	0.878	0.905	0.832	0.953	-0.499
Ys	0.832	**1.000**	0.941	-0.013	0.207	0.048	1.000	0.959	0.951	0.005	0.852	0.207	0.912	0.992	0.959	0.386	0.961	0.023
MP	0.971	0.941	**1.000**	0.326	0.527	-0.293	0.941	0.997	0.999	-0.334	0.625	0.527	0.992	0.965	0.967	0.675	0.998	-0.296
SSI	0.542	-0.013	0.326	**1.000**	0.973	-0.997	-0.013	0.265	0.296	-0.998	-0.531	0.973	0.379	0.080	0.172	0.910	0.263	-0.950
TOL	0.715	0.207	0.527	0.973	**1.000**	-0.963	0.207	0.472	0.499	-0.975	-0.333	1.000	0.577	0.299	0.387	0.981	0.469	-0.909
YSI	-0.512	0.048	-0.293	-0.997	-0.963	**1.000**	0.047	-0.232	-0.262	0.993	0.559	-0.963	-0.347	-0.046	-0.140	-0.894	-0.229	0.948
YI	0.832	1.000	0.941	-0.013	0.207	0.047	**1.000**	0.959	0.951	0.005	0.852	0.207	0.912	0.992	0.959	0.386	0.961	0.023
STI	0.953	0.959	0.997	0.265	0.472	-0.232	0.959	**1.000**	0.999	-0.273	0.672	0.472	0.989	0.981	0.980	0.629	0.999	-0.231
GMP	0.963	0.951	0.999	0.296	0.499	-0.262	0.951	0.999	**1.000**	-0.303	0.650	0.499	0.990	0.973	0.971	0.651	0.999	-0.268
RDI	-0.549	0.005	-0.334	-0.998	-0.975	0.993	0.005	-0.273	-0.303	**1.000**	0.523	-0.975	-0.387	-0.088	-0.182	-0.914	-0.271	0.938
DI	0.420	0.852	0.625	-0.531	-0.333	0.559	0.852	0.672	0.650	0.523	**1.000**	-0.333	0.571	0.795	0.716	-0.150	0.675	0.511
SSPI	0.715	0.207	0.527	0.973	1.000	-0.963	0.207	0.472	0.499	-0.975	-0.333	**1.000**	0.577	0.299	0.387	0.981	0.469	-0.909
M_1STI	0.979	0.912	0.992	0.379	0.577	-0.347	0.912	0.989	0.990	-0.387	0.571	0.577	**1.000**	0.950	0.972	0.722	0.986	-0.328
M_2STI	0.878	0.992	0.965	0.080	0.299	-0.046	0.992	0.981	0.973	-0.088	0.795	0.299	0.950	**1.000**	0.986	0.473	0.979	-0.048
MSTI	0.905	0.959	0.967	0.172	0.387	-0.140	0.959	0.980	0.971	-0.182	0.716	0.387	0.972	0.986	**1.000**	0.555	0.974	-0.116
ATI	0.832	0.386	0.675	0.910	0.981	-0.894	0.386	0.629	0.651	-0.914	-0.150	0.981	0.722	0.473	0.555	**1.000**	0.625	-0.842
HMP	0.953	0.961	0.998	0.263	0.469	-0.229	0.961	0.999	0.999	-0.271	0.675	0.469	0.986	0.979	0.974	0.625	**1.000**	-0.238
ISR	-0.499	0.023	-0.296	-0.950	-0.909	0.948	0.023	-0.231	-0.268	0.938	0.511	-0.909	-0.328	-0.048	-0.116	-0.842	-0.238	**1.000**

