

Research Article

Analysis of Economic-Biological Traits of Hull-Less Barley and Creation of Source Material for Resistance to Environmental Stress Factors

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Received 2 July 2020; Revised 11 August 2020; Accepted 23 August 2020; Published 1 September 2020

Academic Editor: David Clay

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The paper summarizes the experimental data from field and laboratory experiments on the study of the collection material of hull-less barley from ICARDA (*Hordeum vulgare* L.) on saline soils of the Kyzylorda region. The influence of the type of ripening of the variety and weather conditions of vegetation on the formation and variability of the grain yield of spring hull-less barley is shown. Traits less affected by external factors, such as plant height, spike length, number of spikelets per spike, and number of productive spikes per 1 m², are determined. It has been established that during the selection, stabilization on such traits occurs in early generations, which increases the efficiency of selection of adaptive varieties. At the present stage, using in hybridization the best hull-less forms ICNBF8-611/Aths, DeirAlla106/Strain205//Rhn-03/3/BF891M-582, Atahualpa/4/Avt/Attiki//Aths/3/Giza121/Pue, Atahualpa/4/Harrington/3/WI2291/Roho//WI2269, and HIGO/LINO with local recognized varieties, 20 hybrid populations have been obtained, and 150 lines selected from them, identified that donors of valuable traits are of particular interest for creating productive cereal varieties.

1. Introduction

The Kyzylorda region is located in the south of the Republic of Kazakhstan along the lower reaches of the Syrdarya river and occupies a large part of the Turanian lowland with a flat relief. In the west, it consists of the northern and eastern parts of the Aral Sea, in the south, it consists of the northern part of the Kyzylkum desert, and in the north, it consists of the Aral Karakum, Aryskum, and desert plateaus on the outskirts of Central Kazakhstan.

As a result of the monitoring conducted by Hu et al. [1] for Kyzylorda, the monitoring analysis shows that approximately 24.1 × 103 km² of land, which accounts for 10.5% of all Kyzylorda, is in a state of desertification. However, there has been a slight warming and humidifying climate trend. The intensity of agricultural and animal husbandry development is also not strong, and the output

value of agriculture and animal husbandry per unit of land is lower than the average level in Kazakhstan. Therefore, the cause of land desertification is difficult to determine. Further analysis shows that most of the land cover types in this state are desert, and the land around the desert, such as decertified grassland, is very sensitive to climate change and human disturbance. The slight warming and human activities of agriculture and animal husbandry development play a very strong role in promoting desertification.

Long-term rice cultivation in the conditions of the Kyzylorda region led to a general rising of the groundwater level in the fields where rice was cultivated and in adjacent fields of natural agrophytocenoses where rice was not cultivated. The hot and dry climate gives rise to the high evaporation capacity of soil moisture, which enhances the salinization processes, especially when mineralized groundwater is closely occurred. In addition, one of the

factors influencing the deterioration of the meliorative condition of irrigated lands is the increase in the salt regime of groundwater due to the unsatisfactory condition of the collector-discharge and drainage network, which is deformed in all places as a result of their siltation. The agroecological situation of irrigated lands in the Kyzylorda region is interconnected with the salinity of collector-drainage water flow, which varies between 2 and 5 g/L, and has a tendency to increase, and over the past decade, it has increased by 60%. This indicates the ongoing processes of salinization of the territory, caused, on the one hand, by an increase in the salinity of irrigation and ground waters, and, on the other hand, by insufficient drainage of the territory [2].

So, an analysis of the development trends of crop production in the Aral Sea region of Kazakhstan shows that in the future, it will develop under conditions of even more severe limitation of water resources, with increasing degradation of soil cover, processes of salinization, and anthropogenic desertification due to the Aral ecological crisis, as well as with a decrease in water reserves and lack of coordination between countries located in the upper course of the Syrdarya river regarding its effective use. In this connection, within the framework of the crop production diversification program of the Kyzylorda region, in conditions of the low water level and high salinity in the arable horizon of the soil, the expansion of the planting acreage of nontraditional salt-tolerant cereal crops is one of the principal directions of improving the sustainability of the agricultural industry in the region. At the same time, rice plantings in the Kyzylorda region must be kept at the level of 62.0–70.0 thousand hectares as an ameliorative crop, since a further reduction in rice crops may lead to a catastrophic increase in salinization of the engineering-prepared rice field systems of the region.

2. Literature Review

Drought and heat are major abiotic stresses that significantly reduce crop yield and seed quality. In the wake of global climate change, enhancing adaptive capacity of barley varieties by introducing novel germplasm into breeding programs or via new technologies is vital to sustain US barley production and meet the demands of the rapidly growing brewing industry [3]. In this regard, being a salt- and drought-tolerant crop, barley is of great economic importance in the arid regions of the Mediterranean and is rated by scientists as a medium-stable feed and highly stable cereal crop [4–6].

