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DETERMINATION OF DROUGHT RESISTANCE OF SOYBEAN BREEDING MATERIAL

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2016 was established to have the optimal conditions for soybean cultivation, while 2018 with drought intensity (DI) of 0.81 – the most extreme conditions. Having evaluated soybean breeding accessions in the competitive variety trial (CVT) for the drought susceptibility index (DSI), drought tolerance index (DTI), mean yield (MY), yield stability index (YSI), yield index (YI), stress tolerance index (STI) and geometric mean yield (GMY), we selected drought-resistant soybean breeding material.

***Key words**: soybean, variety trial, hydrothermal conditions, drought resistance, yield, drought resistance indices, selection, breeding material.*

Introduction. Soybean is a leading crop in the global agriculture. It covers large areas and is an export-oriented crop in the agrarian sector of Ukraine. Frequent soil and air droughts in a significant territory in Ukraine are stressors for soybean plants, and insufficient resistance of genotypes negatively affects the crop's seed productivity [1–9]. Over the last decades of the 20th century, the annual air temperature in Ukraine started increasing on average 1.5 times faster than on a global scale, which in the coming years may enhance the negative impact on cultivation of agricultural crops, including soybeans [10].

Literature Review and Problem Articulation. Droughts are known to worsen prospects of harvesting good yields in soybean-growing areas [11, 12]. Soybean yields decrease from 3.5–4.0 t/ha under optimal moisture supply to 0.6–0.8 t/ha under dry conditions [13]. Drought regularity stipulates the urgency of solving the problem of boosting drought resistance of soybeans [14]. A short-term water deficit during anthesis, seed setting and ripening leads to bud, ovary and pod drop as well as to reduction in seed size and 48–87% decrease in yield [15]. In the USA, where the climate is more favorable for soybean growing, breeding for drought resistance is more important than further increasing the yield potential. Recently, in the USA, the soybean yields have been raised mainly due to increased drought resistance.

In breeding for adaptability, the mainstream is creation of mid-ripening, most high-yielding soybean varieties that are able to perform maximally under both favorable and arid weather conditions during the growing period. The current breeding of soybeans, which is focused on increasing resistance to extended ranges of climatic parameters, even now allows for development of varieties that would be suitable for profitable cultivation, both under further global warming and aridization and under probable global cooling [16]. Therefore, the main objective of breeders is to create varieties with high yield capacity and adaptability. At the same time, breeding for drought resistance is complicated by necessity to provide identical water stress conditions to analyse a large number of genotypes [17]. To increase the efficiency of breeding for drought resistance, it is recommended to use genetic methods [18] and to consider drought resistance as harvesting yields different genotypes under identical drought conditions [19]. High performance of a variety, which is determined by the entire genetic system of a plant, is an inextricable indicator of drought resistance [20].

There are direct and indirect signs to determine potential drought resistance of soybean varieties; such sings are based on expression levels of some anatomical, morphological,

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biological, physiological, and biochemical traits [14, 21–23]. For a more effective differentiation of genotypes by drought resistance, researchers suggested using different indices, which are determined by yield losses during droughts, compared to the optimal conditions for the growth and development of soybean plants. These indices are based on both resistance and susceptibility of genotypes to drought. They allow for significant simplification and acceleration of screening of breeding material and facilitation of selection of accessions with high resistance to drought. Researchers tested a model of adaptation of grain legumes to insufficient moisture; the model is based on a drought-induced decrease in yield and reflects a model of the crop's response to arid conditions [24–34].

Purpose and Objectives. To evaluate the resistance of soybean genotypes to drought by drought resistance indices calculated from yields in years with contrasting hydrometeorological conditions.

Materials and Methods. Varieties and breeding accessions of the competitive variety trial (CVT) of soybeans in 2008–2021 (60 - 153 accessions) were investigated to assess the influence of year's conditions on the mean yields of soybeans. Fifty breeding accessions and CVT soybean varieties of the Laboratory of Grain Legume Breeding were taken to assess drought resistance. The experiments were carried out in a breeding crop rotation of the PPI NAAS. The forecrop was winter rye. The experiments were conducted in plots of 25 m^2 in four replications in accordance with the qualification examination methods [35, 36]. The soybean breeding accessions and CVT varieties were differentiated by drought resistance indices calculated from the 2016 and 2018 yields.

Drought intensity (DI) was determined by the formula proposed by Fischer R.A. and Maurer R. [24]. Drought resistance of the soybean CVT varieties and breeding accessions was assessed by drought susceptibility index (DSI) [24], drought tolerance index (DTI) [32], mean yield (MY) [32], yield stability index (YSI) [14], yield index (YI) [34], stress tolerance index (STI) [33] and geometric mean yield (GMY) [33]. Data were processed in STATISTICA 10 and Excel, as B.O. Dospekhov recommended [37].

Results and Discussion. Analysis of long-term data (2008–2021) on the hydrothermal conditions at the study site (Elitne village, Kharkivskyi District, Kharkivska Oblast) showed that they were generally favorable for soybean growing. However, irregular precipitation, high temperatures and low relative humidity associated with dry spells during the growing period of the crop cause a clearly expressed aridity in some years, which negatively affects the growth and development of soybean plants.

