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ANALYSIS OF WINTER WHEAT VARIETIES FOR DROUGHT RESISTANCE IN THE CONDITIONS OF THE STEPPE OF UKRAINE (PART 2 – DROUGHT YEARS)

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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, 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 allow distinguishing the varieties of winter wheat according to the productivity under irrigation (*Yp*) showed that the highest productivity was formed by the varieties *Mariia* – 7.41 t/ha and *Schedrist’ odes’ka* – 7.53 t/ha. Under stress conditions (*Ys*), the highest productivity was characterized by the varieties *Kokhana* – 5.24 t/ha, *Koshova* – 5.23 t/ha, *Zysk* – 5.25 t/ha and *Lira odes’ka* – 5.42 t/ha, but they had and high yield under irrigation – 7.08–7.33 t/ha (Table 2).

The *Kokhana*, *Koshova* and *Lira odes’ka* varieties were characterized by a high average yield index of *MP* (6.24–6.35), which shows the potential yield of the varieties under different growing conditions. The yield of these varieties was high under both conditions.

The drought sensitivity index (*SSI*) ranged from 0.77 to 1.52. It characterizes the sensitivity of the genotype to drought – the smaller it is, the greater the drought resistance of the genotype, this is characteristic of winter wheat varieties: *Ledia*, *Zysk* and *Lira odes’ka*, which have the lowest *SSI* index values of 0.77, 0.79 and 0.78, 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. The lowest values of these indices were characterized by the varieties *Ledia* – 1.55 and 11.12 and *Rosynka* – 1.60 and 11.48, respectively. At the same

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 (2018, 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	4.95	5.90	0.84	1.89	0.72	105.59	0.70	5.82	1.08	0.76	13.56	0.67	0.78	0.52	7.40	5.74	64.83
Burhunka	G2	6.96	4.53	5.75	1.07	2.43	0.65	96.63	0.65	5.62	0.97	0.63	17.43	0.65	0.61	0.39	9.18	5.49	37.16
Konka	G3	6.88	4.80	5.84	0.92	2.08	0.70	102.39	0.68	5.75	1.04	0.71	14.92	0.66	0.71	0.47	8.04	5.65	52.52
Kokhana	G4	7.24	5.24	6.24	0.84	2.00	0.72	111.78	0.78	6.16	1.08	0.81	14.35	0.84	0.98	0.82	8.28	6.08	68.67
Koshova	G5	7.33	5.23	6.28	0.87	2.10	0.71	111.57	0.79	6.19	1.06	0.80	15.06	0.87	0.98	0.86	8.74	6.10	63.72
Mariia	G6	7.41	4.91	6.16	1.03	2.50	0.66	104.74	0.75	6.03	0.99	0.69	17.93	0.85	0.82	0.70	10.14	5.91	43.14
Ledia	G7	6.18	4.63	5.41	0.77	1.55	0.75	98.77	0.59	5.35	1.11	0.74	11.12	0.46	0.57	0.27	5.58	5.29	73.60
Rosynka	G8	5.68	4.08	4.88	0.86	1.60	0.72	87.03	0.48	4.81	1.07	0.63	11.48	0.32	0.36	0.11	5.18	4.75	51.42
Khersons'ka bezosta	G9	6.70	4.17	5.44	1.15	2.53	0.62	88.95	0.58	5.29	0.93	0.55	18.15	0.53	0.46	0.24	8.99	5.14	29.24
Askaniis'ka	G10	7.29	5.02	6.16	0.95	2.27	0.69	107.09	0.75	6.05	1.02	0.74	16.28	0.82	0.86	0.71	9.24	5.95	51.77
Harantiia odes'ka	G11	6.93	3.48	5.21	1.52	3.45	0.50	74.24	0.50	4.91	0.75	0.37	24.75	0.49	0.27	0.13	11.39	4.63	14.04
Zysk	G12	7.08	5.25	6.17	0.79	1.83	0.74	111.99	0.76	6.10	1.10	0.83	13.13	0.79	0.96	0.76	7.50	6.03	78.58
Lira odes'ka	G13	7.27	5.42	6.35	0.78	1.85	0.75	115.62	0.81	6.28	1.11	0.86	13.27	0.88	1.08	0.96	7.81	6.21	83.70
Mudrist' odes'ka	G14	7.30	4.30	5.80	1.25	3.00	0.59	91.73	0.65	5.60	0.88	0.54	21.52	0.71	0.54	0.39	11.30	5.41	25.46
Nyva odes'ka	G15	7.22	4.65	5.94	1.09	2.57	0.64	99.19	0.69	5.79	0.96	0.64	18.43	0.74	0.68	0.50	10.01	5.66	36.70
Pylypivka	G16	6.46	4.49	5.48	0.93	1.97	0.70	95.78	0.60	5.39	1.03	0.67	14.13	0.51	0.55	0.28	7.14	5.30	48.28
Tradytsiia odes'ka	G17	7.17	4.33	5.75	1.21	2.84	0.60	92.37	0.64	5.57	0.90	0.56	20.37	0.68	0.55	0.37	10.64	5.40	27.60
Schedrist' odes'ka	G18	7.53	4.90	6.22	1.07	2.63	0.65	104.53	0.76	6.07	0.97	0.68	18.87	0.89	0.83	0.74	10.74	5.94	40.17
Medium grade		6.97	4.69	5.83	1.00	2.28	0.67	100.00	0.67	5.71	1.00	0.68	16.37	0.69	0.70	0.51	8.74	5.59	**49.48**
V, %		6.76	10.58	7.08	19.84	22.09	9.76	10.58	14.45	7.57	9.48	18.04	22.09	24.39	32.64	50.79	20.65	8.17	39.79
$S\dot{x}_{absolute}$		0.11	0.12	0.10	0.05	0.12	0.02	2.49	0.02	0.10	0.02	0.03	0.85	0.04	0.05	0.06	0.43	0.11	4.64
$S\dot{x}_{reletive}$		1.59	2.49	1.67	4.68	5.21	2.30	2.49	3.41	1.78	2.23	4.25	5.21	5.75	7.69	11.97	4.86	1.92	9.38
LSD_{01}		0.35	0.37	0.31	0.15	0.38	0.05	7.90	0.07	0.32	0.07	0.09	2.70	0.13	0.17	0.19	1.35	0.34	14.71
LSD_{05}		0.25	0.27	0.22	0.11	0.27	0.04	5.71	0.05	0.23	0.05	0.07	1.95	0.09	0.12	0.14	0.97	0.25	10.63

