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Influence of Abiotic Stresses on Morphophysiological Characteristics and Biological Value of Grain *Sorghum bicolor* (L.) Moench

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Abstract: Sorghum is the agricultural crop most adaptable to the effects of abiotic factors, able to tolerate prolonged soil and air droughts, changes in air temperature, insufficient precipitation, salinization, acidification of soils, and many others with the least loss of yield compared to traditional crops such as wheat and barley. However, even among sorghum genotypes, there are samples with varying degrees of resistance to stressors, for example, drought. The aim of this study is a comprehensive study of the influence of abiotic factors on the physiological characteristics and biochemical parameters of sorghum grain. The experiment was carried out on the experimental field and laboratory conditions of the Rossorgo Institute. Drought resistance of plants is determined in the initial phase of development and during the flowering period by the degree of seed swelling in hypertonic solutions and the water regime of the leaves (total water content, water deficiency, moisture loss, and water-holding capacity). The quality of the grain is determined using the spectrophotometry method for the main biochemical components, and likewise, the separation of the protein into fractions. The growing conditions of plants in 2021–2022 differ significantly in terms of hydrothermal indicators. As a result of the conducted research for use in breeding programs for the creation of new varieties and hybrids with increased stress resistance selected samples L-65/14, Magistr has high drought resistance in the degree of seed swelling in hypertonic solutions (55.2–58.9%), which turned out to be at the level of the control variant (61.6–63.7%), and indicators of the water regime of the leaves (total water content of leaf tissues—74.20–77.83%; water-retaining capacity—83.77–85.56%; low moisture loss for 1 h/day—2.86–3.01%). These samples were characterized by the biological value determined by the optimal ratio of major indicators of grain and protein fractions: albumin (16.59–22.75%), globulin (8.13–9.09%), glutelin (9.09–14.01%), and prolamin (5.79–11.50%).

Keywords: drought; sorghum; seed swelling; tissue water content; water deficiency of leaves; productivity; protein; albumin; globulin

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1. Introduction

Currently, most crops during the growing season experience the impact of abiotic factors. Increasing temperatures and altering precipitation patterns change crop water requirements, lowering crop potential and production while raising the cost of water availability throughout the agricultural landscape. Drought is one of the main factors causing significant yield loss among abiotic stresses [1,2]. Taking into account global changes in climatic conditions, it is necessary to pay more attention to insurance drought-resistant and plastic crops [3]. Grain sorghum designates not only a high yield of biomass and grain but also a wide adaptation to soil and climatic conditions [4,5]. This crop serves as a source of diet for human beings and animals, and fresh substance for industrial manufacture [6].

It is known that the initial grain quality has a significant impact on the structure and organoleptic properties of the finished products. Many scientists have studied the possibility of using sorghum flour in bread baking [7], in the mixture of wheat-flour crackers, and fermented pancakes [8]. Sorghum can also serve as a raw material for the starch industry [9].

Sorghum contains dietary fiber in the form of resistant starch and has a low glycemic index compared with white rice. Some studies showed that the effect of eating sorghum can reduce blood glucose. Sorghum has the potential as an alternative staple food to achieve a better glycemic response in diabetic patients [10]. The work of Ali Khoddami et al. describes the potential of sorghum in new food products, including sorghum grain composition, the functional properties of sorghum in foods, processing of sorghum-based products, the digestibility of sorghum protein and starch compared to other grains, and the health benefits of sorghum. Regarding the potential for sorghum as a major ingredient in new foods, they suggest that the gluten-free status of sorghum is of relatively minor importance compared to the functionality of the slowly digested starch and the health benefits of the phenolic compounds present [11].

The development of stress-resistant (especially to drought) hybrids and varieties of sorghum crops is of particular importance for agricultural science with the subsequent introduction into production. The literature marks the effect of how drought affects the morphological, physiological, and biochemical processes in agricultural plants [12]. Moreover, the yield depends on the intensity of the drought, its duration, and the stage of crop development [13]. Thus, for sorghum, the onset of drought in the initial period of plant development leads to a decrease in growth and development rates, and during flowering, it contributes to a partial or complete loss of grain yield [1,14]. It is also mentioned that there is a decrease in some physiological parameters in sorghum (pigment content in leaves, osmotic potential, and photosynthesis) and biochemical components in grain (protein and starch content) due to drought [15–17]. Therefore, the inclusion of samples with a more adaptive response to drought in the initial material is a priority in breeding for increasing drought resistance. However, the creation of new stress-resistant varieties or hybrids of sorghum with the necessary agronomic, physiological, and biochemical parameters requires additional research. In this regard, the study of the complex of these traits on grain sorghum is relevant. Thus, the purpose of this study was to evaluate the source material for the creation of varieties or hybrids of sorghum with increased biological value under conditions of abiotic stress.