The weather during the study had very contrasting hydrothermal parameters and had different effects on the growth and development of plants, leading to variations in the yields. The CVT data confirmed a possibility of fulfilling the crop's potential in the eastern Forest-Steppe of Ukraine and harvesting mean yields of 2.59 t/ha in favorable years.

Analysis of the CVT data showed that the mean, depending on the year's conditions, fluctuated significantly from 0.50 t/ha (2018) and 0.51 t/ha (2010) to 2.59 t/ha (2016), or >5-fold, with the mean yield for 2008–2021 of 1.19 t/ha. The mean yields from the CVT varieties across the study years exceeded or equaled the mean annual yields (1.19 t/ha) in 2009, 2011, 2013, 2014, 2015, 2016, and 2019. In 2008, 2010, 2012, 2017, 2018, 2020 and 2021, the yields were lower than the multi-year mean. So, out of the fourteen study years, seven years were favorable and the other seven – unfavorable. It is precisely because of unstable hydrothermal modes during the soybean growing period that such significant fluctuations in yields occur. However, the trend line shows a gradual increase in the CVT yields in the course of the crop breeding, regardless of environmental conditions (Fig. 1).

Comparison of the CVT soybean yields in 2016 (when the precipitation amount in April–September was 371.4 mm) and in 2018 (136.5 mm fell during the same period) demonstrated considerable yield losses because of drought. On average, the crop losses amounted to 2.07 t/ha, or 81%. Analysis of the minimum yields in the study sample in the years with contrasting weather showed a loss of 1.78 t/ha, or 84.8% of yield (Table 1).

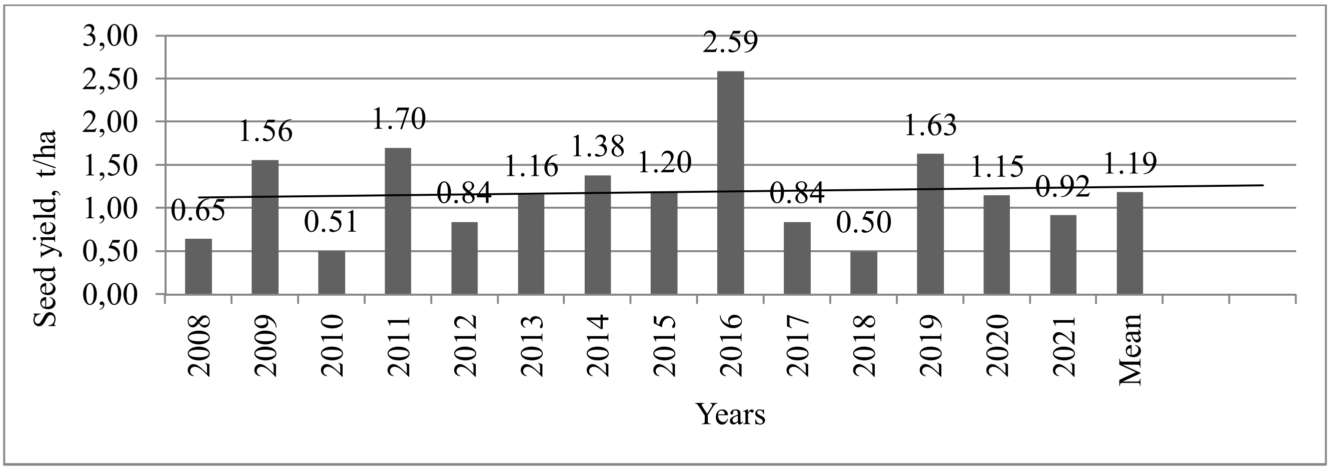

Fig.1. Mean soybean yields in the CVT

Table 1

Soybean yield losses, (competitive variety trial)

Yield, t/ha	Year		Yield loss	
	2016	2018	t/ha	%
Minimum	2.10	0.32	1.78	84.8
Mean	2.57	0.50	2.07	81.0
Maximum	2.90	0.71	2.19	75.5
$LSD_{0.05}$	0.31	0.08	0.22	–

Upon the maximum yield in the experimental sample, the loss was 2.19 t/ha, or 75.5%. Hence, under contrasting moisture conditions, the difference in the minimum yield was greater than the difference in the maximum yield.

Drought intensity (DI; calculated by R.A. Fischer and R. Maurer's formula [24]) in dry 2018 was 0.81, compared to soybean-friendly 2016.

From the yield values, several indices, which characterize the resistance of accessions to drought, were calculated and analyzed (Table 2).

Table 2

Drought resistance indices in the soybean accessions (competitive variety trial), 2016 and 2018.

Value	Index						
	DSI[1]	DTI[2]	MY[3]	YSI[4]	YI[5]	STI[6]	GMY[7]
Minimum	0.87	1.61	2.34	0.12	64.6	1.54	0.92
Maximum	1.09	2.41	3.15	0.30	143.3	7.60	1.38
Mean	1.00	2.11	2.85	0.19	98.9	3.62	1.11

Note: drought susceptibility index (DSI)[1], drought tolerance index (DTI)[2], mean yield (MY)[3], yield stability index (YSI)[4], yield index (YI)[5], stress tolerance index (STI)[6], and geometric mean yield (GMY)[7].