time, the *Rosynka* variety formed a low yield under both growing conditions. At the same time, the *Ledia* variety was characterized by low yield under irrigation and mediocre under stress. That is, these indices characterize the difference between productivity under optimal and limiting conditions, but do not take into account the productivity of the variety under stress.

According to the yield stability index (*YSI*), with fluctuations from 0.50 to 0.75 and the relative drought resistance index (*RDI*), with fluctuations from 0.88 to 1.11, three varieties with high index values stood out: *Ledia* – 0.75 and 1.11, *Zysk* – 0.74 and 1.10, *Lira odes'ka* – 0.75 and 1.11, respectively.

According to the index of productivity (*YI*) and drought resistance (*DI*), the varieties of winter wheat *Kokhana* – 111.78 and 0.81, *Koshova* – 111.57 and 0.80, *Zysk* – 111.99 and 0.83 and *Lira odes'ka* with indicators were selected 115.62 and 0.86, respectively.

According to the first modified index of tolerance to stress, the *Koshova* varieties stood out – 0.87, *Lira odes'ka* – 0.88 and *Schedrist' odes'ka* – 0.89, according to the M_2STI index – 1.08 and *MSTI* – 0.96, the *Lira odes'ka* variety stood out.

The stress tolerance index (*STI*) characterizes the genotype's ability to form a stable yield level regardless of stress factors. The geometric mean productivity (*GMP*) shows the productivity of a specific genotype under stressful conditions relative to the average productivity of the studied genotypes under these conditions. It is believed that they are less sensitive to large differences between the values of potential yield and yield under stress conditions. According to these indices, the varieties *Kokhana* (0.78 and 6.16, respectively), *Koshova* (0.79 and 6.19, respectively) and *Lira odes'ka* (0.81 and 6.28, respectively) stood out.