2. Materials and Methods

2.1. Objects of Study

Five genotypes of *Sorghum bicolor* (L.) Moench of medium height were selected as objects of research: 3 varieties (RSK Kakholong, RSK Korall, Magistr) and 2 lines of grain sorghum (L-65/14, L-50/14) bred by Research Institute "Rossorgo" are subjects of research. The Magister variety and the lines L-65/14 and L-50/14 of grain sorghum are characterized as medium-early (the growing season is up to 110 days). The varieties RSK Kakholong and RSK Korall are medium-ripened: the growing season is 110–121 days.

2.2. Field Studies

The soil of the experimental site is represented by southern chernozem, medium-loamy in texture. The humus content is 3.5%, and the exchange capacity is 17–31 mg/eq. per 100 g of soil. Nitrification ability—7.7 mg/kg; phosphorus—34.2–35.7 mg/kg, potassium (in a carbon ammonium extract)—349–378 mg/kg. The acidity of the soil solution is close to neutral. The samples were sown in a wide-row manner with aisles of 70 cm in the 2–3 decades of May 2021–2022. The plot area is 30.8 m^2. The repetition of the experiment is three times. Plant density (100,000 plants/ha) was set manually. The assessment of agronomic traits was carried out according to the generally accepted method [18].

One of the critical periods of vegetation in sorghum is flowering. In this regard, Table 1 presents the data on the sums of active temperatures and precipitation for a month before flowering. Hydrothermal conditions in 2021–2022 were different, which contributed to an objective assessment of the breeding material.

Table 1. Features of hydrothermal conditions 30 days before the flowering of sorghum samples.

Sample	Sum of Air Temperatures, °C		Precipitation, mm		Hydrothermal Coefficient	
	2021	2022	2021	2022	2021	2022
RSK Kakholong	733.6	688.4	43.5	41.0	0.59	0.59
RSK Korall	733.6	688.4	43.5	41.0	0.59	0.59
Magistr	736.8	689.7	36.1	41.0	0.48	0.59
L-50/14	742.8	689.7	36.1	41.0	0.48	0.59
L-65/14	750.6	689.7	36.1	41.0	0.48	0.59

2.3. Laboratory Research

The determination of swelling of sorghum seeds was carried out in a solution with increased osmotic pressure, simulating a lack of water (sucrose, potassium nitrate). In 3 replicates, 50 seeds of the same size were placed in Petri dishes on filter paper [19]. When choosing the number of seeds in one sample, one should take into account their size. Taking into account the correspondence between the sizes of Petri dishes and seeds, 50 pieces are more optimal for studying water consumption. In the control variant, 5 mL of distilled water (H_2O) was used; in the experimental variant, 5 mL of sucrose ($C_{12}H_{22}O_{11}$) 19 atmospheres or 5 mL potassium nitrate (KNO_3) 72 atmospheres was used. Filled Petri dishes with seeds were placed in a thermostat at a temperature of 25 °C since this temperature is considered optimal for the germination of sorghum seeds. Establishing a fixed temperature makes it possible to avoid the influence of changes in this indicator during the experiment on the result of the research. Previously, in studies conducted on sorghum crops, sensitivity to air temperature was revealed during the period of water absorption by seeds and their further germination, and the species specificity of water absorption dynamics was established [20]. Before each weighing, the seeds were removed from Petri dishes, blotted with filter paper, and then weighed on a laboratory electronic balance with high accuracy (up to 0.001 g). The degree of swelling (%) was calculated by the formula:

$$(M_1 - M_2) \times 100/M_2$$

where M_1 and M_2 are the masses of the swollen and initial samples.

Similar experimental conditions were tested in determining the germination and swelling of sugar sorghum seeds under salt stress conditions [21].

The assessment of the indicators of the water regime of the leaves was carried out according to the guidelines [22]. The largest leaf was taken from 5 plants in two repetitions in the "flowering" phase of each sample.

To determine tissue water content, the leaves were dried in a thermostat at a temperature of 105 °C to constant weight. The amount of water as a percentage of the wet weight of the sample was determined by the formula:

$$((a - b)/a) \times 100\% \quad (1)$$

where a is the weight of the raw sample (g); b—mass of dry sample (g).

The loss of water by leaves as a percentage was determined through 0.5, 1.0, 1.5, and 24 h by weighing the leaves in the laboratory on electronic scales, then the indicator was calculated using the formula:

$$(B/A) \times 100\% \quad (2)$$

where A—water content in the leaves before the start of the experiment (g); B—water loss over a certain period of time (g).

To determine the water deficiency, the leaves were placed in a vessel with water and covered. After 24 h of saturation, the leaves were blotted with filter paper and weighed.

$$(M_2 - M_1) \times 100\%/(M_2 - M_3) \quad (3)$$

where M_1 is the mass of leaves before saturation with water (g); M_2—mass of leaves after 24 h saturation (g); M_3 is the weight of the dry sample (g).

The degree of drought resistance of the samples was assessed according to the classification presented in Table 2.

