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SPRING BARLEY HYBRIDS ASSESSMENT FOR BIOLOGICAL AND ECONOMIC FEATURES UNDER DROUGHT CONDITIONS OF NORTHERN AND CENTRAL KAZAKHSTAN

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SUMMARY

The presented study comprehensively assessed barley (*Hordeum vulgare* L.) hybrid populations of F_3–F_5 generations, comparing with the standard barley cultivars, Karagaydinckiy-5 and Astana-2000. The crossing of isolated barley cultivars of the international collection (obtained from Australia) proceeded under intense continental climatic conditions of Northern and Central Kazakhstan. Barley promising selected populations, i.e., Macguarie × Arna, Flinders × Tselinniy golozerniy, and Flinders × Omskiy golozerniy, showed early maturity (79–83 days), superior plant height (34.4–69.5 cm), and enhanced 1000-grain weight (56.6 g, 56.4 g, and 58.0 g, respectively), and populations, viz., Buloke × Karagandinckiy-6, Fathom × Donezckiy-9, and Onslow × Karabalykckiy-43, for productivity (1 m^2) at 184 g, 116.4 g, and 140.1 g, respectively. Identified in the study were the correlation of productivity and its structural elements, particularly the grain weight per ear (r = 0.486) and grain weight per plant (r = 0.828), mainly determining grain productivity. The determination of structural features variation showed a significant excess (more than 20%) with varying levels. The level of variability of grain mass per plant has shown in hybrid lines, i.e., Fathom × Karagandinckiy-5, Onslow × Karagandinckiy-10, Admiral × Karabalykckiy-150, and Admiral × Donezckiy-9. In grains, the protein content ranged from 10.45% to 16.63%, and the excess over the standard cultivar resulted in the hybrid lines Franklin × Sabir (16.63%), Anodolu-86 × Donezckiy-8 (16.04%), and Flinders × Omskiy golozerniy (15.31%). Based on an average of the study years, the drought-resistant and high-productivity hybrid lines were Buloke × Karagadinckiy-6, Fathom × Donezckiy-9, Onslow × Karabalykckiy-43, Onslow × (Karagandinckiy-5 × Arna), Bass × Karabalykckiy-150, Granal × CMB93H-805-F-1Y-1M-OY-17TRS-OAP, and Granal × CMB89A-380-1M-OGH-105GH-1B-1OY-OAP-19AP-OAP. These promising genotypes can benefit the development of drought-resistant and high-yielding barley cultivars through future breeding programs under prevailing environmental conditions.

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Keywords: Barley (*Hordeum vulgare* L.), hybrids, breeding, drought, traits association, yield-related traits, protein content

Key findings: The study based on hybrid populations of world genetic resources of barley (*Hordeum vulgare* L.) under existing environmental conditions makes it possible to select and develop drought-resistant and high-yielding spring barley cultivars through the conventional breeding program and provide food security to the Republic of Kazakhstan.

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops, ranking second after wheat based on its production in Kazakhstan. Recent years reveal a trend toward an increase in sown areas, yielding an active climb to 2.9 million ha in 2019. Over the past 30 years, creating more than 30 varieties of fodder barley has resulted (Saule, Zhuldyz, Akzhol, Zhan, Ilek 9, Ilek 16, and Ilek 20, to name a few). Cultivation of forage varieties of barley is suitable in the rainfed lands of the southeast and non-irrigated lands of Western and Northern Kazakhstan, where the yield is from 0.6 to 0.12 t/ha. Under the arid conditions of Northern Kazakhstan, which includes the Akmola and Karaganda regions, it is essential to create spring barley varieties characterized by stability in yield and grain quality (Sariev *et al*., 2013). With sustainable growth of animal husbandry and demand in the world market for fodder barley products, the task arises to develop highly productive cultivars distinctly resistant to climatic conditions and superior in grain quality. The said hypothesis gains importance in searching for reserves of new lines and cultivars using the international collection as a donor parent. Advancing breeding can make it more profitable using a wide germplasm variety adapted to existing environmental conditions and plant molecular genetics principles (Vavilov, 1966; Abramova *et al*., 2016).

In delicate farming areas of a severe continental climate, with a limited growing season, early summer droughts, and a lack of heat during grain filling, developing local adaptive cultivars of grain crops, such as, barley, is relatively sensitive (Yusova and Nikolaev, 2016). New cultivars' development considers the relationship of the crucial economically valuable parameters and comprehensively assesses them at all stages of the breeding process. Employing various breeding methods to develop the base material includes advances in molecular biology; however, conventional hybridization is still one of the chief breeding methods (Lisitsyn, 2018; Baidyussen *et al*., 2021). In the forest-steppe zone of Western Siberia, using intraspecific hybridization, creating the spring barley cultivar 'Tolkan' was for drought and lodging resistance, immunity to smut fungi, and dusty and hard smut, averaging a yield of 5.4 t/ha, which exceeded the standard cultivar by 0.8 t/ha (Pakul and Martynova, 2020).

Study and selection in spring barley hybrid populations (F_3–F_4) based on a complex of valuable biological and economic traits makes it possible to select more resistant genotypes in the early generations under abiotic stress and existing environmental factors. Based on the performance-based screening for various features, the spring barley line 105/1-09h310 (Margrette × Bios) came out as a competitive cultivar, with more than a 10% increase in yield (0.59 to 0.75 t/ha) (Zabalueva *et al*., 2013). By studying the American germplasm (28 samples) of six-row barley for three years in Northern Kazakhstan, the possibility emerged to use this germplasm in local breeding, which adapts well to existing climatic conditions. It resulted in yield indicators surpassing the Kazakh local line L50T26, suggesting that the six-row barley breeding program is more successful in Kazakhstan, as local breeders and farmers have not previously used this barley type (Almerekova *et al*., 2019).