Barley (*Hordeum vulgare* L. spp *vulgare*) is an important crop in the agricultural sector of Kazakhstan, and it is grown in many different climatic zones over 1.5 million hectares annually. Currently, it is the second most widely-grown cereal crop in the country after wheat with an average annual total grain yield of 2.0 million tons. The end use for barley in the country is animal feed, and the average yield is 1.5 ton per hectare. Traditionally, two-rowed spring barley is the dominant type in all major barley growing regions as the country has long and cold winters and often arid summers.

The summer time is stressful in two out of three years due to drought and heat causing substantial grain yield loss [7]. The specific character of soil and climatic conditions of the Aral Sea region necessitates the creation of varieties of agricultural crops that are tolerant to biotic and abiotic environmental factors. Studies of many years [8] have shown that the assessment of salt tolerance of plants can be conducted on any type of salinity, so the salinity degree (osmotic pressure of the nutrient solution) of the substrate is of primary importance but not the qualitative composition of salts in it. The studies have found that the degree of salt tolerance of plants depends to some extent on the environmental conditions of the places where this variety has been formed. Thus, when assessing some types of wheat, it was established that in wheat, growing in areas with arid climate and a significant distribution of saline soils, the salt tolerance was significantly higher than in types occupying piedmont and mountainous areas where saline soils were practically not found. As a rule, varieties formed in arid ecological and geographical areas had higher level of salt tolerance than varieties from areas with a mild and humid climate and where practically there was no soil salinization [9]. In this regard, the environmental conditions of the Kyzylorda region are a kind of natural stressful background to conduct selection for early maturation, resistance to salinity, drought, spring frosts, diseases, and pests, which will increase the effectiveness of the work in creating a unique source material for adaptive selection of salt-tolerant varieties.

In 2006, a full-scale selection of barley was launched on the basis of the Kazakh Research Institute of Rice Production [10]. Unique collection of salt-tolerant forms of barley was stocked, a model of adaptive varieties for cultivation on saline soils was developed, and 6 new salt-tolerant varieties of barley were created. In barley, six-rowed barley is advantageous over two-rowed barley for feed due to the larger number of seeds per spike and the higher seed protein content. The growth of six-rowed barley is potentially important for breeding in agriculturally oriented countries, such as Kazakhstan [11, 12]. However, the results of biochemical analysis showed that, despite the aridity of the climate of the Kyzylorda region, there is a decrease in the protein content in the grain. In this respect, increasing the amount of protein is an important task of selection in the region. One of the solutions is the search for and widespread use of hull-less forms in programs of hybridization, which are characterized by a higher content of vegetable protein compared to hulled ones. Civilization faces the tremendous challenges of climate change and ensuring a stable, nutritious, and diverse food supply. Food barley can be part of the solution. One approach to accelerating the acceptance of food barley and to ensuring its broader utilization is to focus on its unique attributes. Meints et al. [13] argue that naked (hull-less) food barley should be viewed as an entirely new cereal crop with agronomic, nutritional, and end-use advantages. It is early maturing and input-use-efficient. It has unique dietary fiber and nutritional characteristics. And finally, it offers a palette of new flavors and qualities for a range of foods.

The main disadvantage of this crop is its low tolerance to adverse environmental factors compared to hulled barleys, which results in their low yield; however, the low fiber content due to the absence of films provides a higher nutritional value of the grain. It should be noted that increasing the protein, its stability by year, and yield of naked and hulled barley in the conditions of the Aral Sea region of Kazakhstan is the main task of selection, the solution of which primarily depends on the availability of completeness of information about the source material. At the present time, the State Register of Selection Achievements of the Republic of Kazakhstan does not contain hull-less barley varieties suitable for cultivation in the adverse ecological conditions of the Aral Sea region. In this connection, it is necessary to create hull-less barley samples, combining the adaptive potential of local hulled varieties of barley and the quality of hull-less ones. High productivity of the source material should be combined with comprehensive resistance to environmental stresses, early maturation, and economically valuable traits. The study of the biological characteristics of hull-less barley samples under stressful soil and climatic conditions of the Kyzylorda region will open up the possibilities to make selection more targeted and accelerate the breeding of new hull-less varieties.

Thus, the literature review on the study of the world collection under various stressful conditions has shown that the effectiveness of the selection work is determined by the right choice of source material, the ability to select for further works the plants that have hereditary positive qualities with the correct and complex assessment of their progeny, which was the main focus of this research work, including the following scientific tasks: search, comprehensive study, creation, and use of the valuable breeding material in practical selection and its preservation.

