RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
56 (5) 1872-1882, 2024
http://doi.org/10.54910/sabrao2024.56.5.11
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

MORPHO-PHYSIOLOGICAL CHARACTERISTICS OF SPRING BARLEY (*HORDEUM VULGARE* L.) IN THE STEPPE ZONE OF AKMOLINSKAYA REGION, KAZAKHSTAN

G.T. SYZDYKOVA[1], T.ZH. AIDARBEKOVA[1*], N.V. MALITSKAYA[2], S.T. SHEGENOV[1], R.E. NURGAZIYEV[1], M.U. ZHABAYEVA[3], and S.K. MAHANOVA[1]

[1]NPJSC Shokan Ualikhanov Kokshetau University, Kokshetau, Kazakhstan
[2]North Kazakhstan State University named after Manasha Kozybayeva, Petropavlovsk, Kazakhstan
[3]Kokshetau University named after Abai Myrzakhmetov, Kokshetau, Kazakhstan
[*]Corresponding author's email: aidarbekova_t@mail.ru
Email addresses of co-authors: syzdykova_1956@mail.ru, natali_gorec@mail.ru, serikshegenov2222@gmail.com, nurrashit@mail.ru, marhaba_zhabaeva@mail.ru, saulemach@mail.ru

SUMMARY

Spring barley (*Hordeum vulgare* L.) is an important food, fodder, and industrial crop. Barley cultivars' evaluation regarding trait variability using a variation factor further divided them into two groups. The first group included cultivars with a high variation factor (cv > 10%) based on the agronomic traits, viz., sprout density, dry biomass yield, number of plants before harvesting, and grain yield potential. The second group contained all other genotypes with a variation factor (cv = 6%) regarding morpho-physiological variables. These are number of nodal roots (cv = 0.8%–1.6%), flag leaf area (cv = 0.8%–1.6%), total leaf area (cv = 3.4%–5.7%), photosynthetic potential (cv = 0.06%–0.27%), photosynthesis net productivity (cv = 2.7%–5.6%), yielding capacity structural elements (grains per ear [cv = 1.0%–2.0%] and 1000-grain weight [cv = 1.5%–5.6%]). Cultivars Pamyat Raisy (1.8 t ha^{-1}) and Arna (1.7 t ha^{-1}) showed a reliable and enhanced yielding capacity compared with the reference cultivar Astana 2000 (1.6 t ha^{-1}), while other cultivars had an average yield potential (1.6 ± 1.8 t ha^{-1}).

Keywords: Barley (*H. vulgare* L.), variability, agronomic traits, morpho-physiological variables, grain yield potential, correlation, factor analysis

Key findings: Barley (*H. vulgare* L.) cultivars Pamyat Raisy (1.8 t ha^{-1}) and Arna (1.7 t ha^{-1}) were superior by the highest grain yield. A correlation was evident between grain yield in the study years with the grains per ear, productive stems, photosynthetic parameters, dry biomass yield, and the number of nodular roots during the "tillering – exit into the tube" period.

Communicating Editor: Dr. Sajjad Hussain Qureshi

Manuscript received January 18, 2024; Accepted: April 29, 2024.

Citation: Syzdykova GT, Aidarbekova TZH, Malitskaya NV, Shegenov ST, Nurgaziyev RE, Zhabayeva MU, Mahanova SK (2024). Morpho-physiological characteristics of spring barley (*hordeum vulgare* l.) in the steppe zone of Akmolinskaya region, Kazakhstan. *SABRAO J. Breed. Genet.* 56(5): 1872-1882. http://doi.org/10.54910/sabrao2024.56.5.11.

INTRODUCTION

Barley (Hordeum vulgare L.) is one of the most valuable and oldest cereal crops, ranking fourth in cultivation and production worldwide, after wheat, rice, and maize (FAOSTAT, 2019; Bahmani et al., 2021). With its short growth duration and suitable adaptability, barley can grow from 42° latitude south to 70° latitude north. Archaeological evidence proves the eastward introduction of barley throughout Eurasia (Lister et al., 2018). The 2017–2018 world barley production reached 142.37 million tons and 160.53 million tons in 2020–2021 (Mohamed et al., 2021).

The barley-sown area increased by 17.5% in 2022 to 2.57 million hectares, while the harvesting area amounted to 2.42 million hectares (+11.4%) in 2023 in Kazakhstan. The barley harvest in Kazakhstan in 2023 reached 2.61 million tons, 2.5% lower than in 2022 due to drought. According to the gross harvest in 2023, North Kazakhstan had 550,100 tons, Kostanay had 427,000 tons, and Akmola regions at 384,800 tons (https://www.apk-inform.com/ru/news/1539416). In modern conditions, agricultural producers place high demands on new varieties since the cultivar is the basis of agricultural production. Along with high yields and stability over the years and diversity of economic uses, new varieties should have a high level of adaptability to environmental stress factors.

It is impossible to combine everything in one variety; therefore, barley breeding in the Scientific and Production Center of the grain Farm named after A.I. Baraev proceeded in several directions - the creation of cereals, forage, and fodder forms (https://baraev.kz/zhanalyktar/). In the Karabalyk Agricultural Experimental Station, the scientists have created and, since 2023, are introducing a new variety of multi-row barley, "Kairat," which has reached state variety testing for the second year (https://eldala.kz/dannye/kompanii/536-karabalykskaya-selskohozyajstvennaya-opytnaya-stanciya).