Drought accounts for more than 80% of losses in agriculture, especially in the crop and livestock sectors, which seriously affects crop plant development in certain phases like seed germination, heading through plant growth to final maturation and harvest, their interaction with the environmental factors, indicating the complexity of plant response to drought is the result of all these factors. Barley, compared with other cereals, adapts well to different drought levels and has different morphological, biochemical, and molecular mechanisms of drought tolerance, yet, the barley response to drought can vary greatly (Kebede *et al*., 2019; Ali *et al*., 2021; Mark *et al*., 2021; Fatemi *et al*., 2022). In barley, identifying the drought resistance gene (HvMYB1) is an influential discovery in the present era, helping increase the grain yield suffering from the negative impacts of climate change (Chesnokov, 2013; Karmanenko, 2014).

The relationship of economically valuable traits shows a correlation between the others, which depends on the cultivars and growing conditions. The correlation can be more effective when the absolute value of the correlation coefficient is significant and adequate. A present correlation between the growing season duration and grain yield complicates breeding for early maturity. Early maturing cultivars with an optimal growing season tend to be less productive. However, in the northern regions of the European part of Russia with a short growing season, such cultivars do not have competition compared with the most effective (Gocheva, 2014; Dontsova and Potokina, 2015; Hailu, 2016; Shrimali, 2017).

Nutritional value (protein content) is an essential quality indicator of barley grain. However, the protein amount in the grain depends on the genotypes, as well as, external factors, i.e., growing and production technology, timely harvesting, and nitrogen level in the soil. Barley grain serves as grain forage, and its high protein composition makes the feed more nutritionally valuable (Isaichev *et al*., 2019). In the northern forest-steppe zone of the Tyumen Region, barley cultivars' testing for protein content ran, comparing with the standard cultivar *Acha* (brewing direction) for the average and high nutrition backgrounds. The results showed, compared with the regular cultivar *Acha*, all cultivars showed a higher percentage of protein content on an average background (ranged from 1.1% to 2.4%) and on a high setting (0.9% to 2.7%), with the cultivar *Vulkan* standing out on both nutritional conditions, which indicates the need to grow such cultivars under these environmental conditions (Yakubyshina, 2022). The presented study comprehensively assessed and selected barley hybrid populations of F_3–F_5 generations more adapted to drought resistance, productivity, and economically valuable traits in Northern and Central Kazakhstan.

MATERIALS AND METHODS

Breeding material and procedure

The research worked on the international collection of spring barley (*Hordeum vulgare* L.) comprising various cultivars obtained from Australia (67), Great Britain (1), Canada (1), Japan (1), USA (3), Sweden (1), Russia (5), and Germany (1). With isolated varieties based on terms of adaptability to local climatic conditions and productivity, crossing of 10 foreign genotypes (Australia-Admiral, Anodolu-86, Buloke, Fathom, Mackau, Macguarie, Westminster, Onslow, Flinders, and USA-Orange) transpired with local cultivars.

The resulting spring barley hybrid populations of F_3–F_5 generations attained evaluation against two regional local standard cultivars, i.e., Karagandinckiy-5 and Astana-2000 (Figure 1). Research continued at the field stations, sowing manually in plots of 1 m^2, with row spacing of 15 cm (seven rows of 50 grains), seeding depth at 5 cm, and plot width

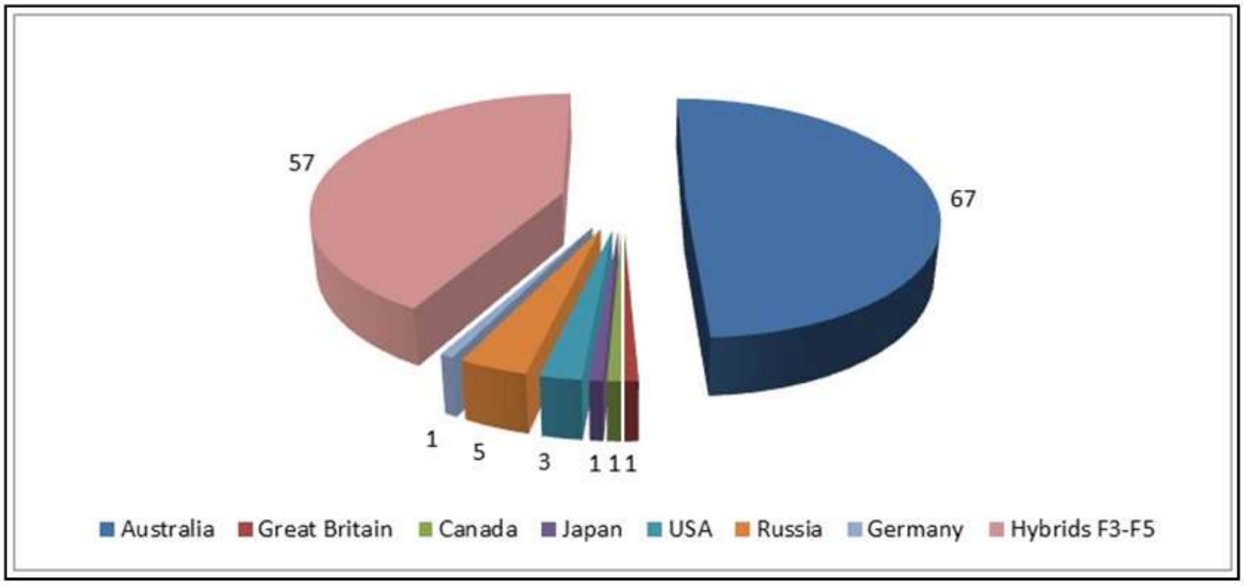
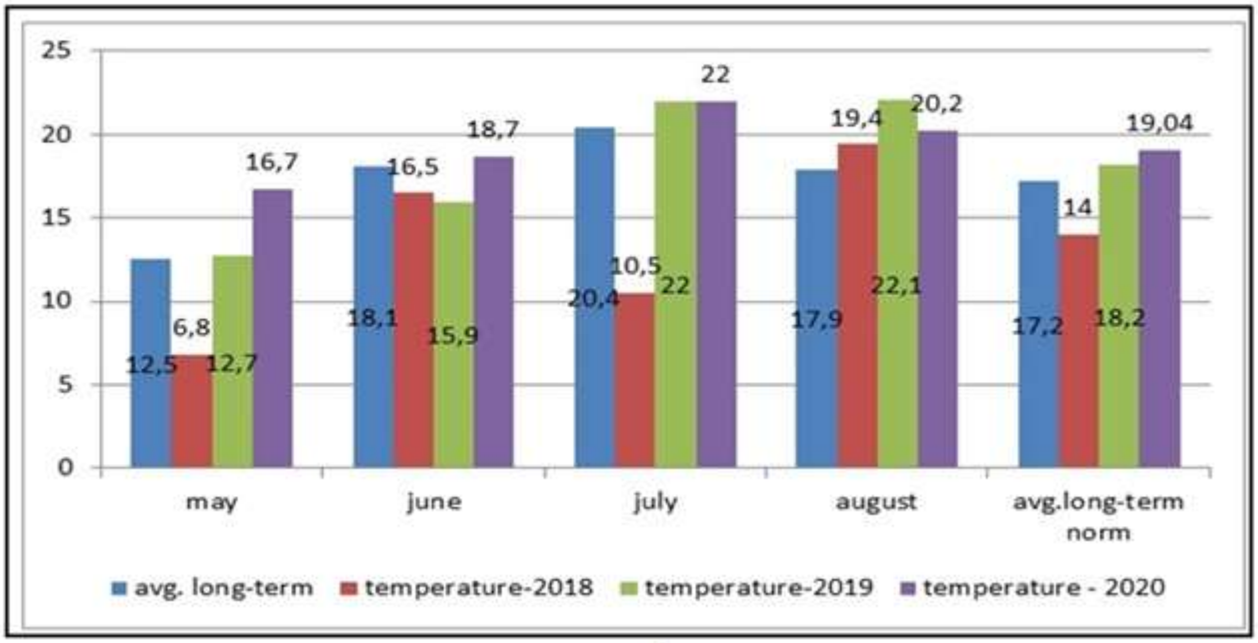