These indices made it possible to differentiate the accessions by drought resistance. The drought susceptibility index (DSI) characterizes the susceptibility of a genotype to drought [24], that is, the lower this index is, the more drought-resistant the accession is. The drought susceptibility index in the studied sample ranged 0.87 to 1.09, with the mean of 1.00.

By the minimum value of this index, the following drought-resistant breeding accessions were selected: KSV 23-18 (3836 / 76-130 selection) (DSI = 0.87), KSV 16-18 (Volgohradka / Mriia) (DSI = 0.91), KSV 50 -18 (Pasteter Schwarus) (DSI = 0.93), KSV 22-18 (selection #14) (DSI = 0.94), KSV 37-18 (Uspikh / Mriia) (DSI = 0.94) (Table 3).

Table 3

DSI-based differentiation of the soybean accessions by drought resistance

Breeding accession/variety	Drought susceptibility index (DSI)	Yield, t/ha		Yield loss	
		2016	2018	t/ha	%
High drought resistance					
KSV 23-18 (3836 / 76-130 selection)	0.87	2.29	0.68	1.61	70.3
KSV 16-18 (Volgohradka / Mriia)	0.91	2.69	0.71	1.98	73.6
KSV 50-18 (Pasteter Schwarus)	0.93	2.47	0.61	1.86	75.3
KSV 22-18 (selection #14)	0.94	2.35	0.56	1.79	76.2
KSV 37-18 (Uspikh / Mriia)	0.94	2.53	0.60	1.93	76.3
Low drought resistance					
KSV 18-18 (Kharkivska 35 / Fiskeby)	1.06	2.69	0.38	2.31	85.9
Estafeta	1.06	2.71	0.38	2.33	86.0
KSV 43-18 (Vitiaz 50 / Mriia)	1.07	2.69	0.36	2.33	86.6
Baika	1.08	2.59	0.33	2.26	87.3
Sprytna	1.09	2.70	0.32	2.38	88.1

The lowest drought resistance according to this index was recorded for KSV 18-18 (Kharkivska 35 / Fiskeby) (DSI = 1.06), Estafeta variety (DSI = 1.06), KSV 43-18 (Vitiaz 50 / Mriia) (DSI = 1.07), Baika (DSI = 1.08), and Sprytna variety (DSI = 1.09).

In the highly drought-resistant group, the yield losses because of drought were 1.61–1.98 t/ha, or 70.3–76.3% of yield. The accessions with low drought resistance lost 2.26–2.38 t/ha, or 85.9–88.1% of yield.

The drought tolerance index (DTI) [32] determines the absolute (t/ha) losses of the crop: the lower the index is, the more drought-resistant the accession is. This parameter varied from 1.61 to 2.41, with the mean of 2.11 (see Table 2). Breeding accessions KSV 23-18 (3836 / 76-130 selection) (DTI = 1.61), KSV 28-18 (4305-04) (DTI = 1.62), Roksolana variety (DTI = 1.74), KSV 29-18 (Vuzkolysta / mutant 82-205) (DTI = 1.77), KSV 22-18 (selection #14) (DTI = 1.79) (Table 4).

Table 4

DTI-based differentiation of the soybean accessions by drought resistance

Breeding accession/variety	Drought tolerance index (DTI)	Yield, t/ha		Yield loss	
		2016	2018	t/ha	%
High drought resistance					
KSV 23-18 (3836 / 76-130 selection)	1.61	2.29	0.68	1.61	70.3
KSV 28-18 (4305-04)	1.62	2.10	0.48	1.62	77.1
Roksolana	1.74	2.20	0.46	1.74	79.1
KSV 29-18 (Vuzkolysta / mutant 82-205)	1.77	2.31	0.54	1.77	76.6
KSV 22-18 (selection #14)	1.79	2.35	0.56	1.79	76.2
Low drought resistance					
KSV 18-18 (Kharkivska 35 / Fiskeby)	2.31	2.69	0.38	2.31	85.9
Estafeta	2.33	2.71	0.38	2.33	86.0
KSV 43-18 (Vitiaz 50 / Mriia)	2.33	2.69	0.36	2.33	86.6
Sprytna	2.38	2.70	0.32	2.38	88.1
KSV 17-18 (Kharkivska 35 / 856-334)	2.41	2.90	0.49	2.41	83.1

The greatest yield losses were observed in KSV 18-18 (Kharkivska 35 / Fiskeby) (DTI = 2.31), Estafeta (DTI = 2.33), KSV 43-18 (Vityaz 50 / Mriya) (DTI = 2.33), Sprytna (DTI = 2.38), and KSV 17-18 (Kharkivska 35 / 856-334) (DTI = 2.41). That is, the absolute yield losses in the highly drought-resistant group assessed by the drought tolerance index ranged 1.61 to 1.79 t/ha, and the relative yield losses in this group were within the range of 70.3–79.1%. In the accessions with low drought resistance, the absolute yield losses were 2.31–2.41 t/ha, or 83.1–88.1% related to the yields under optimal conditions.