Table 2. Scale for evaluating the parameters of the water regime of leaves to determine the relative drought resistance [22].

Drought Tolerance Assessment	Leaf Water Content, %	Water Deficiency, %	Water Loss by Leaves after Wilting, %	Average Water Loss for 1 h of Wilting, %
Low	59.5 and less	20.1 and more	50.1 and more	11.1 and more
Medium	60.0–69.9	10.1–20.0	30.1–50.0	10.1–11.0
High	70.0 and more	up to 10.0	up to 30.0	up to 10.0

Spectroscopy was used to determine the biochemical analysis of grain on an infrared analyzer Spectral Star XT. Grain quality indicators included protein, fat, ash, fiber, starch, and NFE (nitrogen-free extractives). It is based on the fact that the absorption spectra of molecules are characteristic of a given substance, and the absorption intensity is related to the content of the absorbing component in the irradiated object. The grain was preliminarily ground for reasons of clarity. The protein fractions were separated by the extraction method according to the Osborne scheme, which provides for the sequential extraction of proteins with distilled water, 0.5 M potassium chloride solution, 70% ethanol solution, and 0.2% sodium hydroxide solution [23].

2.4. Statistical Analysis

Processing of research results was carried out by methods of dispersion one-factor and two-factor analyses using the program "Agros 2.09" [24]. To confirm a statistically significant difference (LSD_{05}) between the mean values of the studied traits, the calculated Fisher test (F_{05}) was used at $p \leq 0.05$.

3. Results and Discussion

3.1. Physiological Signs

An important physiological mechanism of drought resistance is osmotic adaptation. Swelling is the most important period in the plant development cycle from sowing to germination and a condition for seed germination. It begins when the seeds reach a moisture content above the critical value, the physical state of the grains changes, and conditions are good for the start of biochemical metabolism and the development of biological processes [25]. The further vegetative and productive development of plants depends on the swelling conditions. This method has been tested on many agricultural crops and reflects the adaptive capacity of the plant organism to soil drought, and it actualizes through the processes of growth and development [26].

Considering the intensity of seed swelling throughout the experiment, it is worth noting that in the initial and final periods of the experiment, a high intensity was noted, while in 4–6 h there was a significant slowdown in the increase in the mass of caryopses. A similar dynamic of the swelling process was noted for other agricultural crops, including sorghum [27].

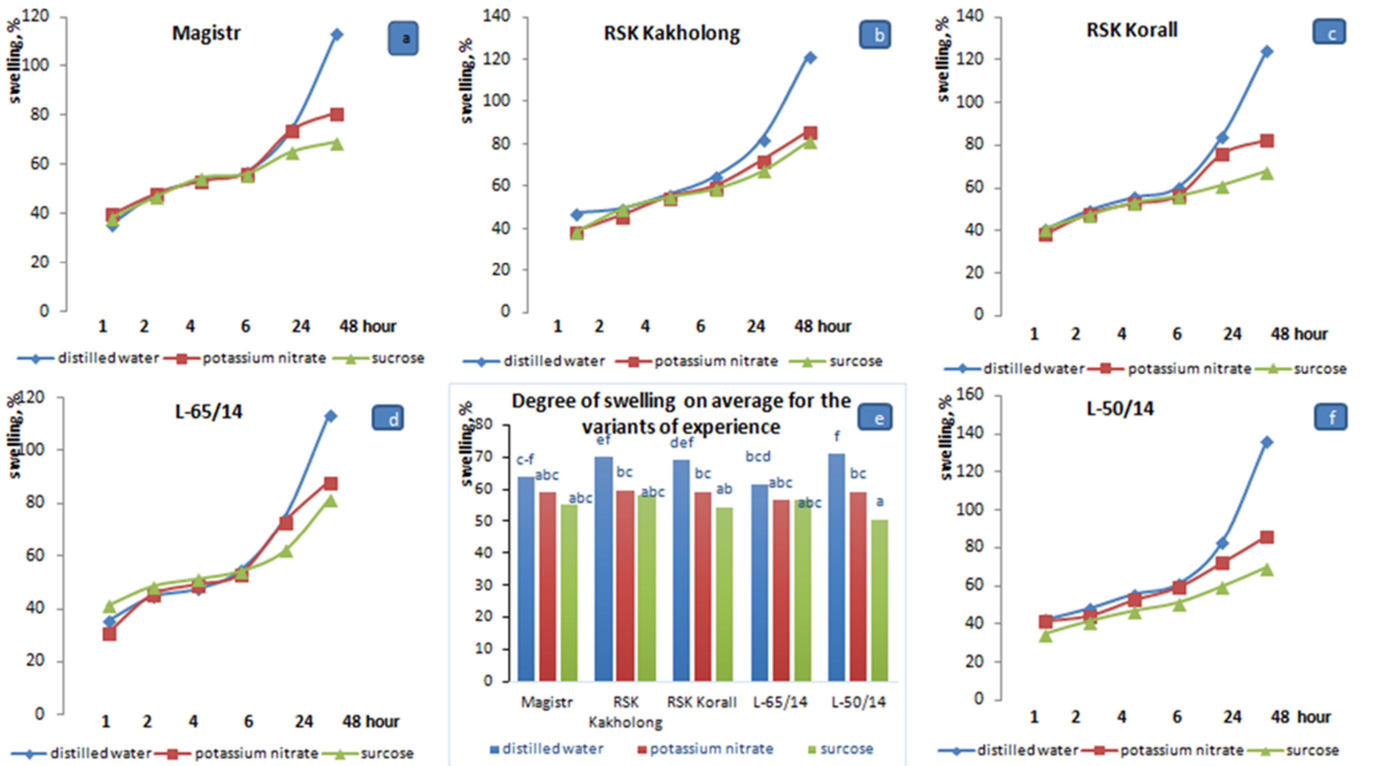
The highest water absorption by the seeds of varieties and lines of grain sorghum on average over the test period is mainly characteristic of the control variant (distilled water): from 51.9 to 61.7% (2021) and from 71.3 to 83.2% (2022). Seed swelling in solutions of sucrose and potassium nitrate was lower: in sucrose 42.2–52.1% and 63.1–75.7%, accordingly; in potassium nitrate 35.3–44.9% and 58.0–73.5%, accordingly. (Table 3). The research results indicate that climatic conditions during the period of seed formation affect the degree of their swelling. On average, over 2 years of research, the greatest swelling of seeds during the experiment period was found in varieties RSK Korall and RSK Kakholong, the smallest in the varieties Magistr and line L-65/14.