3. Methodology

The purpose of the research was to study 50 variety samples of hull-less barley from the ICARDA according to economically valuable and biological traits, create a gene pool of sources of economically valuable traits for use in practical selection, and determine the main selection criteria for resistant forms of hull-less barley at the initial stages of ontogenesis. In each year, each line was grown in three replicated square meter plots at each site. In total, 9 agronomic traits connected with plant architecture and yield components were studied: plant height, flag leaf area, rachis internode length, spike length, number of grains per spike, thousand grain weight, grain weight per spike, number of productive spikes, and grain yield.

3.1. Experimental Conditions. The climate of the Kyzylorda region is sharply continental. The research was conducted on the experimental fields of the research and production station of LLP Kazakh Research Institute of Rice Production named after I. Zhakhaev. The soil of the experimental field is meadow-boggy with a low humus content of up to 1% and

a high value of the dissolved solids of 0.65–0.88%. The type of salinity is chloride-sulfate and medium saline.

The hydrothermal coefficient (HTC) was defined as the ratio of the sum of precipitation for a certain period, multiplied by 10, to the sum of active temperatures above 10°C for the same period. Classification of humidification zones according to the HTC (according to [14]) is as follows: wet 1.6–1.3; slightly arid 1.3–1.0; arid 1.0–0.7; very arid 0.7–0.4; and dry <0.4.

The determination of the qualitative composition of grain was carried out in the analytical laboratory of the Kazakh Research Institute of Agriculture and Plant Growing (Almaty): protein content by the Kjeldahl method and starch by the polarimetric method. In laboratory conditions, the diagnosis of salt tolerance was carried out according to the methodology of the N.I. Vavilov All-Russian Research Institute of Plant Industry (VIR), phenological observations and structural analysis according to the methodology of VIR [15, 16], and statistical processing of the results according to Dospekhov [17]. The general and specific combining ability (GCA and SCA) was evaluated in the system of topcross breeding with source testers of traits. The analysis of combining ability was carried out by the method of Savchenko [18].

General model for topcross analysis of variance:

$$X_{ijk} = m + g_i + g_j + s_{ij} + e_{ijk}, \quad (1)$$

where Ψ_{ijk} is the value of the hybrid ($i \times j$); k is the replication; m is the mean value of the trait in the experiment; g_i and g_j are the GCA of the line and tester; s_{ij} is the line-tester interactions, otherwise SCA; and e_{ijk} is a random error.

4. Results

The economic value of the variety and its suitability for cultivation in a specific zone is largely determined by the length of the growing period as a whole and the nature of the individual stages of development.

It should be noted that various conditions of moisture availability and temperature regime during the years of research allowed us to give an objective assessment of the collected samples of spring barley (Table 1). Thus, the most unfavorable weather and climate conditions were in 2017 and according to the hydrothermal coefficient were characterized as acutely dry. The hydrothermal coefficient for the entire growing season was only 0.12. The average daily temperatures during the laying of generative organs exceeded the average long-term indicators by 5°C and 3°C.

During the flowering period of barley, daytime temperatures reached more than 40°C, which significantly reduced the setting of the grains. Precipitation that fell during the earing-maturation period did not have a positive effect on crop yield, since during this period, the plants were in the phase of waxy ripeness. Such conditions contributed to the rapid passage of the main phases of barley development, in particular, tillering-booting (HTC = 0.03) and booting-earring (HTC = 0.04) periods, with the exception of the sowing-germination period, when the sum of effective temperatures

TABLE 1: Hydrothermal conditions of interphase periods of spring barley in 2017–2019.

Year	Parameters	Periods						
		Seeding-shoots	Shoots-tillering	Tillering-booting	Booting-earring	Earing-maturation	Seeding-earring	Total for the growing season
2017	\sum rainfall, MM	2.9	8.0	0	0	11.1	10.9	22.0
	Average Temperature, °C	8.9	14.5	24.9	23.6	26.3	17.3	20.2
	\sum effective temperatures	77.7	213.8	374.5	259.4	983.5	863.1	1846.6
	HTC, MM/degree celsius	0.37	0.37	0.03	0.04	0.11	0.13	0.12
2018	\sum rainfall, MM	3.0	18.7	5.6	32.4	7.0	59.7	66.7
	Average Temperature, °C	14.6	17.9	22.3	19.8	28.2	18.8	22.1
	\sum effective temperatures	133.7	294.4	290.0	276.9	844.9	939.1	1759.8
	HTC, MM/degree celsius	0.22	0.64	0.19	1.17	0.08	0.64	0.38
2019	\sum rainfall, MM	12.0	20.5	42.6	10.5	2.0	85.6	87.6
	Average Temperature, °C	12.5	17.8	21.8	19.6	28.7	17.9	20.1
	\sum effective temperatures	115.6	278.3	275.6	229.5	856.5	899.0	1725.5
	HTC, MM/degree celsius	1.04	0.74	1.55	0.46	0.02	0.95	0.51

was insufficient for grain germination, which led to late emergence of seedlings and a decrease in field germination. In this regard, in 2017, there was a shortening of the growing season and an average of 74 days. The share of precocious samples in the collection was more than 75%. Although according to the HTC for the entire growing season of 2018 and 2019, they are characterized as dry, and they are characterized by sufficient moisture supply in such critical periods as tillering-booting (HTC=1.55) and “booting-earring” (HTC=1.17), which positively affected the formation of generative organs and determined the high yield of barley in these years.