The mean yield (MY) [32] in the years with contrasting water modes shows the genotype's potential yield in absolute units (t/ha) regardless of weather conditions. The accessions of the studied sample yielded on average 2.34–3.15 t/ha, with the mean of 2.85 t/ha (see Table 2).

The greatest mean yield in the years with contrasting water modes was recorded for KSV 17-18 (Kharkivska 35 / 856-344) (MY = 3.15), KSV 24-18 (Kharkivska 62 / Khodson) (MY = 3.13) , KSV 49-18 (Kharkivska 56 / Ilsoy) (MY = 3.09), KSV 40-18 (Kharkivska 54 / Khodson) (MY = 3.05), and KSV 16-18 (Volgohradka / Mriia) (MY = 3.05). In this group, the losses of yield under arid conditions were 1.62–1.90 t/ha, or 73.6–83.1%, compared to the optimum.

The lowest MY values were observed in KSV 29-18 (Vuzkolysta / mutant 82-205) (MY = 2.58), Podiaka variety (MY = 2.51), KSV 20-18 (Kharkivska 35 / Kyivska 27) (MY = 2.46), Roksolana variety (MY = 2.43), and KSV 28-18 (4305-04) (MY = 2.34) (Table 5).

Table 5

Differentiation of the soybean accessions by mean yield (MY)

Breeding accession/variety	Mean yield (MY), t/ha	Yield, t/ha		Yield loss	
		2016	2018	t/ha	%
High drought resistance (assessed by yield)					
KSV 17-18 (Kharkivska 35 / 856-344)	3.15	2.90	0.49	2.41	83.1
KSV 24-18 (Kharkivska 62 / Khodson)	3.13	2.81	0.64	2.17	77.2
KSV 49-18 (Kharkivska 56 / Ilsoy)	3.09	2.76	0.65	2.11	76.4
KSV 40-18 (Kharkivska 54 / Khodson)	3.05	2.79	0.51	2.28	81.7
KSV 16-18 (Volgohradka / Mriia)	3.05	2.69	0.71	1.98	73.6
Low drought resistance (assessed by yield)					
KSV 29-18 (Vuzkolysta / mutant 82-205)	2.58	2.31	0.54	1.77	76.6
Podiaka	2.51	2.29	0.43	1.86	81.2
KSV 20-18 (Kharkivska 35 / Kyivska 27)	2.46	2.27	0.37	1.90	83.7
Roksolana	2.43	2.20	0.46	1.74	79.1
KSV 28-18 (4305-04)	2.34	2.10	0.48	1.62	77.1

In this group, the yield losses under arid conditions were 1.98–2.41 t/ha, or 76.6–83.7%, compared to the optimal conditions. Hence, despite the fact that the accessions in groups with contrasting drought resistance yielded differently, their relative losses from drought were similar.

The yield stability index (YSI) shows the ratio of yield under stressful conditions to yield under optimal conditions [14], i.e. as this index rises, drought resistance increases. In the studied sample, this parameter varied within 0.12–0.30 with the mean of 0.19 (see Table 2). Accessions with high and low values of the yield stability index (YSI) were selected (Table 6).

The most drought-resistant according to this index were KSV 23-18 (3836 / 76-130 selection) (YSI = 0.30), KSV 16-18 (Volgogradka / Mriia) (YSI = 0.26), KSV 50-18 (Pasteter Schwarus selection) (YSI = 0.25), KSV 22-18 (selection #14) (YSI = 0.24), and KSV 37-18 (Uspikh / Mriia) (YSI = 0.24).

Low values of the yield stability index, and therefore the lowest drought resistance, were recorded for KSV 18-18 (Kharkivska 35 / Fiskeby) (YSI = 0.14), Estafeta (YSI = 0.14), KSV 43-18 (Vitiaz 50 / Mriia) (YSI = 0.13), Baika (YSI = 0.13), and Sprytna (YSI = 0.12).

In the highly drought-resistant accessions according to the yield stability index (YSI), the absolute yield losses ranged 1.61 t/ha to 1.98 t/ha, or 70.3–76.3% in relative units. The accessions with low drought resistance lost 2.26–2.38 t/ha, or 85.0–88.1%.

Table 6

YSI-based differentiation of the soybean accessions by drought resistance

Breeding accession/variety	Yield stability index (YSI)	Yield, t/ha		Yield loss	
		2016	2018	t/ha	%
High drought resistance					
KSV 23-18 (3836 / 76-130 selection)	0.30	2.29	0.68	1.61	70.3
KSV 16-18 (Volgohradka / Mriia)	0.26	2.69	0.71	1.98	73.6
KSV 50-18 (selection from Pasteter Schwarus)	0.25	2.47	0.61	1.86	75.3
KSV 22-18 (selection #14)	0.24	2.35	0.56	1.79	76.2
KSV 37-18 (Uspikh / Mriia)	0.24	2.53	0.6	1.93	76.3
Low drought resistance					
KSV 18-18 (Kharkivska 35 / Fiskeby)	0.14	2.69	0.38	2.31	85.9
Estafeta	0.14	2.71	0.38	2.33	86.0
KSV 43-18 (Vitiaz 50 / Mriia)	0.13	2.69	0.36	2.33	86.6
Baika	0.13	2.59	0.33	2.26	87.3
Sprytna	0.12	2.7	0.32	2.38	88.1

The yield index (YI) under stressful conditions is calculated as the ratio of yield under the influence of a stressor to the mean yield across the studied accessions under the same conditions [34]. It characterizes the yield of a specific accessions in relation to the mean yield across all accessions tested during the dry period and is expressed in percents. In the experimental sample, this index ranged 64.6% to 143.3%, with the mean of 98.9% (see Table 2). Differentiation of the accessions according to this index is presented in Table 7.