Figure 1. The volume of material for spring barley - 2018–2020.

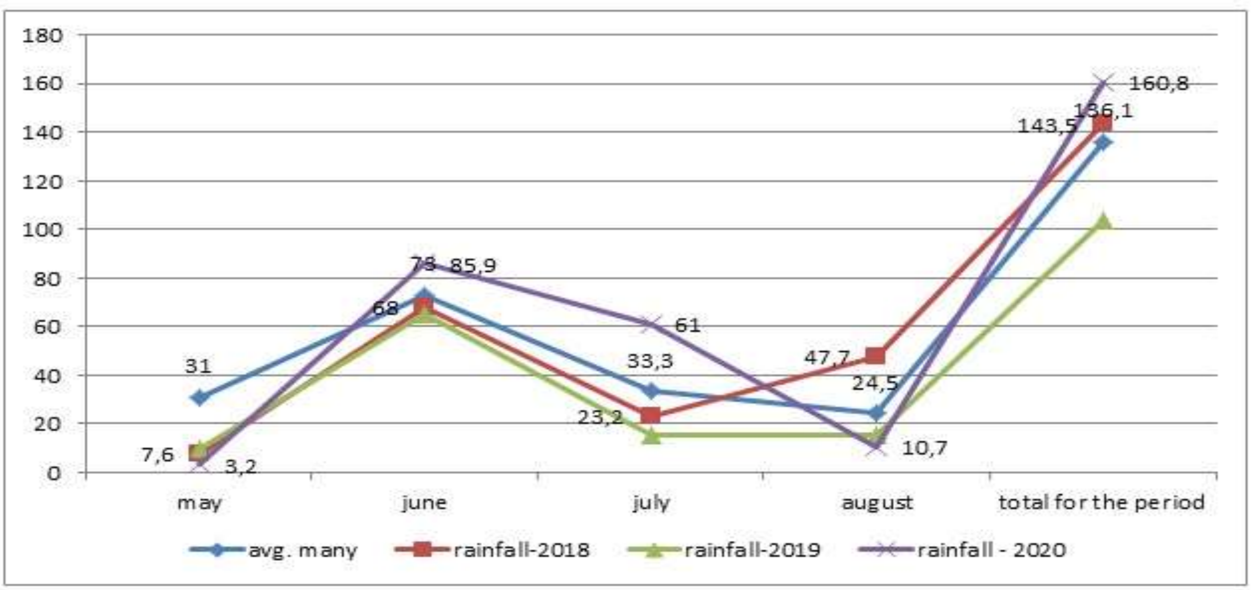
at 1.15 m. Sowing progressed at the optimal time of 20 – 25 May, with the seeding rate recommended for this climatic zone.

Field breeding studies started in 2018–2020 at the Akmola Region (Peasant farm "Niva") and the Karaganda Region (Karaganda Agricultural Experimental Station named after A.F. Khristenko), Kazakhstan. Phenology and statistical processing followed, according to Dospekhov (1985). The method of intraspecific hybridization of ecologically/geographically and genetically distant forms created the source material. In this case, the paternal forms were samples of the international collection, distinguished by adaptability to local weather conditions and productivity, and the maternal types are locally zoned varieties. Hybridization ran in the summer (July), inducing pollination using the Twell-Method proposed by Borlaug, following the All-Russian Institute of Plant Industry guidelines. Direct crossings proceeded in the field (Leningrad, 1973). Sufficiently developed ears got selected for castration. The process had the ear released from the sheath of the upper leaf; then castration began by removing the lower and upper underdeveloped and small spikelets, cutting off the awns and tops of the lemmas. Removal of anthers used tweezers without damaging the stigma. The castrated ears placed under a parchment paper insulator attained pollination by introducing flowering ears of the pollinating variety under the insulator (Moskov, 1987). During the years of research (2018-2020), generations of F_1–F_5 hybrid lines obtained on the spring barley collection faced an assessment for economically valuable traits to create new varieties.