As a result of phenological observations, 3 groups of samples were identified: early (60–65 days); short-season (71–79); and midseason (80–82). According to the results of the analysis of phenological observations, a group of naked barley samples was selected that retains a short growing period, regardless of climatic conditions, which are of interest as sources of early maturation in practical selection. A distinctive feature of this group of samples is the lengthiness of the tillering-booting period, which is reflected in high adaptability to the conditions of the Aral Sea region (Table 2).

The study of spring barley variety samples under rice system conditions has shown that field germination is largely determined by the sum of effective temperatures during the “sowing-seedlings” period, which is confirmed by a high correlation coefficient $r=0.71$. This is due to the fact that in rice crop rotation, barley is placed after rice, and the natural moisture of the soil is quite sufficient to produce seedlings. In our conditions, the limiting factor during the “sowing-seedlings” period is the lack of heat. Thus, on average, from experience in 2017–2019, at \sum effective temperatures = 133.7, field germination was 78%. No significant differences according to this trait between the hulled and hull-less forms were identified. The amplitude of variation of field germination in the context of genotypes has increased from low to high level ($V=9.5\text{--}93.2\%$); in general, the magnitude of

variability was 31.65%, which relates it to a highly variable trait, i.e., this trait is highly dependent on the influence of meteorological conditions of the year. In general, among the studied lines and variety samples, up to 25% of the samples had low field germination (35–50%), and depending on environmental conditions, they were characterized by high variability $V=35.4\text{--}62.3\%$.

The height of plants has varied significantly depending on the weather conditions of the year of study. So, for example, the study of the collection of hull-less barley ICARDA in meteorological conditions of different years has shown that the height of spring barley plants is in large part determined by water availability during the sowing-earring period, $r=0.654$. Thus, on average, according to experience at a HTC = 0.13 in the given period, the height of plants was 68.2 cm, at a HTC = 0.64 was 74.2 cm, and at a HTC = 0.85 was 84.8 cm. Coefficient of trait variability of the hulled group has amounted to 6.9% and is considered to be low-varying, whereas in the hull-less group with a coefficient of 17.6%, it is classified as the medium-varying type of variability.

Studies have shown that under Aral Sea conditions, hull-less samples are highly susceptible to stress factors; therefore, as a result of inhibition of growth processes, a sharp decrease in plant height is observed in years that are unfavorable by natural and climatic conditions. And only individual hull-less forms Arta/Atahualpa, Atahualpa, Atahualpa//Lignee527/Aths, Atahualpa/4/Harrington/3/WI2291/Roho//WI2269, Alanda/Legnee527/Arar/3/Asal, ICNBF8-611/Aths, As46//Giza121/Pue/3/BF891M-616, and Rum/BF891M-616 were distinguished by a low coefficient of variation with a plant height of more than 78 cm, with the value of the Syr Aruy standard as 65.0 cm. Table 3 shows the genotypes with high figures of plant height in combination with early maturation.

The above samples are of practical interest as a source material for tall-growing capacity selection, in particular, for rice crop rotation conditions, since barley is cultivated here mainly as a cover crop of perennial grasses.

TABLE 2: The duration of the interstage periods of the development of selected early maturing samples of hull-less and hulled barley (average for 2017–2019).

Catalogue numbers	Field germination, %	Growing period, days	Seedling-stillering	Length of period, days		
				Tillering-booting	Booting-earring	Earing-full maturity
Syr Aruy, check	70.2	78	14	20	12	22
Harmal	72.5	78	14	16	10	22
WI2291/Roho/WI2269	73.5	74	12	16	12	21
Salmas	75.3	72	14	18	12	24
Rihane	72.3	75	12	20	12	22
Moroc9-75//WI2291	75.2	75	12	18	10	21
Corris	75.2	75	12	19	12	24
Arta/Atahualpa	72.3	74	13	18	10	21
Atahualpa	72.4	70	14	16	16	22
Atahualpa//Lignee527/Aths	82.3	74	14	15	18	24
Atahualpa/4/Harrington/3/WI2291/Roho//WI2269	76.5	76	14	16	15	24
LSD05 (least significant difference)	1.32	1.09				

TABLE 3: Sources of lodging resistance in combination with early maturation (2017–2019).