** – Confidence interval (%): 95*

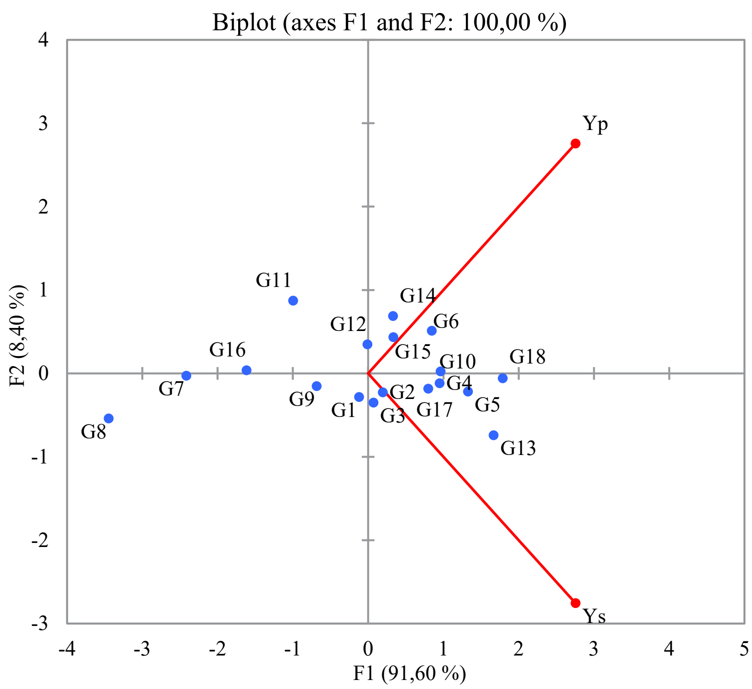

Fig. 1. Genotype-environment interaction of winter wheat varieties and environments (biplot analysis method). The lines show the eigenvectors of the leading factor loads for the environments: ● – humidification conditions; ● – varieties

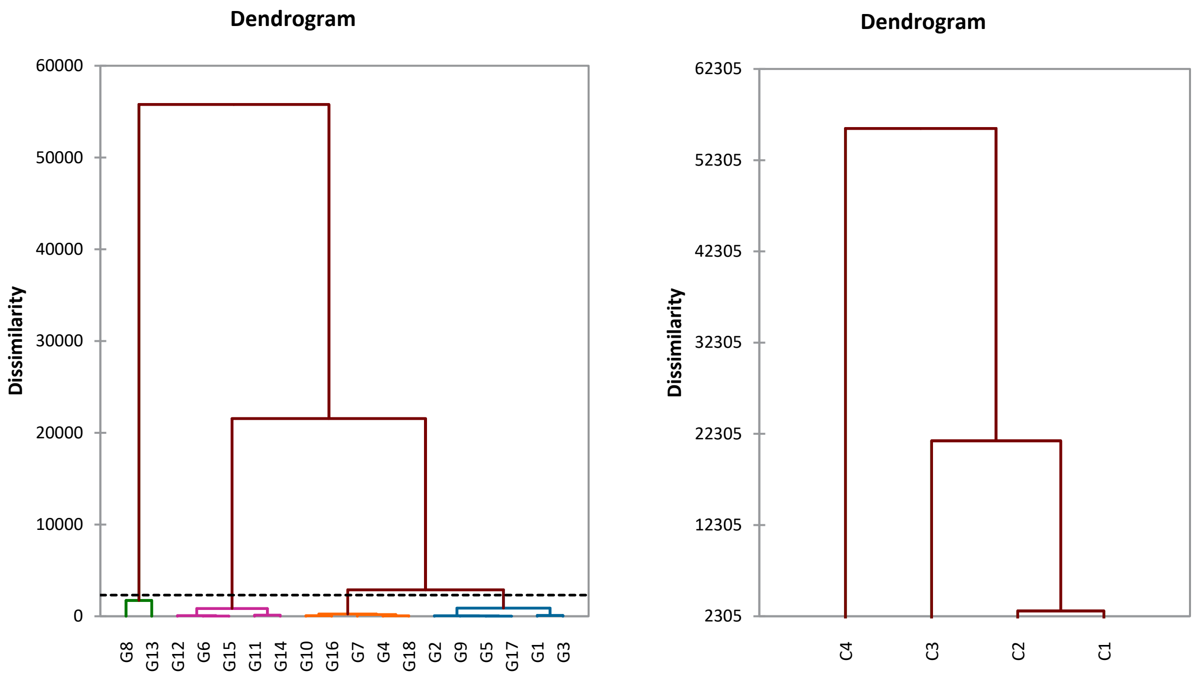

Fig. 2. Clustering dendrogram of eighteen winter wheat varieties according to drought resistance