With the STATISTICA 10 program, a correlation analysis determined the relationship between the mutual influences of traits on productivity. The DNA-extracted solution (70% ethanol) aided the interpretation of the electrophoretic spectra of hordeins based on knowing the genetic control of the studied proteins (Poperelya *et al*., 1989). Seven hordein coding loci became known, three of which (HrdA, HrdB, HrdF) were polymorphic and represented by dozens of alleles (Lyalina *et al*., 2016). With the electropherogram, spatially separating the groups of hordeins controlled by these loci materialized. The group of the less mobile components had a control by the HrdA locus, the components located in the middle of the spectrum had the HrdB managing them, while the HrdF locus controlled the most mobile hordeins.



a



b

Figure 2. Meteorological indicators for temperature (a) and rainfall (b) - 2018–2020- Akmola regions.

In climatic conditions of the Akmola Region (Peasant farm "Niva") during the growing season, the average annual rainfall in June was 73.0 mm and in July, 33.3 mm. In 2020 rainfall in June (85.9 mm) and July (61 mm) exceeded the average by 17.6% and 96%, respectively. However, a slight decrease occurred in June 2018 (68 mm) and 2019 (65.3 mm). But in July, there was a dry period, with rainfall below the annual average of 31% (2018) and 53% (2019). Although, due to heavier rainfall in June, increased plant productivity appeared. Generally, optimal weather conditions prevailed during the plant growth and harvesting stages (Figure 2a, b).

Climatic conditions in 2018 for Karaganda Agricultural Experimental Station, named after A.F. Khristenko, were as follows: During the growing season of plants from May to August, the rainfall was 96 mm, more than the long-term average. In May, rainfall was much lower than the norm (22.2 mm), as reflected in the size of the spring barley-forming crop. The air temperature was below the average annual norm by 3.6°. In 2019, rainfall amounted to 364.9 mm, 56.1 mm higher than the long-term average. The vegetation period of plants accounts for 140.4 mm, which is slightly higher than the norm (+0.9 mm). According to the temperature regime, the hottest was also in July. The maximum temperature reached 36 °C – 38 °C, impacting grain formation and filling. In 2020, 461.4 mm of rain fell, significantly higher than the norm (+128.7 mm). The vegetation period accounts for 153.5 mm, considerably higher than the norm (+12.3 mm), contributing to plants' growth and grain filling. But, the increased air temperature in May and the first 10 days of June (+19.1 °C) and the lack of required rainfall during this period severely dried the topsoil, thus affecting the further development of barley plants.

RESULTS AND DISCUSSION

In the field at Karaganda Agricultural Experimental Station named after A.F. Khristenko, 21 selected landraces of spring barley (*Hordeum vulgare* L.) from the sown 81 cultivars of the international collection showed resistance to late spring frosts and drought and were high yielding compared with local standard cultivars. From the entire international assembly, the selected cultivars from Australian germplasm were Admiral, Anodolu-86, Buloke, Fathom, Orange, Mackau, Macguarie, Westminster, Onslow, and Flinders, which showed high adaptability to local climatic conditions and enhanced 1000-grain weight compared with local standard and check cultivars. Crossings of these isolated cultivars followed through with local standard genotypes, obtaining the F_1 hybrid populations. Speeding up the process, more hybrid generations (F_2, F_4) abound under greenhouse conditions in autumn and winter. During the study period, the selection of 21 crossed lines according to economically valuable traits at the level and above local standard cultivars ensued.

According to the phenotypic performance, the selected genotypes of hybrid populations achieved a mid-ripening status, with a growing season of 79–83 days compared with the standard cultivar Karagandinckiy-5 (78 days). The plant height was below the standard (100 cm) and ranged from 35.4 to 69.5 cm. On average, the spike length was 9.2 cm; however, long spikes protruded in the hybrid population Admiral × Karabalykskiy-150 (12 cm), with the shortest in Admiral × Karagandinckiy-6 (4.3 cm). In hybrid populations, the 1000-grain weight ranged from 38.8 to 58.0 g, and three showed as promising for the said trait, i.e., Macguarie × Arna (56.6 g), Flinders × Tselinniy golozerniy (56.4 g), and Flinders × Omskiy golozerniy (58.0 g) (Figure 3). According to the grains in the ear having more than 20, seven samples stood out, and on the number of grains from one plant over 34, eight samples excelled (Figure 4).

On grain weight per plant, the highest trait values resulted in the hybrid populations Buloke × Karagandinckiy-6 (2.88 g), Onslow × Karabalykskiy 10 (2.92 g), and Onslow × Karabalykskiy 43 (2.94 g), whereas for least were Admiral × Donetskiy-9 (0.86 g), Admiral × Karagandinckiy-6 (0.71 g), and Westminster × Astana-2007 (0.82 g), with the same ratios observed for the attribute, grain weight per spike, which may indicate small-seeded and frail grains (Figure 5). Two-row spring barley populations, viz., Buloke × Karagandinckiy-6 (184 g), Fathom × Donetskiy-9 (116.4 g), and Onslow × Karabalykskiy-43 (140.1 g) revealed highly productive (1 m^2) due to productive bushiness, more ear length and grains per spike, and grain weight per plant.