According to the abiotic tolerance index (*ATI*) with values of 11.39 and 11.30, the most resistant to drought varieties *Harantiia odes'ka* (yield under irrigation – 6.93 t/ha, under stress – 3.48 t/ha) and *Mudrist' odes'ka* (yield under irrigation – 7.30 t/ha, under stress – 4.30 t/ha). On the other hand, the varieties with the smallest reduction in yield when moisture conditions worsen, *Ledia* and *Rosynka*, have the lowest values of this indicator, 5.58 and 5.18, respectively. Although Moosavi et al. (2007) [17] claim that the greater this index, the higher the drought resistance.

According to harmonic productivity (*HMP*), which shows the productivity of a particular genotype under stressful conditions relative to the average productivity of the studied genotypes under these conditions, the *Lira odes'ka* variety stood out with an index value of 6.21.

According to the index of resistance to stress (*ISR*), which characterizes genotypes by resistance to stress not only by a smaller difference in yield in optimal and limiting conditions, but also takes into account high productivity under stress, two varieties were selected: *Zysk* – 78.58 and *Lira odes'ka* – 83.70.

The *Lira odes'ka* variety was singled out as the most drought-resistant according to the largest number of indices (13), the *Koshova* and *Zysk* varieties stood out according to six indices, and the *Kokhana* and *Ledia* varieties – according to five indices.

There is an average positive correlation r = 0.457 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 = 0.717–0.922) with the indices of *MP*, *STI*, *GMP*, M_1STI, *MSTI*. The yield under irrigation is characterized by a high positive correlation (r = 0.751) with the *ATI* index, whereas yield under stress had a low negative correlation r = -0.238. Yield under stress had a high positive correlation (r = 0.748–1.000) with the *YSI*, *YI*, *RDI*, *DI*, M_2STI, *HMP*, *ISR* indices and a high negative correlation (r = -0.758) with the *SSI* index. Instead, the productivity under irrigation was characterized by a low (positive or negative) dependence (r = -0.246–0.233) with the indices *SSI*, *YSI*, *RDI*, *DI*, *ISR* and medium (r = 0.457–0.691) with the indices *YI*, M_2STI, *HMP*. Compared to part 1 – years with sufficient moisture, where the indices were characterized by close relationships (except *DI* and *ISR* indices) with vulnerabilities under different moisture conditions, in dry years there is a clear relationship between the indices and yield under irrigation and under stress. This suggests that it is necessary to exclude these years when analyzing plants for drought resistance, if you analyze the drought resistance of plants 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. In part 3 – years with different moisture supply, we will analyze and see how years with sufficient moisture affect the determination of drought resistance of varieties and can lead to errors in the analysis. The *TOL* and *SSPI* indices were characterized by an average positive relationship with yield under irrigation (r = 0.485) and an average negative (r = -0.556) relationship with stress. That is, the smaller the value of these indices, the more resistant the variety to drought, and conversely, the larger the value, the less drought-resistant the variety (Table 3).

According to the correlation analysis, seven main indices were selected: drought tolerance (*TOL*), stress susceptibility (*SSI*), yield stability (*YSI*), relative drought index (*RDI*), drought resistance (*DI*), stress susceptibility (*SSPI*), resistance to stress (*ISR*) and three auxiliary indices: productivity (*YI*), the second modified stress tolerance index (M_2STI) and harmonic productivity (*HMP*), according to which the winter wheat variety *Lira odes'ka* was characterized by the greatest drought resistance.

According to the results of the GGE biplot analysis, winter wheat varieties *Mariia* (G6), *Nyva odes'ka* (G15) and *Schedrist' odes'ka* (G18), which are in the same quarter with the yield vector under irrigation (*Yp*), form high yields under optimal conditions and their varieties can be attributed to unstable to drought (Fig. 1).

Winter wheat varieties *Anatoliia* (G1), *Kokhana* (G4), *Koshova* (G5), *Zysk* (G12) and *Lira odes'ka* (G13), which are in the same quarter with the yield vector under natural moisture conditions (*Ys*), are characterized by high productivity under stress. These varieties can be considered the most resistant to drought.