Table 7

YI-based differentiation of the soybean accessions by drought resistance

Breeding accession/variety	Yield index (YI)	Yield, t/ha		Yield loss	
		2016	2018	t/ha	%
High drought resistance					
KSV 16-18 (Volgogradka / Mriia)	143.3	2.69	0.71	1.98	73.6
KSV 23-18 (3836 / 76-130 selection)	137.2	2.29	0.68	1.61	70.3
KCB 49-18 (Kharkivska 56 / Ilsoy)	131.2	2.76	0.65	2.11	76.4
KCB 36-18 (Kharkivska Zernokormova / Yuh 30)	129.1	2.71	0.64	2.07	76.4
KCB 24-18 (Kharkivska 62 / Khodson)	129.1	2.81	0.64	2.17	77.2
Low drought resistance					
KCB 18-18 (Kharkivska 35 / Fiskeby)	76.7	2.69	0.38	2.31	85.9
KCB 20-18 (Kharkivska 35 / Kyivska 27)	74.7	2.27	0.37	1.90	83.7
KSV 43-18 (Vitiaz 50 / Mriia)	72.6	2.69	0.36	2.33	86.6
Baika	66.6	2.59	0.33	2.26	87.3
Sprytna	64.6	2.70	0.32	2.38	88.1

The highest drought resistance assessed by yield under stressful conditions was intrinsic to KSV 16-18 (Volgohradka / Mriia (YI = 143.3%), KSV 23-18 (3836 / 76-130 selection) (YI = 137.2%), KSV 49-18 (Kharkivska 56 / Ilsoy (YI = 131.2 %), KSV 36-18 (Kharkivska Zernokormova / Yuh 30) (YI = 129.1 %), and KSV 24-18 (Kharkivska 62 / Khodson) (YI = 129.1%). The stress-caused losses of yield in the drought-resistant group ranged 1.61 t/ha to 2.17 t/ha, or 70.6–77.2%.

The lowest yield under dry conditions was harvested from KSV 18-18 (Kharkivska 35 / Fiskeby) (YI = 76.7%), KSV 20-18 (Kharkivska 35 / Kyivska 27) (YI = 74.7%), KSV 43-18 (Vitiaz 50 / Mriia) (YI = 72.6%), Baika (YI = 66.6%), and Sprytna (YI = 64.6%)s. The yield losses this group were 1.90–2.38 t/ha, or 83.7–88.1%.

The stress tolerance index (STI) is based on identifying genotypes that give high yields under both stressful and optimal conditions [33]. It shows the ability of an accession to consistently yield a lot, regardless of stress factors. The higher this index is, the more drought-resistant the genotype is. This index ranged 1.54 to 7.60, with the mean of 3.62 (see Table 2). Judging by this index, KSV 16-18 (Volgohradka / Mriia) (STI = 7.60), KSV 23-18 (3836 / 76-130 selection) (STI = 6.97), KSV 49- 18 (Kharkivska 56 / Ilsoy) (STI = 6.37), KSV 36-18 (Kharkivska Zernokormova / Yuh 30) (STI = 6.18), and KSV 24-18 (Kharkivska 62 / Khodson) (STI = 6.18) (Table 8) were the most drought-resistant.

Table 8

STI-based differentiation of the soybean accessions by drought resistance

Breeding accession/variety	Stress tolerance index (STI)	Yield, t/ha		Yield loss	
		2016	2018	t/ha	%
High drought resistance					
KSV 16-18 (Volgohradka / Mriia)	7.60	2.69	0.71	1.98	73.6
KSV 23-18 (3836 / 76-130 selection)	6.97	2.29	0.68	1.61	70.3
KSV 49-18 (Kharkivska 56 / Ilsoy)	6.37	2.76	0.65	2.11	76.4
KSV 36-18 (Kharkivska Zernokormova / Yuh 30)	6.18	2.71	0.64	2.07	76.4
KSV 24-18 (Kharkivska 62 / Khodson)	6.18	2.81	0.64	2.17	77.2
Low drought resistance					
KSV 18-18 (Kharkivska 35 / Fiskeby)	2.18	2.69	0.38	2.31	85.9
KSV 20-18 (Kharkivska 35 / Kyivska 27)	2.06	2.27	0.37	1.90	83.7
KSV 43-18 (Vitiaz 50 / Mriia)	1.95	2.69	0.36	2.33	86.6
Baika	1.64	2.59	0.33	2.26	87.3
Sprytna	1.54	2.70	0.32	2.38	88.1

The highly drought-resistant accessions lost 1.61–2.17 t/ha, or 70.3–77.2% of their yields.