ter analysis, three varieties G5 – *Koshova* from cluster 1 and G8 – *Rosynka* and G13 – *Lira odes'ka* were added to the G4 – *Kokhana* variety. Instead, G7 – *Ledia*, G10 – *Askaniis'ka*, G16 – *Pylypivka* and G18 – *Schedrist' odes'ka* moved to cluster 4. The smallest distance to the center of the cluster was observed in the variety G13 – *Lira odes'ka* at the level of 50.113, whereas the largest was 104.855 in G8 – *Rosynka*.

The third cluster included five varieties not resistant to drought, with the smallest distance of 5.649 to the center

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	8.856	1
Burhunka	G2	1	3.903	1
Konka	G3	1	21.943	1
Kokhana	G4	2	83.804	2
Koshova	G5	2	69.743	1
Mariia	G6	3	5.649	3
Ledia	G7	4	12.874	2
Rosynka	G8	2	104.855	4
Khersons'ka bezosta	G9	1	13.368	1
Askaniis'ka	G10	4	8.983	2
Harantiia odes'ka	G11	3	23.383	3
Zysk	G12	3	16.949	3
Lira odes'ka	G13	2	50.113	4
Mudrist' odes'ka	G14	3	8.625	3
Nyva odes'ka	G15	3	9.914	3
Pylypivka	G16	4	7.252	2
Tradytsiia odes'ka	G17	1	14.297	1
Schedrist' odes'ka	G18	4	9.416	2

of the cluster in the variety G6 – *Mariia*, and the largest – 23.383 in G11 – *Harantiia odes'ka*.

The fourth cluster included four varieties with the smallest distance of 7.252 to the center of the cluster in the variety G16 – *Pylypivka*, and the largest – 12.874 in G7 – *Ledia*.

Conclusions. When analyzing winter wheat varieties for the five-year period, where years with sufficient moisture and dry ones were included in the analysis, years with sufficient moisture significantly affected the determination of drought resistance of the varieties and led to significant errors in the analysis. Most of the indices had a high correlation with yield under both conditions, or a high or medium correlation with yield under irrigation and no correlation with yield under stress, so only one index, drought tolerance (*DI*), was selected. Based on this, it is necessary to eliminate such years when analyzing the drought resistance of plants.

According to drought resistance indices and biplot analysis, *Lira odes'ka* is the most drought-resistant selected variety. The *Schedrist' odes'ka* variety stood out according to eight indices, but according to the biplot analysis, it was characterized as medium resistance. According to seven indices, the *Rosynka* variety stood out, which was characterized by the smallest decrease in yield due to deterioration of moisture conditions, but also had low productivity under both conditions.

Using cluster analysis, eighteen varieties of winter wheat were divided into four clusters.

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Коновалова В.М., Тищенко А.В., Базалій Г.Г., Фундират К.С., Тищенко О.Д., Резниченко Н.Д., Коновалов В.О. Аналіз сортів озимої пшениці на посухостійкість в умовах Степу України (Ч. 3 – роки з різним вологозабезпеченням)