The winter wheat variety *Askaniis'ka* (G10), located on the axis between the productivity vectors under both

Table 3

Matrix of correlations between grain yield of winter wheat varieties under irrigation and under natural moisture conditions and drought resistance indices (2018, 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**	0,457	0,845	0,233	0,485	-0,246	0,457	0,766	0,766	-0,229	0,152	0,485	0,911	0,600	0,717	0,751	0,691	-0,096
Ys	0,457	**1,000**	0,862	-0,758	-0,556	0,748	1,000	0,921	0,922	0,760	0,947	-0,556	0,770	0,976	0,914	-0,238	0,958	0,795
MP	0,845	0,862	**1,000**	-0,323	-0,058	0,310	0,862	0,990	0,991	0,326	0,656	-0,058	0,982	0,929	0,958	0,286	0,970	0,423
SSI	0,233	-0,758	-0,323	**1,000**	0,963	-0,999	-0,758	-0,446	-0,446	-1,000	-0,923	0,963	-0,175	-0,625	-0,472	0,808	-0,541	-0,937
TOL	0,485	-0,556	-0,058	0,963	**1,000**	-0,966	-0,556	-0,190	-0,190	-0,962	-0,789	1,000	0,094	-0,399	-0,229	0,936	-0,297	-0,872
YSI	-0,246	0,748	0,310	-0,999	-0,966	**1,000**	0,748	0,433	0,434	0,998	0,917	-0,966	0,162	0,613	0,461	-0,815	0,529	0,936
YI	0,457	1,000	0,862	-0,758	-0,556	0,748	**1,000**	0,921	0,922	0,760	0,947	-0,556	0,770	0,976	0,914	-0,238	0,958	0,795
STI	0,766	0,921	0,990	-0,446	-0,190	0,433	0,921	**1,000**	0,999	0,449	0,750	-0,191	0,956	0,968	0,978	0,157	0,993	0,530
GMP	0,766	0,922	0,991	-0,446	-0,190	0,434	0,922	0,999	**1,000**	0,449	0,749	-0,191	0,953	0,964	0,969	0,157	0,994	0,526
RDI	-0,229	0,760	0,326	-1,000	-0,962	0,998	0,760	0,449	0,449	**1,000**	0,923	-0,962	0,179	0,627	0,475	-0,805	0,544	0,936
DI	0,152	0,947	0,656	-0,923	-0,789	0,917	0,947	0,750	0,749	0,923	**1,000**	-0,789	0,530	0,876	0,767	-0,534	0,815	0,933
SSPI	0,485	-0,556	-0,058	0,963	1,000	-0,966	-0,556	-0,191	-0,191	-0,962	-0,789	**1,000**	0,094	-0,399	-0,229	0,936	-0,297	-0,872
M_1STI	0,911	0,770	0,982	-0,175	0,094	0,162	0,770	0,956	0,953	0,179	0,530	0,094	**1,000**	0,865	0,932	0,429	0,917	0,281
M_2STI	0,600	0,976	0,929	-0,625	-0,399	0,613	0,976	0,968	0,964	0,627	0,876	-0,399	0,865	**1,000**	0,977	-0,073	0,980	0,714
MSTI	0,717	0,914	0,958	-0,472	-0,229	0,461	0,914	0,978	0,969	0,475	0,767	-0,229	0,932	0,977	**1,000**	0,101	0,967	0,585
ATI	0,751	-0,238	0,286	0,808	0,936	-0,815	-0,238	0,157	0,157	-0,805	-0,534	0,936	0,429	-0,073	0,101	**1,000**	0,050	-0,713
HMP	0,691	0,958	0,970	-0,541	-0,297	0,529	0,958	0,993	0,994	0,544	0,815	-0,297	0,917	0,980	0,967	0,050	**1,000**	0,603
ISR	-0,096	0,795	0,423	-0,937	-0,872	0,936	0,795	0,530	0,526	0,936	0,933	-0,872	0,281	0,714	0,585	-0,713	0,603	1,000