Samples	Plant height, cm	Lodging resistance, score	Deviation from the standard, cm	Growing period, days	V, %
Syr Aruy, st	65.0 ± 1.95	9	—	78	17.9
Atahualpa/4/Harrington/3/WI2291/Roho//WI2269	79.5 ± 1.23	9	+11.5	79	14.9
Moroc9-75//WI2291	79.6 ± 0.65	9	+14.6	76	16.4
Corris	78.4 ± 0.89	9	+13.4	75	18.4
Arta/Atahualpa	76.9 ± 1.25	9	+11.9	75	12.5
Arar/Legnee527	75.8 ± 1.34	9	+10.8	72	17.4
Atahualpa	80.2 ± 1.85	9	+15.2	75	13.5
Alanda/Legnee527/Arar/3/Asal	80.0 ± 1.06	9	+15.0	75	12.8
LSD ₀₅ (least significant difference)	2.05				

Final grain productivity is the most important property of the variety, which is the goal of all agricultural industries, and therefore is determined as the main factor among the tasks of selection. In our experiments, the crop yield has varied to a significant extent due to weather conditions and maturity groups. The advantage of early ripening varieties by productivity under adverse conditions is noted. So, in the hyperarid 2017, the early maturing group was significantly higher by yield than the midseason and late maturing groups, and in more favorable weather and climatic conditions, midseason variety samples had the advantage. The yield of the standard Syr Aruy averaged 229 g/m² with fluctuations from 195 g/m² to 349 g/m². The average yield of the studied set of hull-less variety samples varied from 90 to 495 g/m². In arid 2017, the average yield was almost twice as low (Figure 1).

A comprehensive study of the collection set of hull-less forms of barley in comparison with the hulled forms has shown that their level of variability clearly differs by individual economically valuable traits (Figure 2).

As a result, by the value of the coefficient of variation, the studied quantitative traits are divided into three groups: the value of the coefficient of variation of less than 12% is low; 13–20% is average; and more than 21% is high. In hull-less

samples, the first group includes the following traits: plant height, number of spikelets per spike, and number of productive stems per 1 m²; thousand grain weight; the second group includes spike length, number of grains per spike, and grain weight per plant; the third group includes field germination, last internode length, productive tillage capacity, and grain weight per 1 m². In hulled samples, the first group includes the following traits: spike length, number of spikelets per spike, and number of productive stems per 1 m²; the second group includes plant height, number of grains per spike, and thousand grain weight; the third group includes field germination, last internode length, productive tillage capacity, grain weight per plant, and grain weight per 1 m². In general, the nature of variation of traits in both groups was approximately equal. Of particular interest for selection are the traits less affected by external factors, such as plant height, spike length, number of spikelets per spike, and number of productive spikes per 1 m², since during the selection, stabilization by such traits occurs in early generations, and it is possible to carry out selection with more chance of success.

Grain compositional components impacting barley (*Hordeum vulgare* L.) use in food, feed, and fuel products must be combined with improved agronomic traits to produce a commercially viable barley cultivar. Selection

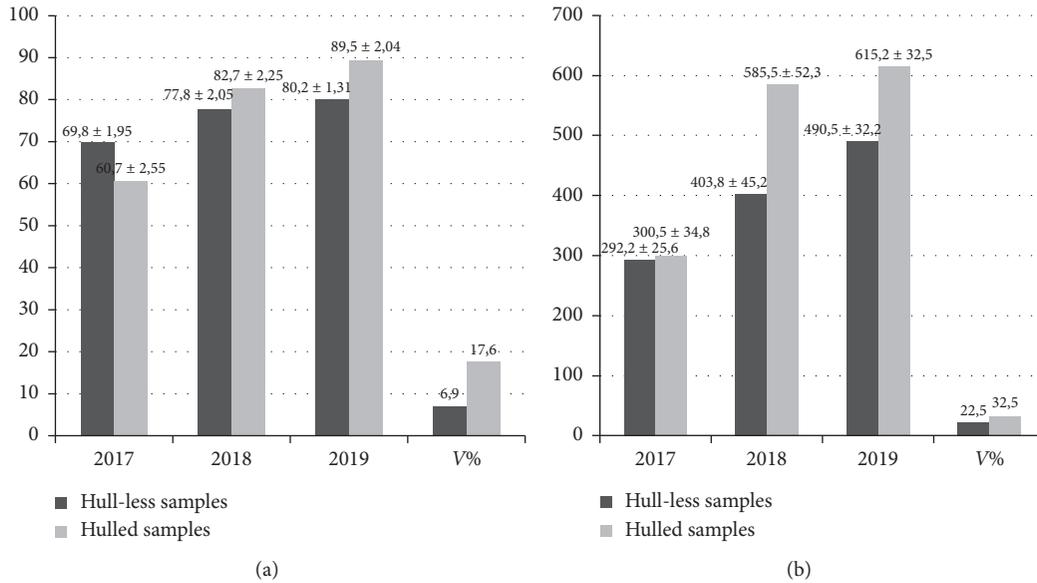


FIGURE 1: Average values and variability of the traits: (a) plant height and (b) grain yield.