Generally, barley has become a poor man's crop because it is easy to cultivate, needs few requirements, and has a high capacity for adaptation to harsh environments (Riehl, 2019). Barley products, especially bread and beer, compose a complete diet based on health benefits from barley; hence, there is a need for agricultural development and reducing pressure on wheat imports (Kling, 2006). As an influential cereal, barley grain mainly serves malt production and animal feeds. The malt can be an ingredient for making beer, industrial alcohol, whisky, and malt syrups. Developing high-yielding barley cultivars with stable productivity requires comprehensive management regarding adaptability to specific environmental conditions. Such an approach was also an economically reasonable direction (Reinert et al., 2019). Farm production requires new cultivars with potential productivity up to 5 t ha^{-1} and higher that form sustainable yielding capacity under extreme environmental conditions and produce high-quality grains (Pryadun, 2020).

In the present era, new barley cultivars' development receives support from extensive breeding that affects considerable morphological modification of plants, facilitates up-to-date barley growing, and substantially increases yielding capacity (Wendler et al., 2015). The new cultivars should be drought-resistant and can dramatically raise their full biological potential (Abebe et al., 2015). A parent breeding material is crucial and requires continuous restoration to obtain new and economically valuable genes and complexes. Therefore, studying and utilizing the world collection is necessary to improve the grain crops' profitable, valuable characteristics (Rozanova and Khlestkina, 2020).

Based on the results of the ecological study of spring barley varieties from the international collection in Central and Northern Kazakhstan conditions, significant attention centered on the grain size (Baidyussen et al., 2021). The degree of variability of the main quantitative traits showed a slight difference in the change of mass of 1000 grains, the number of grains per spike, and the grain mass per spike depending on the cultivation zone (Tokhetova et al., 2017). As marker traits for selecting productive hulled forms of barley, a proposal suggests using the number of grains per spike and a thousand-grain weight during the hull-less form selection (Tokhetova et al., 2020).

Based on the above discussion, the potential research aimed to study the morpho-physiological indices of spring barley cultivars that determine their productivity and identify valuable genotypes for future breeding and production.

MATERIALS AND METHODS

Breeding materials and procedure

During 2015–2017, the experiment titled "Influence of Morpho-Physiological Indices of Barley Cultivars on Identification of Valuable Genotypes for Grain Breeding and Growing" began at the experimental area of the Elite Scientific and Training Center of the Shoqan Walikhanov Kokshetau University, Vasilkovka village, the Akmolinskaya Region, Kazakhstan. The preceding crop was black fallow. The study material included five midseason ripening cultivars of spring barley, i.e., Astana 2000 (reference), Pamyat Raisy, Ayat, Arna, and Baisheshek, procured from various research institutions in Kazakhstan. The cultivar Astana 2000, registered in the Akmolinskaya Region, was the reference genotype. The total plot area was 25 m^{-2}, and the declared area was 20 m^{-2}. All the variants followed a randomized complete block design (RCBD) with four replications. Seeding transpired at optimal dates for the zone—May 25–28, with the seeding rate at 3.5 million germinable seeds per hectare. Seed planting engaged the MSS-7 seeder (by Omsk Experimental Plant LLC, Russia).

Soil analysis

The experimental plot soil was common calcareous heavy loam chernozem. Before seeding, the collection of soil samples from the experimental plot came at the 0–40 cm depth. The humus content identification in the soil samples employed the Tyurin method modified by Simakov, and the humus content was 3.6%. The pH of the water extract analyzed by potentiometric assay was 6.5. Nitrate nitrogen content analysis used the Grandval and Lajoux phenol disulphonic method, while mobile phosphorus and exchangeable potassium content determination utilized the Machigin method. The soil's nitrate nitrogen, mobile phosphorus, and exchangeable potassium content were 15.3, 10, and 610 mg kg^{-1}, respectively (Aidarbekova et al., 2022).

Observations and data recording

Five spring barley (Hordeum vulgare L.) cultivars evaluation focused on six morpho-physiological indices. Data recording in 10 plants of various barley cultivars ensued during the growing season on the number of nodal roots, total leaf area, flag leaf area, photosynthetic potential, dry mass accumulation, and photosynthesis net productivity. Structural element identification for each cultivar occurred on four experimental plots of 0.25 m^{-2} in each replication. The number of plants before harvest, productive stems, grains per ear, 1000-grain weight, and grains yielding capacity proceeded to record. The grain harvest commenced at the wax ripeness stage with a Sampo-500 harvester (by Sampo Rosenlew, Finland). The study translated hopper grains into 14% moisture content and 100% purity.

Statistical analysis

Five spring barley (H. vulgare L.) varieties bore assessment based on six morpho-physiological indicators. The number of nodal roots during the vegetation period showed distinction for 10 plants of each type using the method by Taranovskaya (1957). Determining the assimilation surface of leaves followed the methodology of Nichiporovich (1969). Net photosynthesis productivity (NPP) calculation used the formula proposed by Tretyakov et al. (1990). The assessment of structural elements for each variety continued on four experimental plots measuring 0.25 m^{-2} each across all replicates. The recorded parameters included the number of plants before harvesting, productive stems, grains per spike, the mass of 1000 grains, and the biological grain yield. The assessments and observations progressed following the methodology of State Variety Testing (1985).