Table 3. Degree of swelling of grain sorghum seeds in osmotic solutions (2021–2022), %.

Sample	Experience Variant	Experiment Duration, Hour												Average	
		1		2		4		6		24		48			
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Magistr	H_2O	23.1	48.6	32.2	64.0	37.1	69.7	43.5	70.7	65.4	83.3	105.1	121.6	51.1	76.3
	$C_{12}H_{22}O_{11}$	25.4	54.6	29.9	66.9	37.0	70.2	43.4	70.2	56.6	91.1	60.6	101.3	42.2	75.7
	KNO_3	26.4	51.0	32.8	61.6	34.1	75.5	37.8	74.7	50.2	80.1	56.9	81.5	39.7	70.7
RSK Kakholong	H_2O	26.0	68.6	35.3	63.2	40.6	71.2	50.3	78.5	78.7	85.4	139.5	103.4	61.7	78.4
	$C_{12}H_{22}O_{11}$	29.6	47.4	39.5	52.9	45.6	64.2	52.6	67.8	65.2	79.2	80.3	91.8	52.1	67.2
	KNO_3	24.2	52.4	35.5	63.2	42.7	67.3	46.3	71.4	54.4	79.7	63.7	98.5	44.4	72.1
RSK Korall	H_2O	24.7	56.3	29.6	69.6	34.1	77.1	40.5	80.2	69.3	99.4	132.4	116.5	55.1	83.2
	$C_{12}H_{22}O_{11}$	26.6	50.6	31.0	65.7	35.6	70.3	44.5	69.1	60.2	91.7	68.6	96.7	44.4	74.0
	KNO_3	24.9	57.3	28.0	66.5	32.0	74.2	34.8	77.4	42.5	80.0	49.7	85.9	35.3	73.5
L-65/14	H_2O	18.8	51.8	30.9	58.1	35.7	59.0	46.2	62.7	67.9	81.3	111.8	115.0	51.9	71.3
	$C_{12}H_{22}O_{11}$	26.5	35.4	33.7	57.2	40.5	58.3	47.1	59.5	70.8	75.5	83.7	92.7	50.4	63.1
	KNO_3	27.4	55.0	34.9	62.0	39.5	63.1	41.7	66.9	56.6	67.4	69.0	94.0	44.9	68.1
L-50/14	H_2O	24.6	59.6	31.8	64.1	43.4	67.6	49.9	71.7	78.1	87.9	135.2	137.2	60.5	81.4
	$C_{12}H_{22}O_{11}$	25.8	57.0	31.2	57.1	36.5	68.3	44.9	73.3	56.5	87.5	64.0	107.7	43.1	75.2
	KNO_3	27.0	42.6	33.5	49.4	37.7	55.9	44.2	57.9	51.1	68.1	65.1	74.1	43.1	58.0
F_{05} (A)														15.03 *	7.29 *
F_{05} (B)														328.61 *	122.48 *
F_{05} (AB)														6.86 *	1.41 *
LSD_{05} (A)														5.39	6.83
LSD_{05} (B)														3.41	4.32
LSD_{05} (AB)														13.22	16.73

Note: * $p \leq 0.05$.