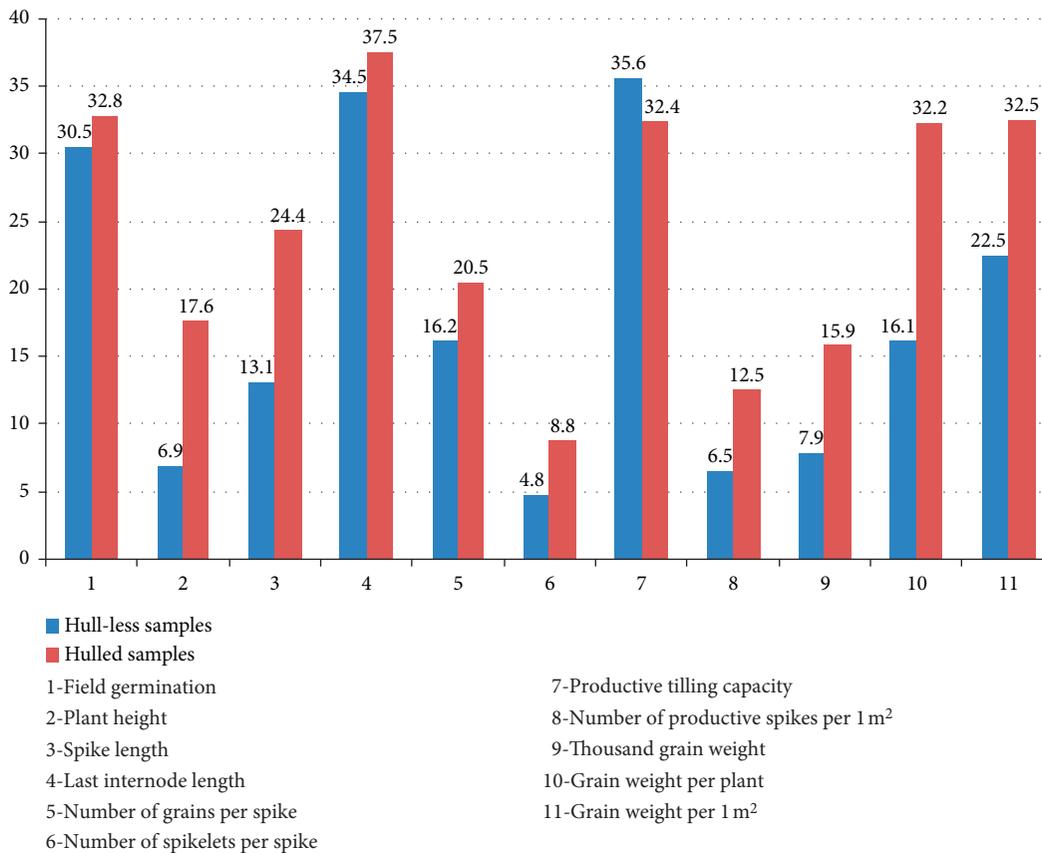


FIGURE 2: Variability of commercial-biological traits in the conditions of the Aral Sea region of Kazakhstan (2017–2019).

for high starch concentration among all barley types is feasible and will facilitate development of barley cultivars better suited for use in feed, malt, and ethanol production [19]. The biochemical analysis of grain carried out by us

in different years of moisture showed that husk and husked forms of barley significantly differed in mass and grain content and starch content but not in protein concentration.

Laboratory analyses were also conducted to determine the salt tolerance of 50 samples of hull-less barley. Finding suitable methods for properly screening the response of crop plants such as barley under salinity stress can be useful for a more efficient use of salty fields across the globe and for the development of salt-tolerant crop plant genotypes [20]. In our research, we used the integrated salt tolerance index (ISTI), according to which were determined. Salt tolerance was determined by the degree of depression of each analyzed trait relative to the values of the control experiment. The integrated salt tolerance index (ISTI, %) was calculated as an average indicator for all studied parameters. The complex of studied biometric indicators made it possible to characterize, in a comparative aspect, the salt tolerance of ICARDA barley genotypes. Expansion of intragroup intergenotypic variability towards an increase in the trait of the samples from ICARDA and the local collection indicates a wide range of phenotypic variation, meaning heterogeneity of genotypes, which makes it possible to expand the selection of a valuable source material for hybridization. The 25 genotypes identified by salt tolerance under laboratory conditions retained this trait even in the field. It is concluded that at the initial stages of development, the most informative traits during the selection for salt tolerance are seed germination and seedling length, which more objectively reflect the adaptability of variety samples.

So, the use of direct field and laboratory methods of assessing barley for salt tolerance made it possible to identify promising resistant variety samples of hull-less barley with a set of positive traits for use in practical selection (Table 4).