The grain harvesting commenced at the wax ripeness stage using the Sampo-500 combine harvester (Sampo Rosenlew, Finland). The grain from the hopper sustained adjustments to a moisture content of 14% and 100% purity. All the recorded experimental data analyses utilized the AgC-Stat software (https://www.agstat.com). Calculations on the average mean values (M), standard error of the mean values (±SEM), variation coefficient (cv), correlation coefficient (r), least significant difference ($LSD_{0.05}$), and character range (Lim) followed the procedure according to Dospekhov (1985)

RESULTS AND DISCUSSION

The observations revealed that the Influence of weather conditions on spring barley genotypes' yielding capacity over the years of research was asymmetrical (http://www.pogodaiklimat.ru). The variables, seed germination, and rooting, sustained considerable influences primarily from soil moisture content. Past studies also reported that moisture deficiency negatively affects the plant germinating power and preservation rate (Abdel-Ghani et al., 2015; Lodhi et al., 2015).

The prevailing weather conditions in the Akmolinskaya Region, Kazakhstan, have affected economically valuable characteristics of spring barley cultivars. Thus, in 2015 and 2016, during spring barley growth and development, the hydrothermic factor values were 0.5 and 0.3, which were below the long-running annual average (0.8), while in 2017, the factor was within the average. Therefore, the germinating power of spring barley cultivars in the field varied between 77.0% (Baisheshek) and 80.7% (Pamyat Raisy). It might be due to weather conditions during seeding and the emergence period. Moreover, the variation coefficient was also relatively low in the years varying in weather conditions. The minimal variation coefficient occurred with the barley cultivar Baisheshek (cv = 2%), while the maximum variation coefficient appeared with the reference cultivar Astana 2000 (cv = 8%) (Table 1). These results established that the field germinating power is a stable genetic characteristic vital for genotype selection (Monteiro et al., 2018) and improving barley plant adaptive traits (Thabet et al., 2018; Kushanova et al., 2023).

Economically valuable traits

Before harvest, observations indicated that plant preservation varied among barley cultivars, ranging from 73.7% (Astana 2000) to 76.7% (Pamyat Raisy). The results revealed that the variation coefficient with cultivar Pamyat Raisy was higher (cv = 7%) than the other four cultivars. Consequently, the existing environmental conditions during the growing period favorably affected the preservation of the cultivar Pamyat Raisy plants. Bento et al. (2021) reported plant preservation depends mainly on water availability in the first half of barley and wheat crop growth. Barley lines selected with improved germinating power and sprouting energy under negative water potential (-1.36 MPa equivalent to 5% breeding intensity) showed better preservation of barley plants under dry weather conditions (Springer and Mornhinweg, 2019; Tetyannikov et al., 2024).

Dynamics of nodal root development

Available water is one of the chief factors determining plant growth and distribution and a haven for the root system (Rich and Watt, 2013). The root system plays a particular role in the grain crop adaptation to drought conditions (Siddiqui et al., 2021). Based on the cultivars' genetic makeup and environmental conditions, the presented research noted considerable differences among the barley cultivars in the number of nodal roots.

In Northern Kazakhstan, the early and even emergence of nodal roots with late dying-off and at the end of the growing period is one of the viable characteristics of drought-resistant and productive barley cultivars. During tillering, the root system structure formation occurs, where the number of nodal roots mainly depends on the number of shoots

Table 1. Economically valuable traits of spring barley (*Hordeum vulgare* L.) cultivars in the Steppe Zone of Kazakhstan (2015–2017).

Cultivars	Density of sprouts (pcs/m^{-2})		Field germinating power (%)		Number of plants before harvest (pcs/m^{-2})		Plant preservation (%)	
	M±SD	VC - Variation coefficient (%)	M±SD	VC - Variation coefficient (%)	M±SD	VC - Variation coefficient (%)	M±SD	VC - Variation coefficient (%)
Astana 2000	240.3±11.91	24.0	80.0±3.90	8,0	177.0±10.55	23.0	73.7±1.03	2.0
Pamyat Raisy	242.0±8.53	19.0	80.7±3.14	7,0	185.7±15.34	34.0	76.7±3.39	7.0
Ayat	234.7±7.71	20.0	78.3±2.73	6,0	175.3±7.71	17.0	74.3±1.03	2.0
Arna	234.7±6.59	14.0	78.0±2.37	5,0	178.7±8.59	19.0	76.0±1.79	4.0
Baisheshek	230.3±3.14	7.0	77.0±0.89	2,0	173.3±5.82	13.0	75.3±1.37	3.0
Trait Lim	230.3 - 240.3		77.0 - 0.70		173.3 - 185.7		73.7 - 76.7	
Min/max	1.0		1.0		1.1		1.0	

Table 2. Static characteristics of morpho-physiological indices of spring barley (*Hordeum vulgare* L.) cultivars under conditions of the Steppe Zone of Kazakhstan (2015–2017).