* – Confidence interval (%): 95

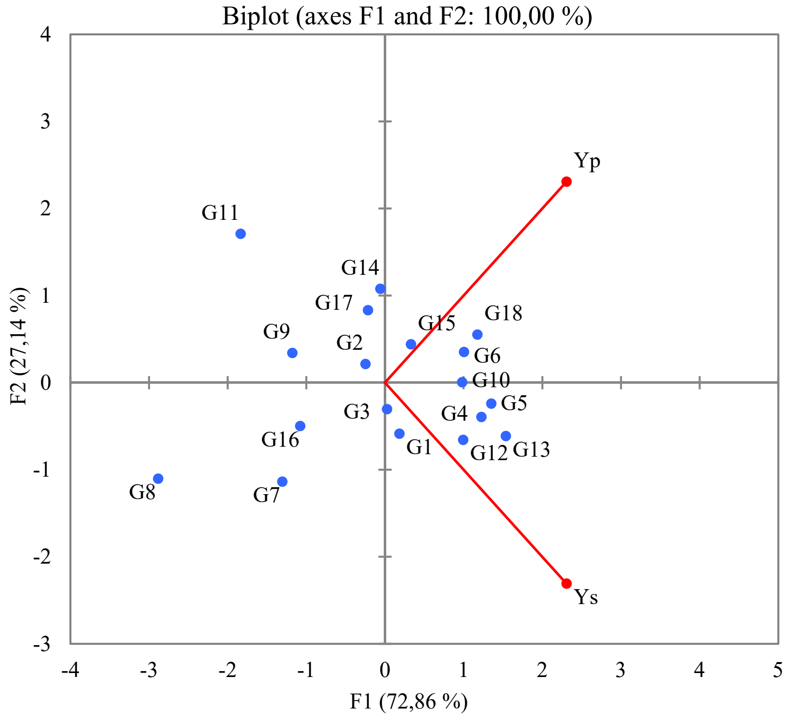

Fig. 1. Genotype-environment interaction of winter wheat varieties and environments (biplot analysis method). The lines show the eigenvectors of the leading factor loads for the ● environments: – ● humidification conditions; – varieties

conditions, is characterized by high productivity under both conditions. This variety can be attributed to average resistance to drought.

Winter wheat varieties *Ledia* (G7) and *Rosynka* (G8), which are located in the III quarter and are as far from the center as possible, are characterized by the smallest decrease in yield under worsening conditions, however, they have 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 the greatest increase in yield under improved conditions, however, it has lower productivity under irrigation than other varieties.

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 three subclusters were the closest in terms of drought resistance indices: G14 – *Mudrist' odes'ka* and G17 – *Tradytsiia odes'ka* united at a distance of 3 and further grouped into 2 cluster, G2 – *Burhunka* and G15 – *Nyva odes'ka* united at a distance of 4 and G6 – *Mariia* and G18 – *Schedrist' odes'ka* united at a distance of 5 and grouped into 3 clusters. In general, three clusters were formed: the six most drought-resistant varieties were united at a distance of 305 in the first cluster, four non-drought-resistant varieties were united in the second cluster at a distance of 365, and eight medium varieties were united in the third cluster at a distance of 342 drought resistance (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 three clusters.

Cluster 1 included the six most drought-resistant varieties and fully coincides with the agglomerative hierarchical cluster analysis. The smallest distance to the center of the cluster was observed in the population G4 – *Kokhana* at the level of 4.530, while the largest was 13.200 in G13 – *Lira odes'ka* (Table 4).

Cluster 2 included the six most drought-resistant varieties. If compared with agglomerative hierarchical cluster analysis, three populations G9 – *Khersons'ka bezosta*, G11 – *Harantiia odes'ka*, G14 – *Mudrist' odes'ka* and G17 – *Tradytsiia odes'ka* were added, moving from the third to the second cluster. The smallest distance to the center of the cluster was observed in the population G17 – *Tradytsiia odes'ka* at the level of 2.073, whereas the largest 22.256 was observed in G11 – *Harantiia odes'ka*.

The third cluster included six varieties of average drought resistance with the smallest distance of 4.964 to the center of the cluster in the variety G16 – *Pylypivka*, and the largest – 14.827 in G8 – *Rosynka*.