Establishing a weak positive correlation arose between productivity and spike length (r = 0.247) and productivity and plant height (r = 0.274). Productivity and number of grains per ear (r = 0.362), productivity and grain weight per ear (r = 0.486), and productivity

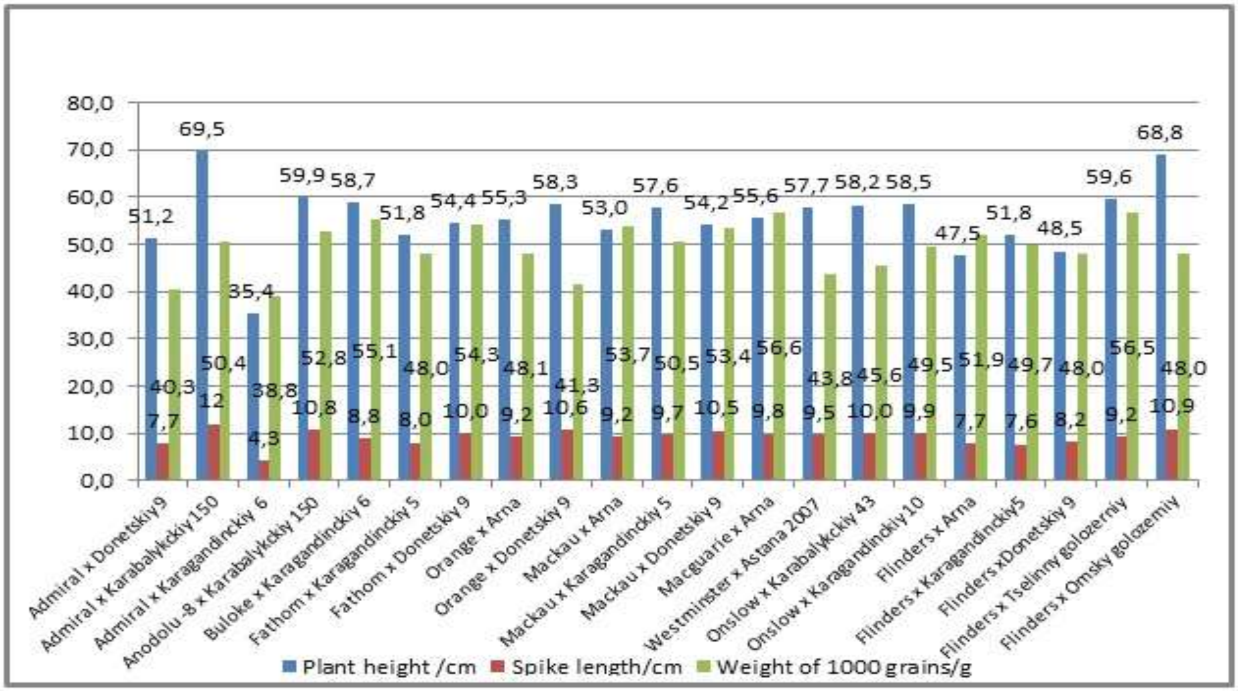


Figure 3. Structure - plant height, ear length, and weight of 1000 grains of F_4 hybrid lines.

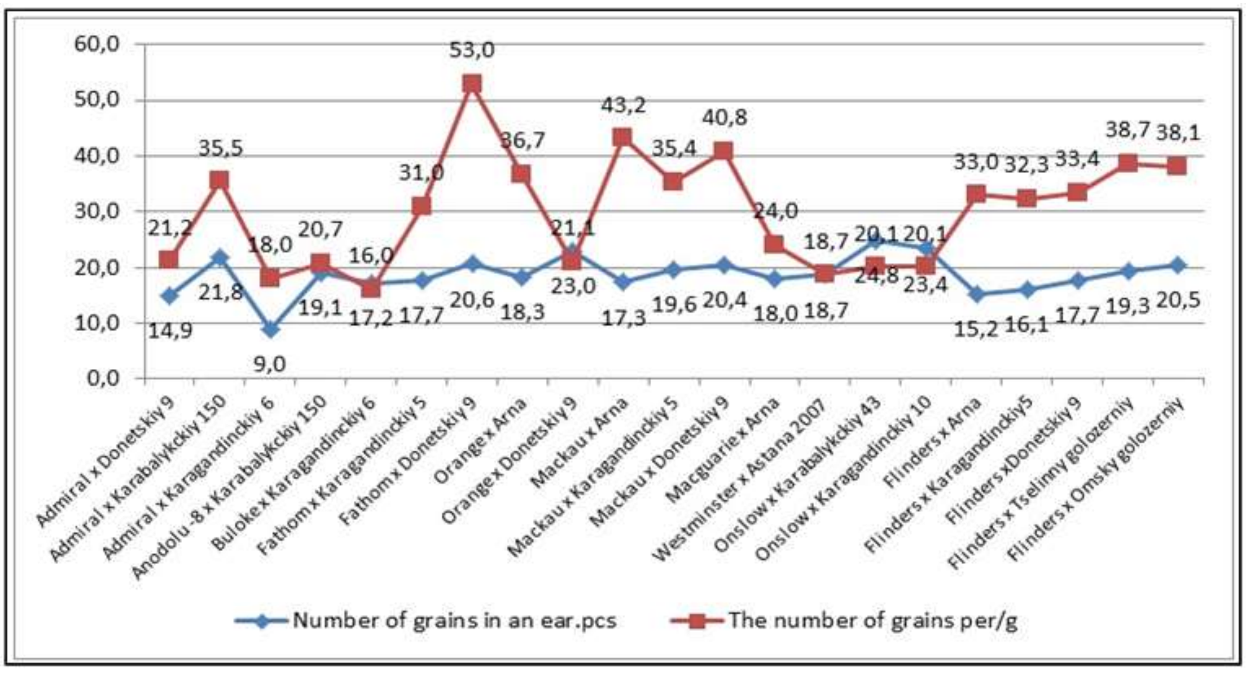


Figure 4. Quantitative indicators of the number of grains in an ear and their weight F_4.