Cultivars	Number of nodal roots (pcs/plant)								Photosynthesis activity indices									
	Tillering		Booting		Earing		Wax ripeness		Flag leaf area (thousand m^{-2} ha^{-1})		Total leaf area (thousand m^{-2} ha^{-1})		Photosynthetic potential (million m^{-2} ha^{-1} day)		Photosynthesis net productivity (g/m^{-2}.Day)		Dry mass yield (t ha^{-1})	
	M±SD	Cv %	M±SD	Cv %	M±SD	Cv %	M±SD	Cv %	M±SD	Cv %	M±SD	Cv %	M±SD	Cv %	M±SD	Cv %	M±SD	Cv %
Astana 2000	4.3±0.29	0.5	6.9±0.52	1.1	13.7±0.63	1.4	11.5±1.14	2.5	4.7±0.69	1.5	13.9±2.35	5.0	1.1±0.12	0.27	9.3±1.44	2.7	8.3±3.65	7.3
Pamyat Raisy	4.5±0.23	0.5	7.6±0.47	1.0	13.9±1.26	2.8	12.6±1.08	2.4	5.1±0.58	1.2	14.3±2.25	4.4	1.2±0.22	0.22	10.9±1.47	3.2	8.5±3.84	7.6
Ayat	4.2±0.18	0.4	7.2±0.18	0.4	14.2±0.40	1.3	12.5±0.67	1.5	4.7±0.36	0.8	12.8±1.73	3.4	1.0±0.00	0.06	9.7±1.44	2.9	8.5±4.19	8.2
Arna	4.6±0.29	0.6	7.7±0.19	0.4	15.0±0.19	0.4	13.5±0.87	1.9	5.2±0.76	1.6	14.1±2.89	5.7	1.1±0.09	0.18	11.6±2.63	5.6	9.2±4.77	9.9
Baisheshek	4.2±0.34	0.7	7.3±0.37	0.8	14.9±0.32	0.7	12.9±0.18	0.4	4.7±0.58	1.2	12.9±2.71	5.3	1.0±0.06	0.12	9.7±1.82	4.0	8.9±4.34	8.9
Trait Lim	4.2 - 4.6		6.9 - 7.7		13.7 - 15.0		11.5 - 13.5		4.7 - 5.2		12.8 - 14.3		1.0 - 1.29		9.3 - 11.6		8.3 – 9.2	
Min/max	1.1		2.1		1.1		1.2		1.1		1.1		1.2		1.2		1.1	

on the plant. The presented results revealed that initiation of the tillering node in barley cultivars started during the fourth leaf period. Over the years of research, the number of nodal roots was 4.4 ± 0.28 per spring barley plant during the booting stage, varying from 4.2 ± 0.34 to 4.6 ± 0.29 pcs. However, the cultivar Arna somewhat registered more nodal roots (4.6 ± 0.29 pcs) than the reference cultivar Astana 2000, accounting for 4.3 ± 0.29 pcs (Table 2).

During the booting period, the observed number of nodal roots, on average, was 7.3 ± 0.19 pcs per plant. The maximum number resulted in the cultivar Arna (7.7 + 0.19 pcs per plant), while in other cultivars, the index was lower, ranging from 0.1 to 0.8 pcs lower. According to Hecht et al. (2019), 1.8 times more nodal roots per unit area were evident in barley sprouting (212 to 3090 pcs) at the grain-filling stage and 1.6 times more at the grain-ripening phase (4285 pcs).

The results further detailed that during the earring stage, the average number of nodal roots per plant was 14.3 ± 0.56 pcs, which was 31%–51% higher than during the preceding periods. The most prominent barley cultivars were Ayat, Arna, and Baisheshek, with 10%–11% higher values than the reference cultivar, Astana 2000. At the wax ripening stage, the average number of nodal roots was 12.6 ± 0.79 pcs per plant, while most barley cultivars exhibited reduced root numbers. Notably, at the wax ripening stage, the cultivar Arna had the maximum number of nodal roots (13.5 ± 0.87 pcs per plant), and the said genotype characteristics positively affected its adaptation to existing environmental conditions. The barley cultivars with variability of nodal roots showed that the variation of this trait was insignificant before the booting stage (cv = 0.5%–0.7%) (Table 2).

The variation coefficient grows from the earring stage to the grain wax ripening stage (cv = 1.3–2.5%), indicating positive variability and a growing number of nodal roots even during the grain formation period. The varying range of this trait was visible during the plant growing period from booting through earring (Lim = 6.9–15.0), which authenticated the significant differences among various barley genotypes for the number of nodal roots. Cultivar biological characteristics were prominent in the number of nodal roots and grain-yielding capacity correlations. During the years of this research, the above correlation at the tillering stage was strong (r = 0.74–0.95, P = 0.04–0.24), while at the booting stage it was weak (r = 0.29–0.72, P = 0.29–0.90). In the dry years of 2015–2016, the correlation at the earring stage was slightly negative (r = -0.04 – -0.24, P = 0.04–0.24), while in the favorable condition of 2017, the correlation was positive (r = 0.48, P = 0.52). In 2015 and 2017, at the milky ripeness stage, the correlation was positive (r = 0.47–0.88, P = 0.51–1.37) but was slightly negative (r = -0.09, P = 0.09) in 2016, possibly due to weather conditions observed in August and September (Hydrothermal index = 0.2–0.8). Therefore, the nodal roots negatively affected plant productivity under arid conditions and positively influenced the same under favorable conditions.

Photosynthetic indices

Leaf effect on plant productivity formation depends on the location, either on top or below. Plant leaves are crucial during early ear differentiation to wax ripening (Syzdykova et al., 2018). In the pertinent research, the recorded maximum leaf area emerged at the earring stage, varying from 12,800 ± 1,730 (Ayat) to 14,300 ± 2,250 m^2 ha^{-1} (Pamyat Raisy), with the average being 13,600 ± 2,390 m^2 ha^{-1}. Past studies also reported that the leaf area changes rapidly at the earring stage (Alqudah et al., 2018).