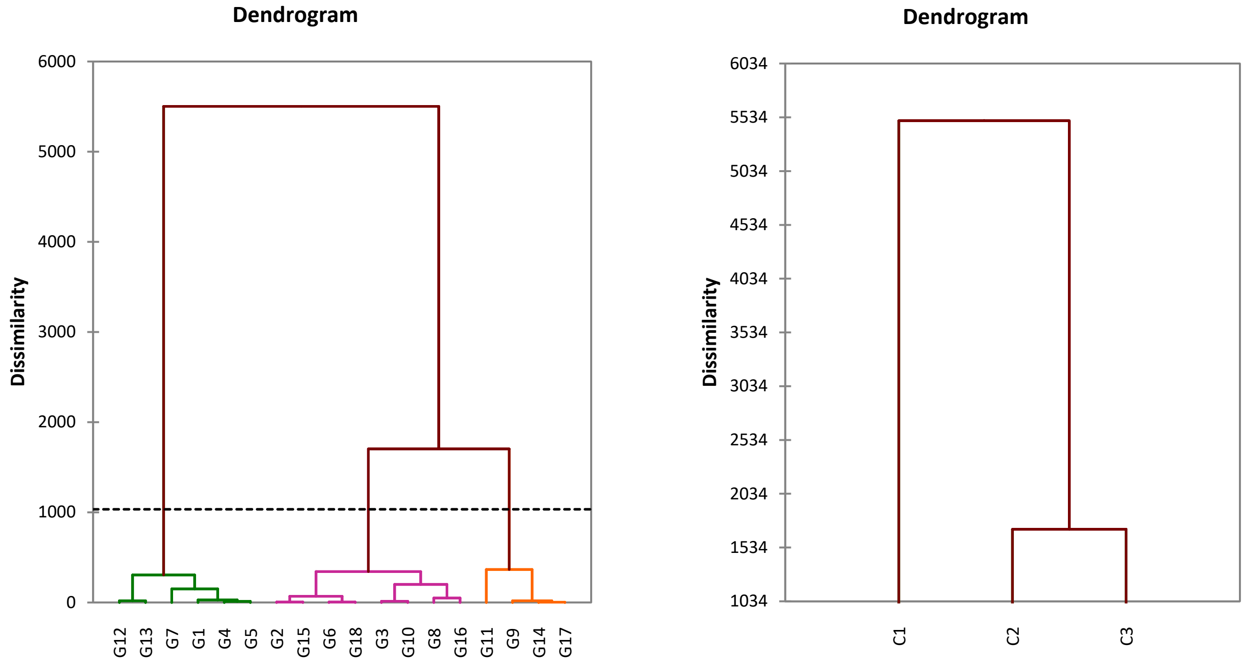

Fig. 2. Clustering dendrogram of eighteen winter wheat varieties according to drought resistance

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	8,215	1
Burhunka	G2	2	11,106	2
Konka	G3	3	5,165	2
Kokhana	G4	1	4,530	1
Koshova	G5	1	9,035	1
Mariia	G6	3	7,202	2
Ledia	G7	1	11,089	1
Rosynka	G8	3	14,827	2
Khersons'ka bezosta	G9	2	2,996	3
Askaniis'ka	G10	3	7,981	2
Harantiia odes'ka	G11	2	22,256	3
Zysk	G12	1	6,982	1
Lira odes'ka	G13	1	13,200	1
Mudrist' odes'ka	G14	2	3,631	3
Nyva odes'ka	G15	2	12,174	2
Pylypivka	G16	3	4,964	2
Tradytsiia odes'ka	G17	2	2,073	3
Schedrist' odes'ka	G18	3	9,752	2

Conclusions. Seven main indices were identified: drought tolerance (*TOL*), stress susceptibility (*SSI*), yield stability (*YSI*), relative drought index (*RDI*), drought resistance (*DI*), stress susceptibility (*SSPI*), stress resistance (*ISR*). and three auxiliary indices: yield (*YI*), second modified stress tolerance index (M_2STI) and harmonic productivity (*HMP*).

According to drought resistance indices and biplot analysis, the most drought-resistant were selected varieties of *Lira odes'ka*, *Kokhana*, *Zysk* and *Koshova*. Varieties *Mariia*, *Nyva odes'ka* and *Schedrist' odes'ka* stood out as the most resistant to drought.

Using cluster analysis, eighteen winter wheat varieties were divided into three clusters: drought-resistant, medium-resistant, and non-resistant.