The lowest STI values were characteristic of KSV 18-18 (Kharkivska 35 / Fiskeby) (STI = 2.18), KSV 20-18 (Kharkivska 35 / Kyivska 27) (STI = 2.06), KSV 43-18 (Vitiaz 50 / Mriia) (STI = 1.95), Baika (STI = 1.64), and Sprytna (STI = 1.54). These accessions lost 1.90–2.38 t/ha, or 83.7–88.1% of their yields under optimal conditions.

The geometric mean (or mean proportional) yield (GMY) [33] of the studied accessions ranged 0.92 t/ha to 1.38 t/ha, with the median of 1.11 t/ha.

The genotypes with high values of this parameter included KSV 16-18 (Volgohradka / Mriia) (GMY = 1.38 t/ha), KSV 24-18 (Kharkivska 62 / Khodson) (GMY = 1.34 t/ha) , KSV 49-18 (Kharkivska 56 / Ilsoy) (GMY = 1.34 t/ha), KSV 36-18 (Kharkivska Zernokormova / Yuh 30) (GMY = 1.32 t/ha), and KSV 23-18 (3836 / 76-130 selection) (GMY = 1.25 t/ha).

According to GMY-based differentiation of the accessions under investigation, the yield losses in the highly drought-resistant group were 1.61–2.17 t/ha, or 70.3–77.2% of yield (Table 9, see Table 2).

Podiaka (GMY = 0.99 t/ha), KSV 43-18 (Vitiaz 50 / Mriia) (GMY = 0.98 t/ha), Sprytna (GMY = 0.93 t/ha), Baika (GMY = 0.92 t/ha), and KSV 20-18 (Kharkivska 35 / Kyivska 27) (GMY = 0.92 t/ha) showed low drought resistance. In the accessions with low resistance to drought, the yield losses ranged 81.2% to 88.1%, or 1.86 t/ha to 2.38 t/ha.

Table 9

GMY-based differentiation of the soybean accessions by drought resistance

Breeding accession/variety	Geometric mean yield (GMY), t/ha	Yield, t/ha		Yield loss	
		2016	2018	t/ha	%
High drought resistance					
KSV 16-18 (Volgohradka / Mriia)	1.38	2.69	0.71	1.98	73.6
KSV 24-18 (Kharkivska 62 / Khodson)	1.34	2.81	0.64	2.17	77.2
KSV 49-18 (Kharkivska 56 / Ilsoy)	1.34	2.76	0.65	2.11	76.4
KSV 36-18 (Kharkivska Zernokormova / Yuh 30)	1.32	2.71	0.64	2.07	76.4
KSV 23-18 (3836 / 76-130 selection)	1.25	2.29	0.68	1.61	70.3
Low drought resistance					
Podiaka	0.99	2.29	0.43	1.86	81.2
KSV 43-18 (Vitiaz 50 / Mriia)	0.98	2.69	0.36	2.33	86.6
Sprytna	0.93	2.70	0.32	2.38	88.1
Baika	0.92	2.59	0.33	2.26	87.3
KSV 20-18 (Kharkivska 35 / Kyivska 27)	0.92	2.27	0.37	1.90	83.7

Thus, we differentiated the breeding material of soybeans by drought resistance indices. Accessions that significantly exceeded the mean values of several indices were classed as drought-resistant. According to most indices (DSI, DTI, YSI, YI, STI, and GMY), KSV 23-18 (3836) / 76-130 selection) stood out. According to five indices (DSI, YSI, YI, STI, and GMY), KSV 16-18 (Volgohradka / Mriia) stood out. KSV 49-18 (Kharkivska 56 / Ilsoy) stood out according to four indices (MY, YI, STI, and GMY). Three accessions were considered as drought-resistant by three indices: KSV 22-18 (selection #14) (DSI, DTI and YSI), KSV 36-18 (Kharkivska Zernokormova / Yuh 30) and KSV 24-18 (Kharkivska 62 / Khodson) (YI, STI and GMY). KSV 28-18 (4305-04) was distinguished due to DTI and MY. 29-18 (Vuzkolysta / mutant 82-205) stood out due to DTI and MY. KSV 50-18 (selection from Pasteter Schwarus) and KSV 37-18 (Uspikh / Mriia) were distinguished by DSI and YSI. Due to MY, KSV 20-18 (Kharkivska 35 / Kyivska 27) and Podiaka stood out. Roksolana stood out according to DTI.

The soybean accessions with high resistance to abiotic stress, which were selected as a result of differentiation by indices, are recommended as starting material in the crop breeding for high resistance to drought.

Conclusions. Evaluation of the soybean CVT breeding accessions and varieties by drought resistance indices allowed for differentiation of them by stress resistance. According to most indices (DSI, DTI, YSI, YI, STI, and GMY), KSV 23-18 (3836) / 76-130 selection) stood out. According to five indices (DSI, YSI, YI, STI, and GMY), KSV 16-18 (Volgohradka / Mriia) stood out. KSV 49-18 (Kharkivska 56 / Ilsoy) stood out according to four indices (MY, YI, STI, and GMY). Three accessions were considered as drought-resistant by three indices: KSV 22-18 (selection #14) (DSI, DTI and YSI), KSV 36-18 (Kharkivska Zernokormova / Yuh 30) and KSV 24-18 (Kharkivska 62 / Khodson) (YI, STI and GMY). KSV 28-18 (4305-04) was distinguished due to DTI and MY. 29-18 (Vuzkolysta / mutant 82-205) stood out due to DTI and MY. KSV 50-18 (selection from Pasteter Schwarus) and KSV 37-18 (Uspikh / Mriia) were distinguished by DSI and YSI. Due to MY, KSV 20-18 (Kharkivska 35 / Kyivska 27) and Podiaka stood out. Roksolana stood out according to DTI. The selected soybean genotypes with high resistance to abiotic stress are recommended as starting material in the crop breeding for high resistance to drought.