The leaf growth pace materially enhances during the stages of ear establishment and subsequent stages of development. Leaf area heritability is necessary to develop plants with small leaves and large ears. Critical to providing the ear with assimilates lies with flag leaves, the size of which varies with growing conditions. The control of leaf growth was primarily genetic, as proven by a moderate to high heritability (0.67%–0.90%) (Alqudah and Schnurbusch, 2015).

During the study years, on average, the flag leaf area was 4,900 ± 590 m^{-2} ha^{-1}, varying from 4,700 ± 580 to 5,200 ± 760 m^{-2} ha^{-1}. However, the barley cultivars Pamyat Raisy and Arna showed the highest values (5,100 ± 580 and 5,200 ± 760 m^{-2} ha^{-1}, respectively), while the other cultivars showed similarity with the reference cultivar Astana 2000 (4,700 ± 690 m^{-2} ha^{-1}). The flag leaf area variability was insignificant (cv = 0.8–1.6). The variability coefficient varies from 3.4% to 5.7%. One must note that cultivar Ayat gave the minimum variability for that trait (cv = 3.4%), indicating a nonsignificance of the said cultivar for the photosynthetic potential.

Establishing crop photosynthetic potential depended on the leaf surface area development and formation. According to the present results, barley cultivars appeared with an average photosynthetic potential (1.1 ± 0.10 million m^{-2} ha^{-1} day). About this trait, the most prominent cultivar was Pamyat Raisy (1.2 ± 0.22), while the average value of the reference cultivar Astana 2000 was 1.1 ± 0.12 million m^{-2} ha^{-1} day. Photosynthetic potential variability of the spring barley cultivars showed a low trait variation (cv = 0.06%–0.27%).

Photosynthesis net productivity more precisely displayed the work of photosynthetic apparatus. Leaf mass area affects the dry mass, which also depends upon the available nutrients and moisture, light intensity, and temperature. In the relevant study, the leaf surface showed that the average vegetation photosynthesis net productivity of spring barley cultivars varied from 9.3 ± 1.44 (Astana 2000) to 11.6 ± 2.63 g m^{-2} day (Arna). Under the steppe Ukraine conditions, the average leaf index m^{-2} of spring barley cultivars during tillering and ear formation enunciated the photosynthesis net productivity varying from 8.01 to 8.89 g m^{-2} day (Panfilova et al., 2019).

Photosynthesis net productivity variability showed a slight variation for the trait (cv = 2.7%–5.6%). Fluctuations of photosynthetic indices in barley cultivars mostly correlated to weather conditions during the years of research and the cultivars' genetic potential. Regarding photosynthetic activity, the most prominent with distinguishing features were the barley cultivars Pamyat Raisy and Arna, which represent a valuable feedstock for developing high-yielding genotypes resistant to extreme weather conditions.

The outcomes signified that flag leaf area closely correlated with plant productivity (r = 0.60–0.73; P = 0.69–0.92). According to Du et al. (2019), a negative correlation occurred between the number of grains in the ear ($r = -0.345$, $P < 0.01$) and the flag leaf area. The promising research showed a strong correlation with the total leaf area (r = 0.60–0.71; P = 0.69–0.88). Wang et al. (2019) conducted the correlation of each top leaf and reported similar results about the leaf length and area of different leaves in barley genotypes.

The association of photosynthetic potential with plant productivity in dry years (2015–2016) was positive, on average (r = 0.42–0.44; P = 0.44–0.47), and closer in the favorable year of 2017 (r = 0.84; P = 1.22). Photosynthesis net productivity index, irrespective of weather conditions, has a functionally positive correlation with grain-yielding capacity (r = 0.56–0.80; P = 0.63–1.09), grains per ear (r = 0.42–0.44; P = 0.44–0.47), and dry biomass yield (r = 0.37–0.97; P = 0.38–2.09). However, in dry years (2015–2016), the correlation was slightly negative with 1000-grain weight (r = -0.04 to -0.35; P = 0.04–0.36), while in the favorable year of 2017, the correlation was positive (r = 0.42; P = 0.44).

Spring barley cultivars were vividly distinct by dry biomass accumulation. Maximum accumulation was visible at the milky wax stage, ranging from 8.3 ± 3.6 (Astana 2000) to 9.2 ± 4.7 t ha^{-1} (Arna). The variation coefficient concerning this trait was very high (cv = 73.3%–99.6%). However, these values depended on the cultivar characteristics and the year's weather conditions. During the study years, the dry biomass yield correlation was prominent with photosynthesis net productivity (r = 0.37–0.97; P = 0.38–2.09), productive stem number (r = 0.13–0.42; P = 0.13–0.44), and grain-yielding capacity (r = 0.25–0.57; P = 0.25–0.64). In the favorable year (2017), it was notable in the grains per ear (r = 0.21; P =

0.21), 1000-grain weight (r = 0.49; P = 0.53), flag leaf area (r = 0.52; P = 0.57), total leaf area (r = 0.44; P = 0.47), and the photosynthetic potential (r = 0.34; P = 0.35). In the dry years of 2015–2016, correlation values for the above traits were slightly negative.

Yield and yielding-capacity structural elements

In the presented study, the comparison of yield structural elements with spring barley cultivars showed the most prominent variation range (Lim = 173.3–186.0) and variation coefficient (cv = 13.0%–34.0 %) regarding plant number before harvesting. The significant variation of the structural elements with years hinged on seeding dates and the cultivar characteristics (Noworolnik, 2012). However, the minimum variability of that trait was evident in the cultivar Baisheshek (cv = 13%).

