IRSTI 34.35.17 https://doi.org/10.26577/EJE2025821014

A.B. Rysbekova[1]*, E.N. Dyussibayeva[1], M.M. Abylkairova[1], A.E. Zeinullina[1], A.E.Orazov[2]

[1] NJSC S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan
[2]JSC Astana International University, Astana, Kazakhstan
*e-mail: a.rysbekova@kazatu.edu.kz

ECOLOGICAL TESTING OF PROSO MILLET COLLECTION UNDER CONDITIONS OF WESTERN AND NORTHERN KAZAKHSTAN

Proso millet (*Panicum miliaceum* L.) is a highly valuable cereal crop and one of the key food crops grown by humans. Proso millet is widespread in America, Europe and Asia. Therefore, the search for ways to increase the production of millet crops due to the growth of the world's population is very relevant today. Of all grain crops, proso millet stands out for its biological characteristics, such as drought and heat resistance. For this reason, proso millet can be grown in different soil and climatic conditions of Kazakhstan. However, this requires a comprehensive assessment of the adaptability of genotypes from various origins for the subsequent expansion of the cultivation range of this crop. For this purpose, domestic and foreign collection varieties of proso millet were selected for ecological testing in two regions: Northern and Western Kazakhstan, which are characterized by different climatic conditions. In our studies, the agricultural technology developed for these regions was used, as well as the guidelines for variety study of the world collection of proso millet. According to the methodology, phenological observations of plant growth and development and analysis of crop structure elements were carried out during the study. The statistical analysis revealed a significant relationship between the traits of productive tillering, weight of 1000 seeds, and number of grains in the main panicle, which can enhance the efficiency of plant breeding efforts aimed at increasing variety yield. Based on the assessment results, highly productive genotypes were identified for the two regions: K-10215 (671.9 g/m²), K-2468 (885.3 g/m²), Yarkoe 5 (572 g/m²), Shortandinskoe 7 (548 g/m²), and Saratovskoe 3 (492.6 g/m²). These genotypes can be utilized in breeding programs to develop new highly adaptive proso millet varieties.

Key words: proso millet, germplasm, ecological testing, correlation analysis.

А.Б. Рысбекова[1]*, Э.Н. Дюсибаева[1], М.М. Абылкаирова[1], А.Е. Зейнуллина[1], А.Е.Оразов[2]

[1]С.Сейфуллин атындағы Қазақ агротехникалық зерттеу университеті КеАҚ, Астана, Қазақстан
[2]Астана халықаралық университеті АҚ, Астана, Қазақстан
*e-mail: a.rysbekova@kazatu.edu.kz

Батыс және Солтүстік Қазақстан жағдайында тары коллекциясын экологиялық сынау

Кәдімгі тары (*Panicum miliaceum* L.) Америкада, Еуропада және Азияда кеңінен таралған бағалы дәнді дақыл және маңызды азық-түлік дақылдарының бірі болып саналады. Сондықтан жер шарындағы халық санының өсуін ескере отырып, тары дақылдарын өндіруді арттыру жолдарын іздестіру бүгінгі таңда өте өзекті мәселеге айналды. Барлық дәнді дақылдардың ішінен тары құрғақшылық пен ыстыққа төзімділік сияқты биологиялық қасиеттерімен ерекшеленеді. Осыған байланысты тары Қазақстанның әртүрлі топырақ-климаттық жағдайында өсіруге тиімді. Дегенмен, бұл дақылдың сорттарын өсіру алаңын кеңейту үшін әртүрлі шыққан генотиптердің бейімделгіштігін кешенді бағалауды талап етеді. Осы мақсатта әртүрлі климаттық жағдайлармен сипатталатын Солтүстік және Батыс Қазақстанда экологиялық сынау үшін тарының отандық және шетелдік коллекциялық сорттары іріктелді. Зерттеу жұмысымызда осы өңірлер үшін әзірленген агротехнологиясын, сондай-ақ әлемдік тары коллекциясын зерттеу үшін тары дақылының алуан түрлілігін зерттеуге арналған әдістемелік нұсқауларды пайдаланылды. Әдістеме бойынша зерттеу кезеңінде өсімдіктердің өсуі мен дамуын фенологиялық бақылаулар және өнімділіктің құрылымдылық элементеріне талдау жүргізілді. Осылайша, статистикалық талдау нәтижелері бойынша өнімді түптену белгісі мен 1000 тұқымның салмағы мен негізгі шашағының дәндер саны арасында тығыз байланыс анықталды. Анықталған байланыстар сорттардың өнімділігін арттыру

бойынша селекциялық жұмыстардың тиімділігін арттыруға мүмкіндік берді. Бағалау нәтижелері бойынша екі аймақта бағалы жоғары өнімді генотиптер: К-10215 – 671,9 г/м², К-2468 – 885,3 г/м², Яркое 5-572 г/м², Шортанды 7 -548 г/м², Саратовское 69 м² анықталды. Бөліп алынған сортүлгілерді жаңа жоғары бейімді тары сорттарын әзірлеу үшін пайдалануға болады.
Түйін сөздер: тары, гендік қор, экологиялық сынақ, корреляциялық талдау.