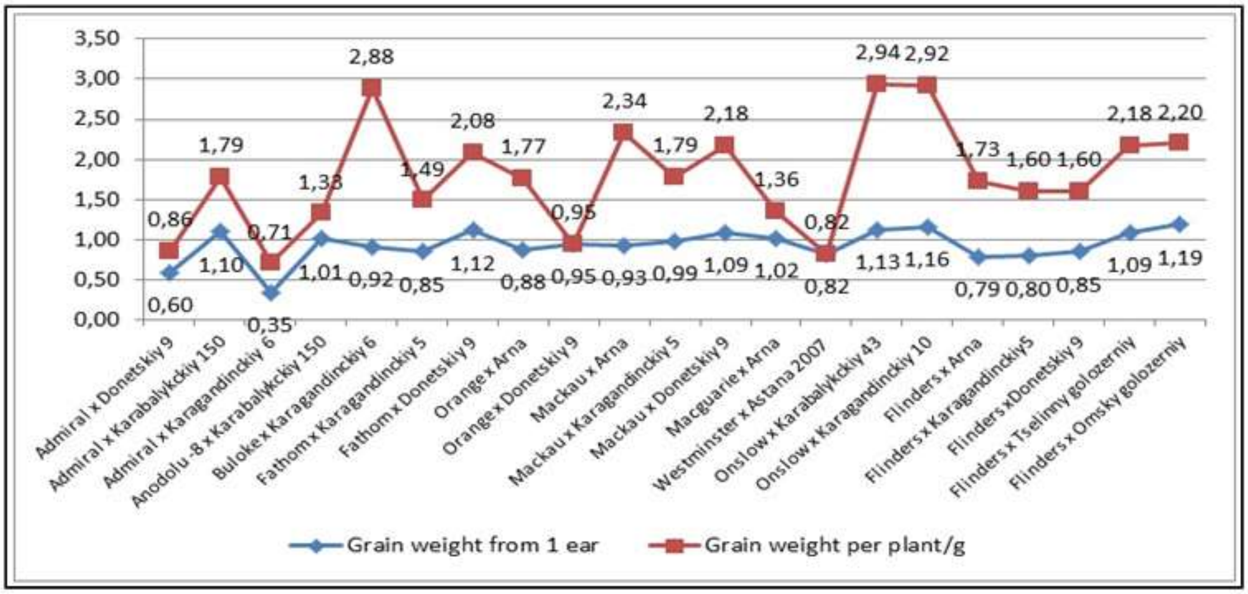


Figure 5. Structural analysis indicators - F_4 - grain weight per ear and per plant.

and weight of 1000 grains (r = 0.470) have an average positive correlation. A high positive correlation was apparent between productivity and grain weight per plant (r = 0.828), productivity, and productive bushiness (r = 0.727) (Table 1). The nature of the obtained associations among the yield-related traits of the hybrid lines can further guide the choice of any characteristic to acquire the desired results in the selection process of the promising genotypes.

The coefficient of variation showed the degree of variability in populations in terms of tillering, plant height, spike length, grain weight per spike, and 1000-grain weight. The vital signs of variability were the spike length and grains per spike, influencing the total productivity (Tokhetova *et al.*, 2017; Ivanova and Volkova, 2019). Plant variation provided a positive correlation of F_3–F_4 hybrid lines of spring barley per 1 m^2 in terms of plant height, ear length, grains per spike, grains per plant, and grain weight per plant, compared with standard cultivars having all traits are moderate and significant variable, except for plant height in the hybrid populations, i.e., Mackau × Karagandinckiy-5, Macguarie × Arna, and Flinders × Omskiy golozerniy, where the variability was nonsignificant. Wide variability occurred for grain weight per plant, varying from 25.1% to 79.7%. Analyzing the grain mass variability per plant, more promising hybrid combinations were Fathom × Karagandinckiy-5, Onslow × Karagandinckiy-10, Admiral × Karabalykskiy-150, and Admiral × Donetskiy-9 (Table 2).

At the second field station of the Akmola Region (Peasant farm "Niva"), in the same spring barley collection from Australia, studies also ran against the local standard cultivar Astana-2000. Phenological observations for days to heading did not differ significantly from the conditions of Central Kazakhstan. Hybridization proceeded among the isolated cultivars (Franklin, Anodolu-86, Fathom, Flinders, Orange, Macguarie, Westminst, and Onslow) and locally released standard cultivars. Through the study years (2018–2020), the selected nine F_5 drought-tolerant hybrid lines with high productivity faced comparison with the standard Astana 2000. For the above-standard Astana 2000 traits, grain size (19–26 g), grains per spike (3.4–5 pcs), and the 1000-grain weight (55–71 g), four promising hybrid combinations emerged, i.e., Onslow × (Karagandinckiy-5 × Arna), Bass × Karabalykskiy-150, Granal × SMV93N-805-F-1Y-1M-OY-17TRS-OAP, and

Table 1. Correlation of Structural Characteristics of F_5 Hybrid Lines of Spring Barley.

Hybrid Lines	Vegetation period (days)	Plant height (cm)	Productive tillering (#)	Spike length (cm)	Grains per spike (#)	Grains per plan^{-1} (g)	Grains plant^{-1} (#)	Grains plant^{-1} (g)	1000-grain weight (g)	Grain weight in one sq.m. (g)
Admiral × Donetskiy 9	79	51.2	1.4	7.7	14.9	0.60	21.2	0.86	40.3	24.00
Admiral × Karabalykskiy 150	79	69.5	1.6	12	21.8	1.10	35.5	1.79	50.45	57.20
Admiral × Karagandinckiy 6	79	35.4	2.0	4.3	9.0	0.35	18.0	0.71	38.88	14.00
Anodolu -86 × Karabalykskiy 150	79	59.9	1.3	10.8	19.1	1.01	20.7	1.33	52.87	68.68
Buloke × Karagandinckiy 6	80	58.7	3.1	8.8	17.2	0.92	16.0	2.88	55.08	184.00
Fathom × Karagandinckiy 5	79	51.8	1.7	8.0	17.7	0.85	31.0	1.49	48.02	23.80
Fathom × Donetskiy 9	79	54.4	1.8	10.0	20.6	1.12	53.0	2.08	54.36	116.48
Orange × Arna	81	55.3	2.0	9.2	18.3	0.88	36.7	1.77	48.08	28.16
Orange × Donetskiy 9	80	58.3	1.0	10.6	23.0	0.95	21.1	0.95	41.30	22.80
Mackau × Arna	79	53.0	2.5	9.2	17.3	0.93	43.2	2.34	53.75	74.40
Mackau × Karagandinckiy 5	79	57.6	1.8	9.7	19.6	0.99	35.4	1.79	50.51	35.64
Mackau × Donetskiy 9	79	54.2	2.0	10.5	20.4	1.09	40.8	2.18	53.43	95.92
Macguarie × Arna	80	55.6	1.3	9.8	18.0	1.02	24.0	1.36	56.66	32.64
Westminster × Astana 2007	82	57.7	1.0	9.5	18.7	0.82	18.7	0.82	43.85	13.12
Onslow × Karabalykskiy 43	81	58.2	2.6	10.0	24.8	1.13	20.1	2.94	45.56	140.12
Onslow × Karagandinckiy 10	80	58.5	2.5	9.9	23.4	1.16	20.1	2.92	49.57	92.80
Flinders × Arna	82	47.5	2.2	7.7	15.2	0.79	33.0	1.73	51.97	41.08
Flinders × Karagandinckiy 5	82	51.8	2.0	7.6	16.1	0.80	32.3	1.60	49.68	83.20
Flinders × Donetskiy 9	83	48.5	1.9	8.2	17.7	0.85	33.4	1.60	48.02	57.80
Flinders × Tselinny	83	59.6	2.0	9.2	19.3	1.09	38.7	2.18	56.47	87.20
Flinders × Omsiy golozerniy	82	68.8	1.8	10.9	20.5	1.19	38.1	2.20	58.04	61.86
Correlation: Grain weight in		0.274	0.727	0.247	0.362	0.486	0.075	0.828	0.470	