Dense plant population formation emerged with the barley cultivar Pamyat Raisy, probably due to a lower plant dying out. Plant preservation with the said cultivar was 76.7%, 0.7%–3.0% higher than other barley cultivars. Remarkably, this trait had high stability with reference cultivar Astana 2000, as evidenced by a low variation coefficient (cv – 8%). However, a higher variation appeared in the cultivar Baisheshek (cv – 25.0%). With the spring barley cultivar, the variation ranged from 208.0 to 223.0 pcs m^{-2} (Table 3). Grains per ear have linkages with length, number of internodes in the inflorescence, and the number of fertile spikelets. Two-rowed barley produces 30 to 40 grains per ear (Madić et al., 2012). According to Blum (2017), more grain formation surfaced in the moisture-abundant period from sprouting through booting. Therefore, the moisture deficiency after flowering results in lower barley grains and, eventually, lowers yielding capacity.

In spring barley cultivars, the number of grains per ear varied from 16.3 ± 0.52 (Baisheshek) to 17.7 ± 0.52 pcs (Pamyat Raisy), while the average value of the reference cultivar Astana 2000 was 16.7 ± 1.03 pcs. Grains per ear showed a lower variation coefficient (cv = 1.0%–2.0%) and was a more stable trait in the spring barley cultivars. The 1000-grain weight has a low variation, ranging from 44.4 ± 0.73 (Astana 2000) to 46.1 ± 0.9 (Baisheshek), possibly due to the genotypes' genetic makeup and existing weather conditions. Regarding this trait, the variation coefficient revealed a more stable trait (cv = 1.5%–5.6%), indicating that breeding based on the trait was superior under local conditions.

Grain yield, being a dependent trait, depends on its main constituents. The findings of many experiments stated that the yielding capacity of grain crop cultivars has articulate differences mainly due to growing conditions. Similarly, according to Li et al. (2020), the duration of ear formation, plant height, and ear length influenced yielding capacity, contributing to the grain crop adaptation to the prevailing environment. High variability (cv = 10%–20%) characterized barley cultivars' yielding capacity under the conditions of Northern Kazakhstan (Table 3). The association of grain yield's main structural elements has several differences, as traced by the study years. Thus, grain-yielding capacity, over the years of research, had a close association with the number of productive stems (r = 0.67–0.75; P = 0.81 – 0.97) and a medium association with the grains per ear (r = 0.41–0.56; P = 0.43–0.63).

During study years, apparent relations were noticeable between morpho-physiological indices and grain-yielding capacity, viz., the flag leaf area (r = 0.60–0.73; P = 0.69–0.92), total leaf area (r = 0.60–0.71; P = 0.69–0.88), photosynthetic potential (r = 0.42–0.84; P = 0.44–1.22), photosynthesis net productivity (r = 0.56–0.80; P = 0.63), nodal roots at the tillering stage (r = 0.74–0.95; P = 0.95–1.83), and the booting stage (r = 0.29–0.72; P = 0.29–0.90). However, during the dry years of 2015–2016, association of grain-yielding capacity with 1000-grain weight was negative (r = -0.39 – -0.71; P = 0.41-0.88), and in the favorable year of 2017, the said correlation was positive (r = 0.61, P = 0.70).

Table 3. Yielding capacity and yield structural elements with spring barley cultivars (*Hordeum vulgare* L.) in the Steppe Zone of Kazakhstan (2015–2017).

Cultivars	Number of plants before harvest (pcs m^{-2})		Number of productive stems (pcs m^{-2})		Grains per ear (pcs)		1000-grain weight (g)		Biological yielding capacity (t ha^{-1})	
	M±SD	VC - Variation coefficient (%)	M±SD	VC - Variation coefficient (%)	M±SD	VC - Variation coefficient (%)	M±SD	VC - Variation Coefficient (%)	M±SD	VC - Variation coefficient (%)
Astana 2000	177.0±10.55	23.0	209.7±3.72	8.0	16.7±1.03	2.0	44.4±0.73	1.5	1.6±0.10	20.0
Pamyat Raisy	185.7±15.34	34.0	223.0±6.75	15.0	17.7±0.52	1.0	45.0±1.60	3.2	1.8±0.06	10.0
Ayat	175.3±7.71	17.0	208.0±6.16	15.0	17.0±0.89	2.0	46.0±1.82	4.0	1.6±0.09	10.0
Arna	178.7±8.59	19.0	216.3±6.95	15.0	17.0±0.89	2.0	45.8±2.61	5.6	1.7±0.09	20.0
Baisheshek	173.3±5.82	13.0	212.3±11.67	25.0	16.3±0.52	1.0	46.1±0.9	2.0	1.6±0.10	20.0
Trait Lim	173.0 – 186.0		208.0 - 223.0		16.3 - 17.7		44.4 - 46.1		1.6 - 1.8	
Min/max	1.1		1.1		1.1		1.0		1.1	
LSD$_{0.05}$ 2015							2.74		0.10	
LSD$_{0.05}$ 2016							4.65		0.23	
LSD$_{0.05}$ 2017							2.25		0.11	

CONCLUSIONS

The studied barley cultivars characterization showed a high variability rate (over 10%), as indicated by sprout number, dry biomass yielding capacity, number of plants before harvesting, and grain-yielding capacity. Low variability (below 6%) was distinct with all the studied cultivars regarding the number of nodal roots, flag leaf area, total leaf area, photosynthetic potential, photosynthesis net productivity, grains per ear, and 1000-grain weight. The most prominent barley cultivars for grain-yielding capacity were the Pamyat Raisy (1.8 t ha^{-1}) and Arna (1.7 t ha^{-1}). A correlation was evident between grain-yielding capacity during research years and grains per ear, number of productive stems, photosynthetic indices, dry biomass yield, and the number of nodal roots during the tillering and booting periods.