Due to a combination of traits, the hull-less variety samples Atahualpa/4/Avt/Attiki//Aths/3/Giza121/Pue, ICNBF8-611/Aths, DeirAlla106/Strain205//Rhn-03/3/BF891M-582, and Atahualpa/4/Harrington/3/WI2291/Roho//WI2269 are most interesting for selection in the Aral Sea region. At the present stage, using in hybridization the best hull-less forms with local recognized varieties, 20 hybrid populations have been obtained, and 150 lines selected from them are of particular interest for creating productive cereal varieties.

Hybridological analysis of F_1 plants showed that in traits such as spike density, cohesion of flower glumes with caryopsis (hulled), serration of awns, nondroop spike shape, uniformity of hybrid plants according to dominant characters, or single gene inheritance with dominance was observed. The dominance of a two-row spike structure over a six-row one was also revealed; however, intermedial forms were found in some populations. And when crossing the awned forms with the awnless ones, changes in dominance have been observed (awnlessness-awnedness), which is associated with the action of various loci. Table 5 shows the main morphological traits of barley and the features of their inheritance in F_1 .

In our research, the use of ecological and geographic remote forms in hybridization has been positively evaluated, and the effectiveness of which depends on determining the combination value of the genotypes involved. Using the topcross method for F_1 hybrids, general and specific combining abilities of 5 variety samples of hull-less barley were

studied: ICNBF8-611/Aths, DeirAlla106/Strain205//Rhn-03/3/BF891M-582, Atahualpa/4/Avt/Attiki//Aths/3/Giza121/Pue, Atahualpa/4/Harrington/3/WI2291/Roho//WI2269, HIGO/LINO, and Granal 447 were used as female parents. Varieties of hulled barley Syr Aruy, Medicum 127, Odessa 100, and Altyn Aray were used as testers. The main criteria for the selection of female parents were early maturation and absence of film and of male parents were high grain content, grain size, and tall-growing capacity. In general, analysis of variance revealed significant differences in the general (GCA) and specific (SCA) combining ability of the traits under study ($F_{fact} > F_{tabl}$), with the exception of the traits “productive tilling capacity and grain weight per plant.”

Genetic and statistical parameters of the traits under study varied both under the influence of environmental factors and from the varieties used in the topcross, including additive, dominant, and epistatic genetic interactions. Given the weather and climatic conditions of the region, it was concluded that in the best growing conditions, the control of quantitative traits was performed by genes with dominant effects, and in adverse growing conditions, by genes with additive interactions. The predominance of additive genetic interactions in the control of the studied traits in the unfavorable years indicates the possibility of efficient selection already in the F_2 generation. An analysis of the variance σ^2_s and σ^2_g for each parent form made it possible to determine the value of the individual parent forms (Table 6).

The conducted genetic and statistical analysis showed that in the inheritance of economically valuable traits of barley in the conditions of the Kyzylorda region, all known types of inheritance were revealed—from over dominance to depression. As marker traits for the selection of productive hulled forms of barley, it is proposed to use the number of grains per spike and to use thousand grain weight for the selection of hull-less forms. Thus, as a result of studying the combining ability of hull-less and hulled variety samples of barley, we have identified donors of economically valuable traits that are recommended for widespread use in synthetic selection: ICNBF8-611/Aths, DeirAlla106/Strain205//Rhn-03/3/BF891M-582, Medicum 127, Altyn Aray (productivity donors); ICNBF8-611/Aths, HIGO/LINO, Atahualpa/4/Avt/Attiki//Aths/3/Giza121/Pue (early maturation donors); Atahualpa/4/Harrington/3/WI2291/Roho//WI2269, DeirAlla106/Strain205//Rhn-03/3/BF891M-582, Atahualpa/4/Avt/Attiki//Aths/3/Giza121/Pue, Odessa 100, and Medicum 127 (adaptability donors).

5. Conclusion

A comprehensive selection and genetic analysis of the commercial-biological traits of hull-less barley in the specific natural and climatic conditions of the Aral Sea region of Kazakhstan has shown its high adaptability to environmental stress factors, which makes it possible to create ecologically plastic, salt- and drought-tolerant hull-less food varieties. The authors of this research, in order to increase the efficiency of selection of hull-less barley for productivity and quality in unfavorable ecological zones of Kazakhstan, recommend:

TABLE 4: Promising samples of hull-less barley for practical selection (average for 2017–2019).