The study of the dynamics of swelling of the seeds of the samples revealed some features. Thus, in the Magistr variety and line L-65/14, during the first 24 h, more intense seed swelling occurred in a sucrose solution, and only during the second day of the experiment did it decrease compared to the process occurring in distilled water (Figure 1a,d). It is worth mentioning that in line L-65/14, a higher degree of seed swelling was found in the experiment with potassium nitrate in the first 1–6 h of the experiment, however, the intensity decreased in the subsequent hours and increased in sucrose. On average, over 48 h, the swelling in the experiment with potassium nitrate (55.2–56.5%) and sucrose (56.7–58.9%) in these samples was at the level of the control variant (61.6–63.7%), which indicates their drought resistance in the initial period of plant development.



$F_{05}(A) = 5.18^*$; $F_{05}(B) = 142.77^*$; $F_{05}(AB) = 1.88^*$; $LSD_{05}(A) = 7.29$; $LSD_{05}(B) = 4.61$; $LSD_{05}(AB) = 17.87$

Figure 1. Dynamics (**a**–**d**,**f**) and average degree of seed swelling (**e**) of varieties and lines of grain sorghum (average for 2021–2022). Note: * $p \leq 0.05$. Different letters indicate values that differ significantly from each other in the column or the table by comparison with the Dunn's test.

Considering the intensity of the swelling of the samples separately by years of research, it should be noted that in the conditions of 2022, the indicators of the RSK Kakholong variety in the experiment with potassium nitrate did not significantly differ from the indicators in the control variant—72.1 and 78.4%, accordingly; in line L-50/14, the values of seed swelling in the experiment with sucrose were at the control level—75.2 and 81.4%.

Researchers noted that sorghum is sensitive to drought and high air temperatures before and after flowering [12,15,16]. Prolonged drought during the flowering period affects the productivity of sorghum; in the period after flowering, the graininess of the inflorescence and the frailty of the seeds, which also lead to a loss of yield [17,28]. Despite this, sorghum tolerates drought more easily than other agricultural crops due to the peculiarities of osmotic adaptation and stomatal regulation [16]. Drought-tolerant genotypes and varieties have been reported to maintain high relative water content even under arid stress [29].

In addition, drought resistance was determined by the parameters of the water regime of the leaves and in the critical-for-sorghum period—flowering. In samples, the values of total tissue water content varied in the range of 74.20–78.85%, with water deficiency—14.05–18.49%, water-holding capacity—83.18–86.49%, and average moisture loss per 1 h per day—2.86–3.09% (Table 4).

Significant changes in the values of water deficit depending on the hydrothermal conditions during the given growing season were revealed. Thus, in the conditions of 2022, the water deficit in the varieties RSK Korall and RSK Kakholong is significantly lower than in the conditions of 2021: 9.09–10.49% and 17.61–19.46%, respectively. The lowest variability of the indicator for two years was in the variety Magistr (13.07–15.67%) and line L-65/14 (18.38–18.61%). The influence of hydrothermal conditions on the parameters of the water regime of leaves was previously revealed in the CMS lines of grain sorghum [3].

Table 4. Parameters of the water regime of leaves of grain sorghum samples (2021–2022), %.

Sample	Water Content of Leaf Tissues			Water Deficiency			Water-Holding Capacity			Moisture Loss in an Average of 1 h/Day		
	2021	2022	Average	2021	2022	Average	2021	2022	Average	2021	2022	Average
RSK Kakholong	79.90	75.51	77.71	17.61	10.49	14.05	82.65	90.33	86.49	3.18	3.00	3.09
RSK Korall	81.82	75.87	78.85	19.76	9.09	14.43	81.45	88.24	84.85	3.20	2.98	3.09
Magistr	75.58	72.82	74.20	13.07	15.67	14.37	87.33	83.78	85.56	2.86	2.85	2.86
L-50/14	78.41	75.88	77.15	12.92	17.01	14.97	84.12	82.24	83.18	3.04	2.85	2.94
L-65/14	78.30	77.36	77.83	18.61	18.38	18.49	83.64	83.90	83.77	3.04	2.97	3.01
F_{05}	14.63 *	14.55 *	14.97 *	10.58 *	11.38 *	0.33	10.44 *	25.44 *	0.27	16.71 *	15.91 *	11.19 *
LSD_{05}	1.63	1.69	3.85	2.85	4.77	–	1.94	2.66	–	0.09	0.07	0.17

Note: * $p \leq 0.05$.

The variety Magistr was distinguished by lower values of tissue hydration and moisture loss for 1 h/day: on average for 2 years, they amounted to 74.20% and 2.86%, accordingly. In line L-65/14, indicators of water deficiency, water content of leaf tissues, water-holding capacity, and average moisture loss per 1 h per day remained stable throughout the study period.