REFERENCES

Abdel-Ghani AH, Neumann K, Wabila C, Sharma R, Dhanagond S, Owais SJ, Börner A, Graner A, Kilian B (2015). Diversity of germination and seedling traits in a spring barley (*Hordeum vulgare* L.) collection under drought simulated conditions. *Genet. Resour. Crop Evol.* 62(2): 275–292. doi:10.1007/s10722-014-0152-z.

Abebe TD, Naz AA, Léon J (2015). Landscape genomics reveal signatures of local adaptation in barley (*Hordeum vulgare* L.). *Front. Plant Sci.* 6: 813. doi:10.3389/fpls.2015.00813.

Aidarbekova TZh, Syzdykova GT, Malitskaya NV, Khusayinov AT, Zhabayeva MU, Makhanova SK, Shoikin OD (2022). Comparative evaluation of soft wheat (*Triticum aestivum* L.) lines in the steppe zone of the North-Kazakhstan region. *Agric. Biol.* 57 (1): 66–80. doi:10.15389/agrobiology.2022.1.66rus.

Alqudah AM, Schnurbusch T (2015). Barley leaf area and leaf growth rates are maximized during the pre-anthesis phase. *Agronomy* 5(2): 107–129. doi:10.3390/agronomy5020107.

Alqudah AM, Youssef HM, Graner A, Schnurbusch T (2018). Natural variation and genetic make-up of leaf blade area in spring barley. *Theor. Appl. Genet.* 131(4): 873–886. doi:10.1007/s00122-018-3053-2.

Bahmani M, O'Lone CE, Juhász A, Nye-Wood M, Dunn H, Edwards IB, Colgrave ML (2021). Application of mass spectrometry-based proteomics to barley. *Res. J. Agric. Food Chem.* 69(31): 8591–8609. doi:10.1021/acs.jafc.1c01871.

Baidyussen AA, Kushanova RZ, Djataev SA, Sereda GA, Sereda TG, Eltser VV (2021). The degree of expression of large grain size is determined by the genotype and conditions that arise before grain formation. *Bull. Altai State Agric. Uni.* 1(195): 21–27.

Bento VA, Ribeiro AFS, Russo A, Gouveia CM, Cardoso RM, Soares PMM (2021). The impact of climate change in wheat and barley yields in the Iberian Peninsula. *Scien. Rep*. 11(1): doi:10.1038/s41598-021-95014-6.

Blum A (2017). Plant Breeding for Stress Environments. Boca Raton: CRC Press. 231. doi:10.1201/9781351075718.

Dospekhov BA (1985). Methodology for Field Experiments. M. Agropromizdat.

Du B, Liu L, Wang Q, Sun G, Ren X, Li Ch, Sun D (2019). Identification of QTL underlying the leaf length and area of different leaves in barley. *Scien. Reps.* 9: 4431. doi: 10.1038/s41598-019-40703-6.

FAOSTAT (2019). Food and Agriculture Organization of the United Nations. 2019. Available online: https://www.fao.org/faostat/en/#home (accessed on 30 October 2021).

Fedin MA (ed.) (1985). Methodology of state variety testing of agricultural crops. Moscow. 269 p.

Hecht VL, Temperton VM**,** Nagel KA, Rascher U, Pude R, Postma JA (2019). Plant density modifies root system architecture in spring barley (*Hordeum vulgare* L.) through a change in nodal root number**.** *Plant Soil.* 439(1-2): 1–22. doi:10.1007/s11104-018-3764-9.

https://baraev.kz/zhanalyktar/

https://eldala.kz/dannye/kompanii/536-karabalykskaya-selskohozyajstvennaya-opytnaya-stanciya

https://www.apk-inform.com/ru/news/1539416

Kling J (2006). An introduction to barley-notes from css 330 world foods class. Accessed on 18 April 2004.

Kushanova RZh, Baidyussen AA, Sereda GA, Jatayev SA, Sereda TG (2023). Spring barley hybrids assessment for biological and economic features under drought conditions of Northern and Central Kazakhstan. *SABRAO J. Breed. Genet*. 55(3): 850-863. http://doi.org/10.54910/sabrao2023.55.3.20.

Li Z, Lhundrup N, Guo G, Dol K, Chen P, Gao L, Chemi W, Zhang J, Wang J, Nyema T, Dawa D, Li H (2020). Characterization of genetic diversity and genome-wide association mapping of three agronomic traits in Qingke barley (*Hordeum vulgare* L.) in the Qinghai-Tibet Plateau. *Front. Genet*. 11: 638-15. doi:10.3389/fgene.2020.00638.

Lister DL, Jones H, Oliveira HR, Petrie CA, Liu X, Cockram J, Kneale CJ, Kovaleva O, Jones MK (2018). Barley heads east: Genetic analyses reveal routes of spread through diverse Eurasian landscapes. *PLoS One* 13(7): e0196652. doi:10.1371/journal.pone.0196652.

Lodhi RD, Prasad LC, Bornare SS, Madakemohekar AH, Prasad R (2015). Stability analysis of yield and its component traits of barley (*Hordeum vulgare* L.) genotypes in multienvironment trials in the North-eastern plains of India. *SABRAO J. Breed. Genet*. 47(2): 143-159.