Standard variety and numbers	Growing period, days	Plant height, cm	Flag leaf area, cm ²	Rachis internode length, cm	Spike length, cm	Number of grains per spike, pcs	Thousand grain weight, g	Grain weight per spike, g	Number of productive spikes, pcs/m ²	Grain yield, centner (ha)	Protein content %	Starch content %
Syr Aruy, st Atahualpa/4/	79	72.0	3.08	18.5	8.0	22.5	42.8	0.95	338	20.4	14.0	65.5
Harrington/3/WI2291/Roho//WI2269	82	80.7	3.03	24.5	8.5	24.0	41.5	0.99	335	26.5	14.5	66.2
DeirAlla106/Strain205//Rhn-03/3/BF891M-582	81	81.3	3.23	23.6	9.2	46.5	40.9	1.9	330	34.4	15.6	68.5
HIGO/LINO	82	82.0	4.56	28.2	9.0	42.0	42.0	1.76	330	25.1	15.0	67.9
Arta/Atahualpa/Atahualpa/4/Avt/	82	80.0	6.35	20.4	10.5	26.5	44.5	1.18	332	27.8	15.2	65.5
Attiki//Aths/3/Giza121/Pue	82	85.3	3.54	24.3	8.9	48.0	40.5	1.94	320	37.5	16.2	67.8
ICNBF8-611/Aths	79	82.7	3.08	21.7	8.5	42.0	41.0	1.72	325	34.5	15.8	66.8
Atahualpa Alanda/	77	84.0	3.17	25.3	8.9	24.0	44.8	1.08	340	25.4	14.8	68.5
Legnee527/Arar/3/Asal	80	83.0	4.26	23.5	10.5	26.0	42.0	1.09	342	26.0	15.2	69.5
ICNBF 8-655	77	79.9	5.38	24.8	9.6	25.4	43.0	1.09	338	26.2	15.5	67.5
BF 891M	79	85.2	4.36	29.3	9.2	25.3	44.8	1.13	341	25.9	16.0	68.0
ICNBF 8-611/Aths	81	80.5	4.98	25.2	8.6	48.9	40.7	1.99	321	32.0	15.4	68.7
Libya4/Atahualpa	81	83.0	4.47	20.8	9.0	25.6	42.0	1.08	340	27.0	15.8	68.0
LSD ₀₅ (least significant difference)	0.23	1.36	0.24	1.07	0.34	0.65	0.31	0.08	2.3	1.38	0.09	1.02

TABLE 5: Inheritance of morphological traits of barley and their manifestation in F₁.

Trait	Manifestation of a trait		Inheritance features
	Dominant	Recessive	
Spike structure	Two-row	Multirow	Complete dominance, with the occurrence of intermedial forms
Awnedness-awnlessness	Awnlessness	Awnedness	Awnlessness is more often dominant, but elements of a change in dominance have been identified
Furcate-awnedness	Furcate	Awnedness	Complete dominance
Spike density	Loose	Dense	Complete dominance
Cohesion of flower glumes with caryopsis	Hulled	Hull-less	Complete dominance

(i) to use the locally adaptive and environmentally plastic hull-less barley genotypes identified by the complex of useful traits ICNBF8-611/Aths, Deir-Alla106/Strain205//Rhn-03/3/BF891M-582,

Atahualpa/4/Harrington/3/WI2291/Roho//WI2269, and Atahualpa/4/Avt/Attiki//Aths/3/Giza121/Pue, HIGO/LINO as donors in hybridization programs;

TABLE 6: Estimates of the effects of general combining ability (\hat{g}_i and \hat{g}_j), 2017–2019.

Lines and varieties	Plant height	Spike length	Number of grains per spike	Thousand grain weight	Grain weight per spike	Length of the growing period
ICNBF8-611/Aths	-2.2	+0.8	+0.9	+3	+2.7	-5.4
DeirAlla106/Strain205//Rhn-03/3/BF891M-582	+1.6	-2.3	-2.2	+2.5	-3	+1
Atahualpa/4/Harrington/3/WI2291/Roho//WI2269	+2.3	+1.2	-2.5	-3.5	-2.7	+2.7
Atahualpa/4/Avt/Attiki//Aths/3/Giza121/Pue	+2	-1	-1.7	+1.8	+1.7	-3
HIGO/LINO	+1.2	+2	+1.7	-5.2	-1.7	-4
Syr Aruy	-3.1	-0.9	+1.8	+1.9	+2.3	-3
Medicum 127	+3.5	+1.6	+3	+3.7	+2.3	+5.4
Odessa 100	+3.5	-0.5	-1.5	-2.1	-0.8	+2.3
Altyn Aray	+2	-1.2	+2.8	+3.8	+2	-3.7
Granal 447	-3.5	+2.3	-4.8	-3.5	-4.5	+2.3
LSD ₀₅ (least significant difference) (GCA lines/testers)	0.95	0.43	0.54	0.48	0.86	1.02
	0.23	0.37	0.47	0.63	0.54	0.96

(ii) in order to increase the performance of the selection of salt- and drought-tolerant forms in the early stages of ontogenesis as the most informative traits to use the rate of germination in saline solution or sucrose, the total weight of the 14-day-old seedlings, and the length of seminal roots;

(iii) as marker traits for the selection of productive hulled forms of barley, it is proposed to use the number of grains per spike and to use thousand grain weight during the selection of hull-less forms.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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