The study of moisture loss by leaves in dynamics made it possible to reveal the genotypic specificity of the samples. Thus, in the first 30–90 min of the experiment, the varieties Magistr and RSK Kakholong were characterized by the lowest intensity of moisture loss: 5.51–5.60% after 30 min; 9.86–9.94% after 60 min; and 13.51–14.44% after 90 min of wilting on average for the study period, which indicates a high ability of plants to retain moisture under stress conditions (Table 5). Low values of moisture loss were noted in the varieties Magistr (38.55%) and L-50/14 (70.77%) after 24 h. This indicator turned out to be the highest—74.28%—in the RSK Kakholong variety.

Table 5. Moisture loss by leaves of varieties and lines of grain sorghum in the process of wilting (2021–2022), %.

Sample	Loss of Moisture during Wilting After:											
	30 min			60 min			90 min			24 h		
	2021	2022	Average	2021	2022	Average	2021	2022	Average	2021	2022	Average
RSK Kakholong	7.46	3.74	5.60	12.66	7.07	9.86	17.35	9.66	13.51	76.49	72.07	74.28
RSK Korall	7.36	4.51	5.94	13.53	8.38	10.95	18.55	11.76	15.15	76.96	71.47	74.21
Magistr	4.54	6.49	5.51	8.34	11.55	9.94	12.67	16.22	14.44	68.75	68.35	68.55
L-50/14	5.51	6.66	6.09	10.55	12.95	11.75	15.88	17.75	16.82	73.10	68.45	70.77
L-65/14	6.20	6.32	6.26	11.41	11.01	11.21	16.36	16.10	16.23	72.96	71.33	72.15
F_{05}	15.09 *	8.61 *	0.06	14.33 *	12.79 *	0.36	10.44 *	25.49 *	0.27	16.37 *	15.74 *	11.53 *
LSD_{05}	0.85	1.29	-	1.47	1.92	–	1.94	2.65	-	2.25	1.76	3.59

Note: * $p \leq 0.05$.

Overall, the study of the characteristics of the water regime of the leaves made it possible to characterize the source material as drought-resistant. According to the classification of relative drought resistance, the presented samples should be classified as medium-drought-resistant only in terms of water deficit.

3.2. Morphometric Traits and Yield

The manifestation of drought (both soil and air) during the flowering period of plants negatively affects their growth and yield formation [30]. The study of breeding traits, such as plant height, leaf area, grain weight per inflorescence, grain yield, and biomass dry matter, and many others, are widely used in diagnosing genotypes for drought resistance [13,15]. The literature marks that leaf surface area can contribute to resistance to water stress [31]. During the evaluation of morphometric characteristics, attention was paid to the main indicators that are elements of plant productivity—plant height, inflorescence length, and area of the largest leaf.

An assessment of the morphometric parameters of sorghum and yield showed that in the 2021 season, under drier conditions, the value of breeding traits was lower than in the 2022 season. In line L-50/14, only the area of the largest leaf did not change significantly: in the conditions of 2021, it was 176.5 cm^2, and in 2022 it was 173.0 cm^2 (Table 6). Line L-50/14 formed the yield of biomass and grain under the conditions of 2022 higher than in 2021: 23.25 and 15.28 t/ha, and likewise 5.24 and 3.37 t/ha, respectively. Moreover, an increase in plant height (123.0 cm) and panicle length (27.0 cm) was also noted. In terms of plant height, the most stable indicators were in the RSK Kakholong variety—115.6–117.2 cm—and significant differences in the area of the largest leaf—184.9–313.7 cm^2.

Table 6. Morphometric traits and yield of grain sorghum samples (2021–2022).

Sample	Plant Height, cm			Panicle Length, cm			Largest Leaf Area, cm^2			Biomass Yield, t/ha			Grain Yield, t/ha		
	2021	2022	Average	2021	2022	Average	2021	2022	Average	2021	2022	Average	2021	2022	Average
RSK Kakholong	115.6	117.2	116.4	23.7	12.3	18.0	184.9	313.7	249.3	16.10	19.73	17.91	4.19	4.74	4.47
RSK Korall	109.8	117.8	113.8	20.1	11.8	16.0	203.6	269.5	236.5	14.23	18.40	16.31	3.86	4.39	4.13
Magistr	101.5	121.8	111.7	13.8	10.6	12.5	194.1	177.0	187.3	13.00	16.77	14.88	3.46	4.61	4.04
L-50/14	98.4	123.0	110.7	19.6	27.0	23.3	176.5	173.0	174.8	15.28	23.53	19.41	3.37	5.24	4.31
L-65/14	120.5	135.4	127.9	19.8	21.1	20.5	160.2	175.4	169.3	12.88	14.78	13.83	3.78	3.96	3.87
F_{05}	22.50 *	7.16 *	4.49 *	41.59 *	30.43 *	4.37 *	2.89 *	7.92 *	2.77	2.21	4.49 *	3.35 *	0.79	2.89 *	0.39
LSD_{05}	5.72	8.08	10.13	1.63	3.83	6.17	26.55	64.44	-	-	5.74	3.40	-	0.28	-

Note: * $p \leq 0.05$.