Table 2. Variation in traits of yield structure of hybrid barley lines $F_{3.\ -\ \%}$

Hybrid lines	Plant height (%)	Spike length (%)	Grains spike^{-1} (%)	Grains plant^{-1} (%)	Grain weight plant^{-1} (%)
Karagandinckiy 5	5.8	11.6	12.4	4.2	19.4
Admiral × Donetskiy 9	18.1	25.1	23.3	48.5	52.3
Admiral × Karabalykskiy 150	12.5	13.7	22.9	37.5	54.2
Admiral × Karagandinckiy 6	17.8	33.7	25.9	24.3	34.5
Anodolu -86 × Karabalykskiy 150	19.6	23.6	28.9	18.3	35.4
Buloke × Karagandinckiy 6	18.0	22.3	20.1	24.9	39.4
Fathom × Karagandinckiy 5	20.3	19.9	20.1	59.3	79.7
Fathom × Donetskiy 9	15.2	17.6	20.4	40.0	37.7
Orange × Arna	14.5	33.4	40.8	48.2	50.8
Orange × Donetskiy 9	28.2	44.0	36.5	34.7	49.7
Mackau × Arna	18.1	29.8	39.4	49.5	30.3
Mackau × Karagandinckiy 5	8.7	21.0	19.3	38.7	37.1
Mackau × Donetskiy 9	12.5	21.3	25.6	40.8	49.2
Macguarie × Arna	3.6	7.2	24.3	27.5	27.6
Westminster × Astana 2007	17.0	32.6	42.5	44.3	61.8
Onslow × Karabalykskiy 43	13.5	16.0	14.4	23.8	32.8
Onslow × Karagandinckiy 10	14.1	23.7	25.0	24.8	53.8
Flinders × Arna	16.5	23.7	31.2	18.7	42.1
Flinders × Karagandinckiy 5	11.4	14.8	24.5	22.8	35.8
Flinders × Donetskiy 9	20.9	19.0	18.9	30.2	34.5
Flinders × Tselinny golozerniy	16.1	13.7	15.3	12.2	25.7
Flinders × Omsiy golozerniy	5.5	24.9	26.3	26.9	25.1

Note: Since the variability is measured as a percentage, all values are shown in percentage (%).

Table 3. Indicators of protein content in hybrid lines of spring barley F_4.

Hybrid Lines	Maternal lines							
	Franklin- 14.57%	Anodolu-86 - 15.31%	Fathom- 14.86%	Flinders- 13.39%	Orange- 13.84%	Macguarie- 11.62%	Westminst- 13.84%	Onslow- 12.84%
ST - Astana 2000	15.16							
Franklin × Sabir	16.63							
Anodolu-86 × Donetskiy 8		16.04						
Fathom × Donetskiy 9			13.24					
Flinders × Karagandinckiy 5				10.45				
Orange × Karagandinckiy 5					13.84			
Macguarie × Arna						15.01		
Westminst × Karagandinckiy 80							13.84	
Onslow ×Karagandinckiy 10								13.69
Flinders × Omskiy golozerniy				15.31				

Granal × CMB89A-380-1M-OGH-105GH-1B-1OY-OAP-19AP-OAP. A recorded high mass of 1000-grain weight was with hybrid lines, i.e., Bass × Karabalykskiy 150 (62 g) and Granal × CMB89A-380-1M-OGH-105GH-1B-1OY-OAP-19AP-OAP (71 g) and classified as large-seeded, despite the number of grains per spike.

The crucial grain quality signs are the grain protein content and the creation of new cultivars. Genetically predisposed the formation of grain with the highest content of protein is currently in demand for fodder production (Bendina *et al*., 2020). In Kazakhstan, the barley grain protein content varied from 10%–15%, but in some genotypes, it reached up to 20% (Sidelnikova, 2015; Tokhetova *et al*., 2020). The analysis of the grain protein composition of the promising hybrid lines came through in F_3–F_4 populations compared with the local standard Astana-2000 and parental genotypes. Hybrid populations, viz., Lines Franklin × Sabir (16.63%), Anodolu-86 × Donetskiy-8 (16.04%), and Flinders × Omskiy golozerniy (15.31%), showed a higher protein content than the local standard, indicating the correct selection of parental forms. Compared with the parent types, on protein content in the grain, five hybrid lines have 14%–29% higher protein content than the parents, i.e., Franklin × Sabir (16.63%) vs. Franklin -14.57%, Macguarie × Arna (15.01%) vs. Macguarie - 11.62%, Flinders × Omskiy golozerniy (15.31%) vs. Flinders-13.39%, indicating the inheritance of grain quality from spring barley paternal types to their segregating populations. The remaining hybrids were practically at the level of maternal forms (Table 3).