Madić M, Kneţević D, Paunović A, Đurović D (2012). Genetic analysis of spike traits in two - and multi-rowed barley crosses. *Genetika* 44(3): 475–482. doi: 10.2298/GENSR1203475M.

Mohamed AH, Omar AA, Attya AM, Elashtokhy MMA, Zayed EM, Rizk RM (2021). Morphological and molecular characterization of some Egyptian six-rowed barley (*Hordeum vulgare* L.). *Plants (Basel)* 10(11): 2527. doi:10.3390/plants10112527.

Monteiro VA, Amabile RF, Spehar CR, Faleiro FG, Vieira EA, Peixoto JR, Ribeiro Junior WQ, Leite-Montalvão AP (2018). Genetic parameters and morpho-agronomic characterization of barley in the Brazilian Savannah. *J. Instt. Brewing* 124: 121–131. doi:10.1002/jib.484.

Nichiporovich (1969). Methodical instructions for accounting and control of the main indicators of photosynthetic activity processes in crops. Moscow. 57.

Noworolnik K (2012). Morphological characters, plant phenology and yield of spring barley (*Hordeum sativum* L.) depending on cultivar properties and sowing date. *Acta Agrobot.* 65 (2): 171–176. doi:10.5586/aa.2012.071.

Panfilova A, Korkhova M, Gamayunova V, Fedorchuk M, Drobitko A, Nikonchuk N, Kovalenko O (2019). Formation of photosynthetic and grain yield of spring barley (*Hordeum vulgare* L.) depend on varietal characteristics and plant growth regulators. *Agron. Res.* 17(2): 608–620. doi: 10.15159/ar.19.099.

Pryadun UP (2020). Intensive idiotype modelling of spring barley cultivars for the Ural region. *Proceed. Orenburg State Agrarian Uni.* 4(84): 57–63. doi: 10.37670/2073-0853-2020-84-4-57-63.

Reinert S, Osthoff A, Léon J, Naz AA (2019). Population genetics revealed a new locus that underwent positive selection in barley. *Int. J. Mol. Sci. 20*(1): 202. doi:10.3390/ijms20010202.

Rich SM, Watt M (2013). Soil conditions and cereal root system architecture: Review and considerations for linking Darwin and Weaver. *J. Exp. Bot.* 64(5): 1193-208. doi: 10.1093/jxb/ert043.

Riehl S (2019). Barley in archaeology and early history. In Oxford Research Encyclopedia of Environmental Science; Oxford University Press: Oxford, UK.

Rozanova IV, Khlestkina EK (2020). NGS sequencing in barley breeding and genetic studies. *Vavilov J. Genet. Breed*. 24(4): 348–355. doi:10.18699/VJ20.627.

Siddiqui MN, Léon J, Naz AA, Ballvora A (2021). Genetics and genomics of root system variation in adaptation to drought stress in cereal crops. *J. Exp. Bot.* 72(4): 1007–1019. doi:10.1093/jxb/eraa487.

Springer TL, Mornhinweg DW (2019). Seed germination and early seedling growth of barley at negative water potentials. *Agronomy* 9(11): 671-10. doi:10.3390/agronomy9110671.

Syzdykova GT, Sereda SG, Malitskaya NV (2018). Selection of spring soft wheat (*Triticum aestivum L.*) cultivars with regard to adaptivity to conditions of the steppe zone of the Akmolinskaya region of Kazakhstan. *Agric. Biol.* 53(1): 103–110. doi:10.15389/agrobiology.2018.1.103rus.

Taranovskaya MG (1957). Methods of studying root systems. Moscow. Selkhozgiz. State Publishing House of Agricultural Literature. pp. 216.

Tetyannikov NV, Bome NA, Bazyuk DA (2024). Yield stability analysis of barley mutants using parametric and nonparametric statistics. *SABRAO J. Breed. Genet*. 56(2): 463-475. http://doi.org/10.54910/sabrao2024.56.2.2.

Thabet SG, Moursi YS, Karam MA, Graner A, Alqudah AM (2018). Genetic basis of drought tolerance during seed germination in barley. *PLoS One* 2: 13(11): e0206682. doi:10.1371/journal.pone.0206682.

Tokhetova LA, Tautenov IA, Zelinski GL, Demesinova AA (2017). Variability of main quantitative traits of the spring barley in different environmental conditions. *Ecol. Environ. Conserv*. 23(2): 1093–1098.

Tokhetova LA, Umirzakov SI, Nurymova RD, Baizhanova BK, Akhmedova GB (2020). Analysis of economic-biological traits of hullless barley and creation of source material for resistance to environmental stress factors. *Int. J. Agron.* Article ID: 8847753.

Tretyakov NN, Karnaukhova TV, Panichkin LA (1990). Workshop on Plant Physiology. Moscow. Agropromizdat. 1990. pp. 270 (in Russian).

Wang Q, Sun G, Ren X, Li C, Sun D (2019). Identification of QTL underlying the leaf length and area of different leaves in barley. *Scien. Rep*. 9(1): 3–9. doi:10.1038/s41598-019-40703-6.

Wendler N, Mascher M, Himmelbach A, Johnston P, Pickering R, Stein N (2015). Bulbosum to Go: A toolbox to utilize *Hordeum vulgare*/bulbosum introgressions for breeding and beyond. *Mol. Plant* 8(10): 1507–1519. doi:10.1016/j.molp.2015.05.004.