In 2022, RSC Korall had higher plant height, the largest leaf area, grain yield, and biomass.

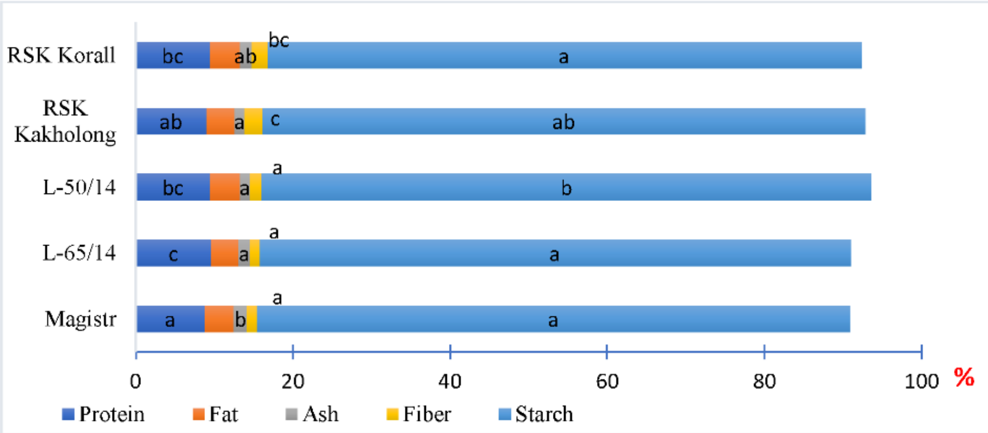
A slight reaction to the variability of climatic conditions was in line L-65/14: the length of the inflorescence varied in the range of 19.8–21.1 cm, the biomass yield was 12.88–14.78 t/ha, and the grain yield was 3.78–3.96 t/ha. Apparently, this line turned out to be more stress-resistant.

The analysis of valuable breeding traits showed a specific reaction of grain sorghum genotypes to changes in hydrothermal conditions during the growing season of plants, which made it possible to identify the most stress-resistant samples.

3.3. Biochemical Indicators

The biochemical composition of grain, which determines its quality, forms as a result of complex metabolic processes occurring in plants under the influence of various factors (biotic and abiotic), alongside a result of the implementation of information embedded in the genotype. Apparently, high-quality grain forms only with the optimal physiological and biochemical state of plants. The results of the experiment on the content of major substances in sorghum grain of various genotypes are shown in Figure 2.

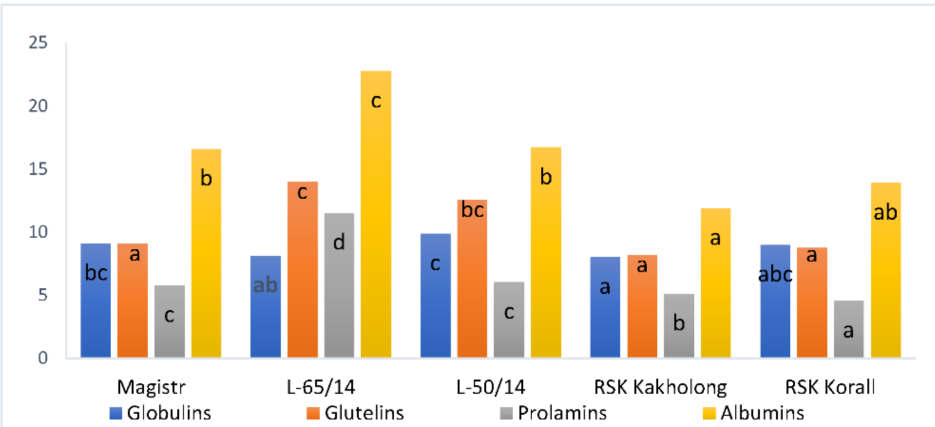
The conducted studies showed that the level of protein in sorghum grain varied from 8.8 to 9.6%. Sorghum sample L-65/14 contained the largest amount of protein, which significantly differed from other samples within 1.3–9.0%. In terms of fat content, on the contrary, this sample had the lowest value of all (3.5%). The maximum fat index (3.8%) was in the samples of RSK Coral and L-50/14. Mineral substances in the grain of the studied samples were in the range of 1.29–1.67%. On this basis, the Magister variety stood out, in which the excess of the indicator turned out to be at the level of 22%. Fiber and starch were determined from polysaccharides in laboratory conditions. It is worth mentioning that the smallest amount of fiber was present in the Magistr and L-65/14 samples (1.2%). These samples had the lowest starch content in the grain, at 75%. Obviously, a decrease in the level of some components occurs at the expense of an increase in others. The results of the analysis of the main components of the sorghum grain of the experimental samples have confirmations in similar studies by other scientists [32–36].