According to electrophoresis results of hordeins in hybrid populations (F_3–F_4), it revealed that the two crossed lines, i.e., Macguarie × Arna and Westminst × Karagandinckiy-80, were significantly not different from the parental forms. Some of the spring barley hybrids have the same amount, mobility, and intensity of protein components, which might be because hybridization did not occur or the hybrid fully inherited the hordein genes from only one parental genotype, with the hybrid not obtained through the interaction of both parental cultivars. Hybrids Westminst ×

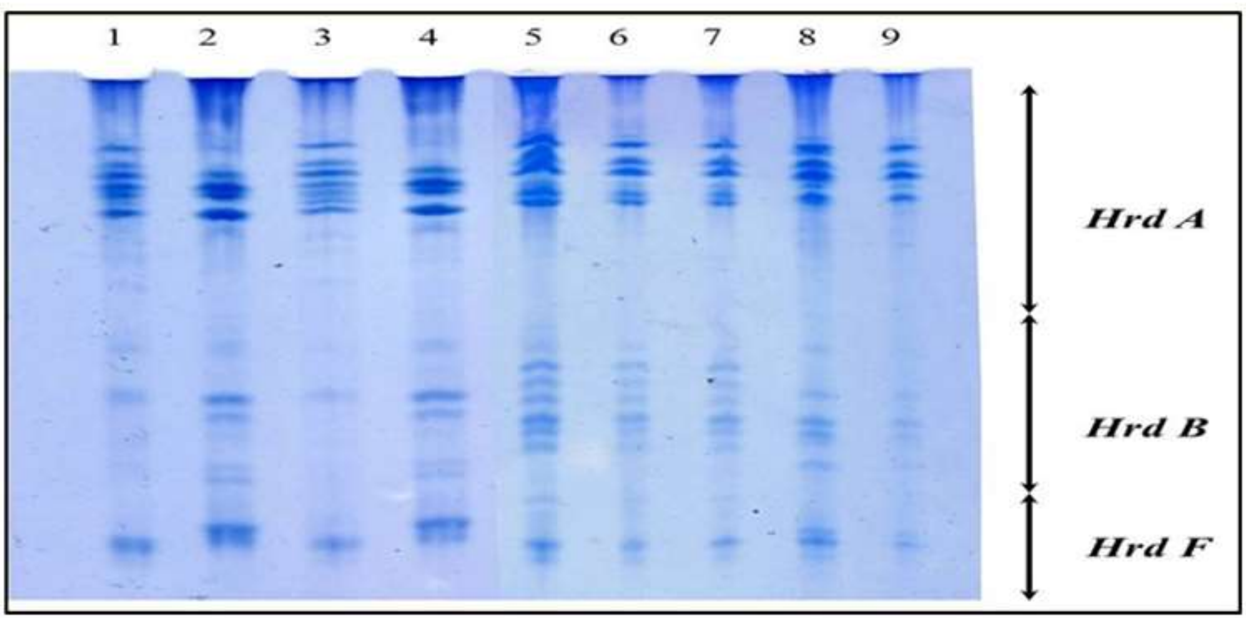


Figure 6. The electrophoretic spectrum of barley hybrid hordeins.
No. 1–3 - Flinders × Omskiy golozerniy; No. 4 - Flinders; No. 5, 7–9 - Onslow × Karagandinckiy 10; No. 6 - Onslow.

Karagandinckiy-80, Fathom × Donetskiy-9, Flinders × Karagandinckiy-5, Orange × Karagandinckiy-5, Onslow × Karagandinckiy-10, and Flinders × Omskiy golozerniy differed significantly from the parental genotypes in mobility, with the presence of protein components controlled by Hrd loci. The electrophoresis showed the hordein of the hybrid Flinders × Omskiy golozerniy with Flinders (lanes 1–3) and Onslow × Karagandinskiy 10 with the Onslow cultivar. In Anodolu 86 × Donetskiy, eight hybrids have seven components in the parental form, Fathom × Donetskiy 9 with four, and Flinders × Karagandinckiy 5 and Orange × Karagandinckiy have five each spectrum components in the zone controlled by the HrdA locus (Figure 6).

CONCLUSIONS

In the presented study, the promising spring barley hybrid populations passed as mid-ripening with 79–83 days, showing relatively suitable for the growing season in this region. Genotypes marked with short plants and medium-stemmed (35.4–69.5 cm) reflect resistance to lodging and drought. Based on 1000-grain weight (38.8–58.0 g), the selected promising hybrid populations were Macguarie × Arna (56.6 g), Flinders × Tselinny golozerniy (56.4 g), and Flinders × Omskiy golozerniy (58.0 g). For productivity (1 m^2), the hybrid lines were Buloke × Karagandinckiy 6 (184 g), Fathom × Donetskiy 9 (116.4 g), and Onslow × Karabalykskiy 43 (140.1g). Based on grain protein content against the local standard cultivar Astana 2000 (15.16%), the highest grain protein content emerged in the hybrid population Franklin × Sabir (16.63%), Anodolu-86 × Donetskiy-8 (16.04%), and Flinders × Omskiy golozerniy (15.31%). Correlation analysis identified that yield-related traits, viz., spike length, grains per spike, and 1000-grain weight, closely associate with each other and eventually affect productivity. Prospective hybrid lines that stand out in terms of productivity and resistant to drought, i.e., Buloke × Karagandinckiy-6, Fathom × Donetskiy-9, Onslow × Karabalykskiy-43, Onslow × (Karagandinckiy-5 × Arna), Bass × Karabalykskiy-150, Granal × CMB93H-805-F-1Y-1M-OY-17TRS-OAP, and Granal × CMB89A-380-1M-OGH-105GH-1B-1OY-OAP-19AP-OAP proved promising for use as the basis for developing drought-resistant and high-yielding spring barley cultivars adapted to local conditions. The said breeding materials are under investigation for further improvement at the same research stations in Kazakhstan.

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