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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., Боровик В.О. Аналіз сортів озимої пшениці на посухостійкість в умовах Степу України (Ч. 2 – посушливі роки)

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 продуктивність при зрошенні сформували сорти озимої пшениці *Марія* – 7,41 т/га та *Щедрість одеська* – 7,53 т/га. За стресових умов найбільшою урожайністю характеризувалися сорти *Кохана* – 5,24 т/га, *Кошова* – 5,23 т/га, *Зиск* – 5,25 т/га та *Ліра одеська* – 5,42 т/га. За більшою кількістю індексів (13), як найбільш посухостійкий, був виділений сорт *Ліра одеська*, сорти *Кошова* та *Зиск* виділилися за шістьома індексами, сорти *Кохана* та *Ледя* – за п'ятьма індексами. Урожайність при стресі мала високу позитивну кореляцію (r = 0,748–1,000) з індексами *YSI*, *YI*, *RDI*, *DI*, *M_2STI*, *HMP*, *ISR* та високу від'ємну кореляцію (r = -0,758) з індексом *SSI*. Натомість урожайність при зрошенні характеризувалася низькою (позитивною, або від'ємною) залежністю (r = -0,246–0,233) з індексами *SSI*, *YSI*, *RDI*, *DI*, *ISR* та середньою (r = 0,457–0,691) з індексами *YI*, *M_2STI*, *HMP*. Індекси *TOL* і *SSPI* характеризувалися середньою позитивною залежністю з врожайністю при зрошенні (r = 0,485) та середньою від'ємною (r = -0,556) – при стресі. **Висновки.** Виділено сім основних індексів: толерантності до посухи (*TOL*), сприйнятливості до стресу (*SSI*), стабільності урожаю (*YSI*), відносний індекс посухи (*RDI*), посухостійкості (*DI*), схильності до стресу (*SSPI*), стійкості до стресу (*ISR*) та три допоміжні індекси: урожайності (*YI*), другий модифікований індекс толерантності до стресу (*M_2STI*) та гармонійної продуктивності (*HMP*). За індексами посухостійкості та біплот-аналізом, як найбільш посухостійкі виділені сорти *Ліра одеська*, *Кохана*, *Зиск* та *Кошова*. Сорти *Марія*, *Нива одеська* та *Щедрість одеська* виділилися 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.G., Fundirat K.S., Tyshchenko O.D., Reznichenko N.D. Konovalov V.O., Borovyk V.O. Analysis of winter wheat varieties for drought resistance in the conditions of the Steppe of Ukraine (Part 2 – drought years)

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 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 productivity under irrigation was formed by winter wheat varieties *Maria* – 7.41 t/ha and *Shchedrist Odeska* – 7.53 t/ha. Under stressful conditions, the highest productivity was characterized by the varieties *Kokhana* – 5.24 t/ha, *Koshova* – 5.23 t/ha, *Zysk* – 5.25 t/ha and *Lyra Odeska* – 5.42 t/ha. The *Lyra Odeska* variety was singled out as the most drought-resistant according to the largest number of indices (13), the *Koshova* and *Zysk* varieties stood out according to six indices, and the *Kokhan*a and *Ledya* varieties – according to five indices. Yield under stress had a high positive correlation (r = 0.748–1.000) with the *YSI*, *YI*, *RDI*, *DI*, *M_2STI*, *HMP*, *ISR* indices and a high negative correlation (r = -0.758) with the SSI index. Instead, the productivity under irrigation was characterized by a low (positive or negative) dependence (r = -0.246–0.233) with the indices *SSI*, *YSI*, *RDI*, *DI*, *ISR* and medium (r = 0.457–0.691) with the indices *YI*, *M_2STI*, *HMP*. The *TOL* and *SSPI* indices were characterized by an average positive relationship with yield under irrigation (r = 0.485) and an average negative (r = -0.556) relationship with stress. **Conclusions.** Seven main indices were identified: drought tolerance (*TOL*), stress susceptibility (*SSI*), yield stability (*YSI*), relative drought index (*RDI*), drought resistance (*DI*), stress susceptibility (*SSPI*), stress resistance (*ISR*). and three auxiliary indices: yield (*YI*), second modified stress tolerance index (*M_2STI*) and harmonic productivity (*HMP*). According to drought resistance indices and biplot analysis, the most drought-resistant varieties of *Lyra Odeska*, *Kokhan*a, *Zysk* and *Koshova* were selected. Varieties *Maria*, *Nyva Odeska* and *Shchedrist Odeska* 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.