F_{05} (protein) = 3.94 *;
LSD_{05} (protein) = 0.50;
F_{05} (fat) = 1.71;
F_{05} (ash) = 5.67 *;
LSD_{05} (ash) = 0.19;
F_{05} (fiber) = 17.43 *;
LSD_{05} (fiber) = 0.33;
F_{05} (starch) = 3.58 *;
LSD_{05} (starch) = 1.55.

Figure 2. Biochemical composition of sorghum grain (average for 2021–2022), %. Note: * $p \leq 0.05$. Different letters indicate values that differ significantly from each other in the column or the table by comparison with the Dunn's test.

The proteins of agricultural crops are unequal in amino acid composition, solubility, and digestibility; therefore, the quality of crop products is assessed not only by the content but also by the usefulness of proteins based on the study of their fractional composition. Based on such studies, it is possible to obtain the amino acid profile of the protein in the grain. The study of the quality of the grain protein complex makes it possible to identify genotypes with the most valuable properties and conduct the selection in this direction. According to our data, the quantitative values of protein fractions significantly depended on the sorghum genotype (Figure 3).



F_{05} (albumins) = 20.84 *;
LSD_{05} (albumins) = 3.52;
F_{05} (globulins) = 6.41 *;
LSD_{05} (globulins) = 0.98;
F_{05} (prolamins) = 741.00 *;
LSD_{05} (prolamins) = 0.40;
F_{05} (glutelins) = 28.35 *;
LSD_{05} (glutelins) = 1.91

Figure 3. Fractional composition of sorghum, g/100 g of protein. Note: * $p \leq 0.05$. Different letters indicate values that differ significantly from each other in the column or the table by comparison with the Dunn's test.

Given that the albumin fraction is the most complete protein fraction, which contains all the essential amino acids, line L-65/14 stands out from all samples. The amount of albumin in the protein of this sample exceeded the smallest value by almost two times in comparison with the RSK Kakholong variety. The globulin fraction also characterizes a significant amount of essential amino acids: in the grain protein of the studied sorghum samples, it was 8.01–9.87%. Significant differences were within 20%, and the indicators of globulins in sorghum Magistr, L-65/14, and RSK Korall did not differ statistically. It is important to note that along with a high level of complete protein in grain L-65/14, this sample has the largest number of defective protein fractions—prolamin and glutelin. In addition, the L-65/14 line was distinguished by the minimum value of the insoluble protein residue compared to RSC Coral, which has the highest value of the insoluble residue; the difference was 15.6%.

The main proteins of sorghum are prolamins and glutelins, which are characterized by low digestibility and inferiority due to the incomplete composition of essential amino acids [37]. According to other data, sorghum protein contains quite a lot of albumins and a high amount of globulins [38], which was also noted in our studies. At the same time, the protein digestibility of sorghum conformingly depends on many factors: the organizational structure of the grain, the number of phenolic compounds, cell wall components, and starch, which can vary depending on the genotype of the sample [39].

Storage proteins are mainly in the endosperm of the grain. It is common knowledge that the prolamine fraction of sorghum protein consists of kafirin, which has anti-nutritional properties. Kafirins make up 48–70% of whole-grain proteins. They are rich in proline, asparagine, and glutamine and, conversely, contain very low levels of lysine [40]. According to our data, the prolamin fraction of the protein in the experimental samples of sorghum was in the range of 5.1–11.5 g/100 g of protein. The second-largest protein fraction in the studied samples was glutelin. These values are well consistent with the results of studies by a number of researchers [41].

Therefore, in the studied samples of sorghum, the content of complete proteins in the grain was at a high level (11.89–22.75 g/100 g of protein) and has wide variability depending on the genotype. On average, the rest of the protein fractions were allocated glutelin, then globulin, and the lowest amount of prolamins.

4. Conclusions

To develop new drought-resistant varieties and hybrids of sorghum, it is advisable to select parental components that have increased stress resistance and a complex of breeding-valuable traits. The indicators of seed swelling in hypertonic solutions, the water regime of grain sorghum leaves, morphometric features, and the biological value of grain were analyzed for this purpose. As a result of the research, there were two samples that combine a complex of physiological, morphological, and biochemical parameters—Magistr and L-65/14. Thus, in the initial period of development under simulated drought conditions, the swelling of seeds in hypertonic solutions (sucrose and potassium nitrate) turned out to be at the level of the control variant (distilled water)—55.2–58.9% and 61.6–63.7%, respectively. Further study during the vegetation period of plants, specifically, in the flowering phase, showed that the samples have a high total water content of leaf tissues (74.20–77.83%), water-retaining capacity (83.77–85.56%), and low moisture loss for 1 h/day (2.86–3.01%), which indicate their relative drought resistance. In addition, these sorghum genotypes have a weak variability of agronomic traits (including yield) under different hydrothermal conditions during the growing season, and the grain has a higher content of albumin protein fraction (16.59–22.75%).

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