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ВИЗНАЧЕННЯ ПОСУХОСТІЙКОСТІ СЕЛЕКЦІЙНОГО МАТЕРІАЛУ СОЇ

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Мета і задачі дослідження. Визначити стійкість генотипів сої до посухи за індексами посухостійкості на основі аналізу врожайності у контрастні за гідрометеорологічними умовами роки.

Матеріали і методи дослідження. Матеріалом для визначення впливу умов року на рівень середньої врожайності сої та посухостійкості були сорти та селекційні номери конкурсного сортовипробування (КСВ). Досліди закладались у чотирьох повтореннях із обліковою площею ділянки 25 м^2. Інтенсивність посухи (D) визначали за формулою запропонованою Fischer R.A. та Maurer R. Диференціацію селекційних номерів та сортів КСВ сої здійснювали за врожайністю у 2016 р. та 2018 р. за індексами сприйнятливості до посухи (DSI), толерантності до посухи (TOL), середньої врожайності (MP), стабільності врожаю (YSI), врожайності (YI), толерантності до стресу (STI), середнього геометричного врожайності (GMP). Обробку результатів досліджень проводили за Б.О. Доспеховим із використанням програм STATISTICA 10 та Excel.

Обговорення результатів. За час проведення досліджень (2008–2021 рр.) найвищу врожайність сої у КСВ було отримано у 2016 р. – 2,57 т/га, а найнижчу у 2018 р. – 0,50 т/га. Порівняння врожайності сої у КСВ у 2016 р. та 2018 р. показало, що втрати від посухи середньої врожайності становили 2,07 т/га, або 81 %. У мінімальної врожайності втрати дорівнювали 1,78 т/га, або 84,8 %. У максимальної – 2,19 т/га, або 75,5 %. Отже, різниця мінімальної врожайності була більше, ніж різниця максимальної врожайності. Рівень інтенсивності посухи (D) у посушливому 2018 р. дорівнював D = 0,81. За показниками врожайності проведено розрахунок та аналіз ряду індексів, які характеризують стійкість зразків до посухи. Значення індексу сприйнятливості до посухи (DSI) у знаходилось у межах від 0,87 до 1,09, при середньому значенні 1,00. Індекс толерантності до посухи (TOL) дорівнював 1,61–2,41 при середньому значенні 2,11. Середня врожайність (MP) знаходилась у межах 2,34–3,15 т/га і мала середнє значення на рівні 2,85 т/га. Значення індексу стабільності врожаю (YSI) варіювало від 0,12 до 0,30 при середньому значенні 0,19. Індекс урожайності у стресових умовах (YI) дорівнював 64,6–143,3 %, при середньому значенні 98,9 %. Індекс урожайності у стресових умовах (YI) коливався від 64,6 % до 143,3 %, при середньому значенні 98,9 %. Середнє геометричне (або середнє пропорційне) врожайності (GMP) досліджуваних зразків знаходилось у межах від 0,92 т/га до 1,38 т/га, при значенні медіани 1,11 т/га. За кожним індексом проведено диференціацію зразків досліджуваних зразків сої і виділено посухостійкий селекційний матеріал.

Висновки. За більшістю індексів: сприйнятливості до стресу (DSI), толерантності до посухи (TOL), стабільності врожаю (YSI), урожайності (YI), толерантності до стресу (STI) та середнім геометричним урожайності (GMP) виділився номер КСВ 23-18 (3836 / 76-130 добір). За п'ятьма індексами: сприйнятливості до стресу (DSI), стабільності врожаю (YSI), урожайності (YI), толерантності до стресу (STI) та середнім геометричним урожайності (GMP) вирізнявся номер КСВ 16-18 (Волгоградка / Мрія). За показниками чотирьох індексів: середньої врожайності (MP), урожайності (YI), толерантності до стресу (STI) та середного геометричного урожайності (GMP) виділився номер КСВ 49-18 (Харківська 56 / Ilsoy). За трьома індексами ідентифіковані як посухостійкі три номери: КСВ 22-18 (добір №14) – за індексами сприйнятливості до стресу (DSI), толерантності до посухи (TOL) та стабільності врожаю (YSI); номери КСВ 36-18 (Харківська зернокормова / Юг 30) та КСВ 24-18 (Харківська 62 / Ходсон) – за індексами урожайності (YI), толерантності до стресу (STI) та середнім геометричним урожайності (GMP). Селекційний номер КСВ 28-18 (4305-04) виділився за індексом толерантності до стресу (TOL) та рівнем середньої врожайності (MP). За індексом толерантності до стресу (TOL) та рівнем середньої врожайності (MP) виділився номер 29-18 (Вузьколиста / мутант 82-205). Номери КСВ 50-18 (добір з Pasteter Schwarus) та КСВ 37-18 (Успіх / Мрія) вирізнились за індексами сприйнятливості до стресу (DSI) та стабільності врожаю (YSI). За рівнем середньої врожайності (MP) виділився номер КСВ 20-18 (Харківська 35 / Київська 27) та сорт Подяка. Сорт Роксолана виділився за індексом толерантності до стресу (TOL). Виділені генотипи сої з високим рівнем стійкості до абіотичного стресу рекомендуються для використання у селекції культури на високу посухостійкість.