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.** Отримані експериментальні дані дозволяють виділити сорти озимої пшениці, що істотно перевищують середньосортову за урожайністю при зрошенні (*Yp*): *Марія* і *Щедрість одеська* з урожайністю 7,41–7,53 т/га, в стресових умовах (*Ys*): *Ліра одеська* – 6,25 т/га і *Щедрість одеська* – 6,12 т/га. За більшою кількістю індексів (12), як найбільш посухостійкий, був виділений сорт *Ліра одеська*, сорт *Щедрість одеська* виділився за вісьмома індексами та сорт *Росинка* – за сімома. Урожайність сортів пшениці за обох умов зволоження має високий позитивний кореляційний зв'язок (r = 0,832–1,000) з індексами *MP*, *YI*, *STI*, *GMP*, M_1STI, M_2STI, *MSTI*, *HMP*. Урожайність при зрошенні характеризується високою позитивною залежністю (r = 0,715) з індексами *TOL* і *SSPI*, середньою позитивною залежністю (r = 0,542) з індексом *SSI* та середню від'ємну r = (-0,499–-0,549) з індексами *YSI*, *RDI* і *ISR* натомість з урожайністю при стресі залежність відсутня (r = -0,013–0,207). Урожайність при стресі мала високу кореляцію (r = 0,852) з індексом *DI* та середню (r = 0,420) з врожайністю при зрошенні. За результатами GGE біплот-аналізу сорти озимої пшениці *Кохана*, *Асканійська* та *Щедрість одеська* можна охарактеризувати як середньопосухостійкі, *Ліра одеська* – найбільш стійким до посухи, *Марія*, *Мудрість одеська* та *Нива одеська* можна віднести до сортів не стійких до посухи. **Висновки.** Більшість індексів мали високу залежність з врожайністю за обох умов, або високу чи середню залежність з врожайністю при зрошенні та відсутність зв'язку з врожайністю при стресі, тому було виділено лише один індекс – посухостійкості (*DI*). За індексами посухостійкості та біплот-аналізом, як найбільш посухостійкий виділений сорт *Ліра одеська*. Сорт *Щедрість одеська* виділився за вісьмома індексами, проте за біплот-аналізом він характеризувався як середньої стійкості. За сімома індексами виділився сорт *Росинка*, що характеризувався найменшим зниженням врожайності за погіршення умов зволоження, проте володів і низькою продуктивністю за обох умов.

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

Konovalova V.M., Tyshchenko A.V., Bazalii H.G., 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 3 – years with different moisture supply)

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 18 varieties of winter wheat 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. 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 obtained experimental data make it possible to distinguish winter wheat varieties that significantly exceed the average variety in terms of productivity under irrigation (*Yp*): *Maria* and *Shchedrist Odeska* with a yield of 7.41–7.53 t/ha, in stressful conditions (*Ys*): *Lyra Odeska* – 6, 25 t/ha and the *Shchedrist Odeska* – 6.12 t/ha. According to the most indices (12), the *Lyra Odeska* variety was singled out as the most drought-resistant, the *Shchedrist Odeska* variety was distinguished according to eight indices, and the *Rosynka* variety – according to seven. The yield of wheat varieties under both moisture conditions has a high positive correlation (r = 0.832–1.000) with the indices *MP*, *YI*, *STI*, *GMP*, M_1STI, M_2STI, *MSTI*, *HMP*. Yield under irrigation is characterized by a high positive correlation (r = 0.715) with the *TOL* and *SSPI* indices, an average positive correlation (r = 0.542) with the SSI index, and an average negative r = (-0.499–-0.549) with the *YSI*, *RDI* and *ISR* indices on the other hand, there is no dependence with productivity under stress (r = -0.013–0.207). Yield under stress had a high correlation (r = 0.852) with the *DI* index and a moderate correlation (r = 0.420) with yield under irrigation. According to the results of the GGE biplot analysis, winter wheat varieties *Kokhan*a, *Askaniyska* and *Shchedrist Odeska* can be characterized as moderately drought-resistant, *Lyra Odeska* is the most drought-resistant, *Maria*, *Mudrist Odeska* and *Nyva Odeska* can be classified as non-drought resistant varieties. **Conclusions.** Most of the indices had a high correlation with yield under both conditions, or a high or medium correlation with yield under irrigation and no correlation with yield under stress, so only one index, drought tolerance (*DI*), was selected. According to drought resistance indices and biplot analysis, *Lyra Odeska* is the most drought-resistant selected variety. The *Shchedrist Odeska* variety stood out according to eight indices, but according to the biplot analysis, it was characterized as medium resistance. According to seven indices, the *Rosynka* variety stood out, which was characterized by the smallest decrease in yield due to deterioration of moisture conditions, but also had low productivity under both conditions.

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