Ключові слова: *соя, сортовипробування, гідротермічні умови, посухостійкість, врожайність, індекси посухостійкості, добір, селекційний матеріал.*

DETERMINATION OF DROUGHT RESISTANCE OF SOYBEAN BREEDING MATERIAL

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The purpose and objectives of the study. To determine the resistance of soybean genotypes to drought according to drought resistance indices based on the analysis of yield in years contrasting in terms of hydrometeorological conditions.

Materials and research methods. The material for determining the influence of year conditions on the level of average yield of soybeans and drought resistance were varieties and breeding numbers of the competitive variety test (CVT). Experiments were carried out in four repetitions with a plot area of 25 m2. Drought intensity (D) was determined by the formula proposed by Fischer R.A. and Maurer R. Differentiation of breeding numbers and varieties of CVT soybeans was carried out according to yield in 2016 and 2018 according to indices of drought susceptibility (DSI), drought tolerance (TOL), average yield (MP), yield stability (YSI), yield (YI), stress tolerance (STI), geometric mean yield (GMP). Processing of research results was carried out according to B.O. Dospehov [27] using STATISTICA 10 and Excel programs.

The discussion of the results. During the research period (2008–2021), the highest yield of soybeans in CVT was obtained in 2016 – 2.57 t/ha, and the lowest in 2018 – 0.50 t/ha. A comparison of soybean yield in CVT in 2016 and 2018 showed that the average yield loss due to drought was 2.07 t/ha, or 81%. At the minimum yield, losses were equal to 1.78 t/ha, or 84.8%. At the maximum – 2.19 t/ha and 75.5%, respectively. Therefore, the minimum yield difference was greater than the maximum yield difference. The level of drought intensity (D) in the dry year of 2018 was equal to 0.81. According to yield indicators, a number of indices were calculated and analyzed, which characterize the resistance of samples to drought. The value of the drought susceptibility index (DSI) ranged from 0.87 to 1.09, with an average value of 1.00. The drought tolerance index (TOL) was 1.61–2.41 with an average value of 2.11. The average yield (MP) was in the range of 2.34–3.15 t/ha and had an average value of 2.85 t/ha. The yield stability index (YSI) value varied from 0.12 to 0.30 with an average value of 0.19. The yield index under stress conditions (YI) was 64.6–143.3%, with an average value of 98.9%. The stress yield index (YI) ranged from 64.6% to 143.3%, with an average value of 98.9%. The geometric mean (or proportional mean) yield (GMP) of the studied samples ranged from 0.92 t/ha to 1.38 t/ha, with a median value of 1.11 t/ha. According to each index, the researched soybean samples were differentiated and drought-resistant breeding material was selected.

Conclusions. According to most indices: stress susceptibility (DSI), drought tolerance (TOL), crop stability (YSI), productivity (YI), stress tolerance (STI) and geometric mean yield (GMP) number CVT 23-18 (3836 / 76-130 selection). According to five indices: stress susceptibility (DSI), yield stability (YSI), yield (YI), stress tolerance (STI) and geometric mean yield (GMP) number CVT 16-18 (Volgohradka / Mriya) stood out. Number CVT 49-18 (Kharkivska 56 / Ilsoy) stood out according to the indicators of four indices: average yield (MR), yield (YI), stress tolerance (STI) and geometric mean yield (GMP). According to three indices, it is identified as drought-resistant number CVT 22-18 (selection №14) – according to indices of stress susceptibility (DSI), drought tolerance (TOL) and yield stability (YSI); numbers CVT 36-18 (Kharkivska zernokormova / Yug 30) and CVT 24-18 (Kharkivska 62 / Hodson) – according to indices of yield (YI), stress tolerance (STI) and geometric mean yield (GMP). Selection number CVT 28-18 (4305-04) stood out according to stress tolerance index (TOL) and average yield level (MR). Number 29-18 (Narrow-leaved / mutant 82-205) stood out according to the stress tolerance index (TOL) and the level of average yield (MR). Numbers CVT 50-18 (selection from Pasteter Schwarus) and CVT 37-18 (Success / Dream) were distinguished by indices of susceptibility to stress (DSI) and yield stability (YSI). According to the level of average yield (MR), number CVT 20-18 (Kharkivska 35 / Kyivska 27) and Podyaka variety stood out. The Roksolana variety stood out according to the stress tolerance index (TOL). Selected genotypes of soybeans with a high level of resistance to abiotic stress are recommended for use in crop breeding for high drought resistance.

***Key words**: soybean, variety trial, hydrothermal conditions, drought resistance, yield, drought resistance indices, selection, breeding material.*