А.Б. Рысбекова[1]*, Э.Н. Дюсибаева[1], М.М. Абылкаирова[1],
А.Е. Зейнуллина[1], А.Е. Оразов[2]
[1]НАО «Казахский агротехнический исследовательский университет имени С. Сейфуллина»,
Астана, Казахстан
|[2]АО «Международный университет Астана», Астана, Казахстан
*e-mail: a.rysbekova@kazatu.edu.kz

**Экологическое испытание коллекции проса
в условиях Западного и Северного Казахстана**

Просо обыкновенное (*Panicum miliaceum* L.) – ценная крупяная культура является одной из важнейших продовольственных культур, которая широко распространена в Америке, Европе и Азии. Следовательно, поиск путей увеличения производства просяных культур при росте населения земли весьма актуален на сегодняшний день. Из всех зерновых культур просо выделяется своими биологическими особенностями, как засухоустойчивостью, а также жароустойчивостью. По этой причине просо можно выращивать в разных почвенно-климатических условиях Казахстана. Однако, это требует комплексной оценки адаптивности генотипов различного происхождения для последующего расширения ареала возделывания сортов данной культуры. С этой целью были подобраны отечественные и зарубежные коллекционные сортообразцы проса для экологичекого испытания в двух регионах: Северного и Западного Казахстана, характеризизующихся разными климатическими условиями. В наших исследованиях была использована агротехника, разработанная к данным регионам, а также методические указания по сортоизучению культуры проса по изучению мировой коллекции. Согласно методологии в период исследования были проведены фенологические наблюдения за ростом и развитием растений и анализ по элементам структуры урожая. Так, по результатам статистического анализа установлена значительная связь признака продуктивная кустистость с массой 1000 семян и числом зерен с главной метелки, что позволит повысить эффективность селекционых работ на повышению продуктивности сортообразцов. По итогам экологической оценки по двум регионам выделены ценные высокопродуктивные генотипы: К-10215 – 671,9 г/м², К-2468 – 885,3 г/м², Яркое 5 – 572 г/м², Шортандинское 7 – 548 г/м², Саратовское 3 – 492,6 г/м², которые могут быть использованы в селекционных программах при создании новых высокоадаптивных и продуктивных сортов проса в условиях Северного и Западного Казахстана.
Ключевые слова: просо, генофонд, экологическое испытание, корреляционный анализ.

Introduction

Proso millet (*Panicum miliaceum* L.) has a significant weight in the grain balance of multiple regions of Kazakhstan [1]. This cereal crop belongs to annual cereals. Archaeological data suggests that proso millet was first cultivated in Northern China approximately 10,000 years ago [2]. Today, it is widely cultivated across America, Europe, and Asia and remains one of the most important food crops globally [3]. Proso millet is valued for its short growth cycle and low moisture requirements, making it an excellent choice for crop rotation. Its inclusion in rotation helps conserve moisture in deep soil layers, suppress winter weeds, and reduce pest and disease incidence, making it an ideal companion crop for other cereals [4]. Additionally, in cases where adverse weather conditions delay or prevent the sowing of other crops, proso millet can be used as an intercrop to minimize economic losses [5]. Beyond its role as a food crop, proso millet is widely utilized in poultry and livestock feed, snack production, and winemaking, with the highest demand currently observed in poultry fodder production [6].

However, one of the reasons for proso millet low yield is drastic continentality and aridity of the climate in the main regions of the country [7]. Due to global climate change and complex natural and climatic conditions of Kazakhstan, the development of adaptive properties in cultivated plants becomes a priority direction of agricultural science in addressing the issues of food security of the country [8]. In order to expand the area of distribution of agricultural plants, it is necessary to assess the response rate of varieties in different soil and climatic zones. This approach has proven to be one of the most effective methods in plant breeding, enabling the identification of a variety adaptive potential, stress tolerance, genetic flexibility and plasticity, as well as its resistance to abiotic and biotic stresses. Since different crop genotypes respond differently to the same cultivation environment, ecological testing and study of variety-environment interactions are crucial steps before introducing new varieties into agricultural production [9].

The success of crop breeding relies on understanding the genotypically determined interrelationships of quality traits, selecting suitable parental forms for hybridization, and conducting an objective evaluation and selection of breeding material [10]. Correlation analysis between traits is widely used in breeding, particularly in the early stages of cereal crop development, where a large number of genotypes is assessed with limited seed material. Grain quality traits exhibit variability in their correlations depending on individual characteristics, growth periods, and environmental conditions. Therefore, identifying traits that consistently exhibit stable relationships or significant divergence is essential. When the absolute value of the correlation coefficient is sufficiently high or approaches a linear dependence, correlation coefficients can be effectively utilized in breeding programs [11]. For successful variety development, it is crucial to combine multiple quality traits while ensuring stability across different years. To avoid random selection, plant breeders should focus on key indicators of quality and productivity that demonstrate consistency and strong correlations with other important traits. The analysis of correlations consists in selecting the most significant genotypes from a set of quantitative indicators for improving the efficiency of selection [12]. Thus, the aim of the research was the ecological testing of proso millet collection samples of different ecological and geographical origins in the Western and Northern regions of Kazakhstan and the selection of highly adaptive variety samples for their subsequent involvement in the breeding process aimed at improvement of the quality and productivity of the crop.

Materials and methods

The proso millet gene pool was used as research material. There were 90 samples obtained from different countries such as Kyrgyzstan (1), Argentina (1), Pakistan (1), France (1), Afghanistan, USA (1), Uzbekistan (1), Canada (1), Iran (2), Australia (2), Belarus (2), Hungary (2), China (3), Tajikistan (3), India (5), Ukraine (5), Turkey (12), Russia (20), Kazakhstan (22), as well as 4 local breeding lines (Figure 1).

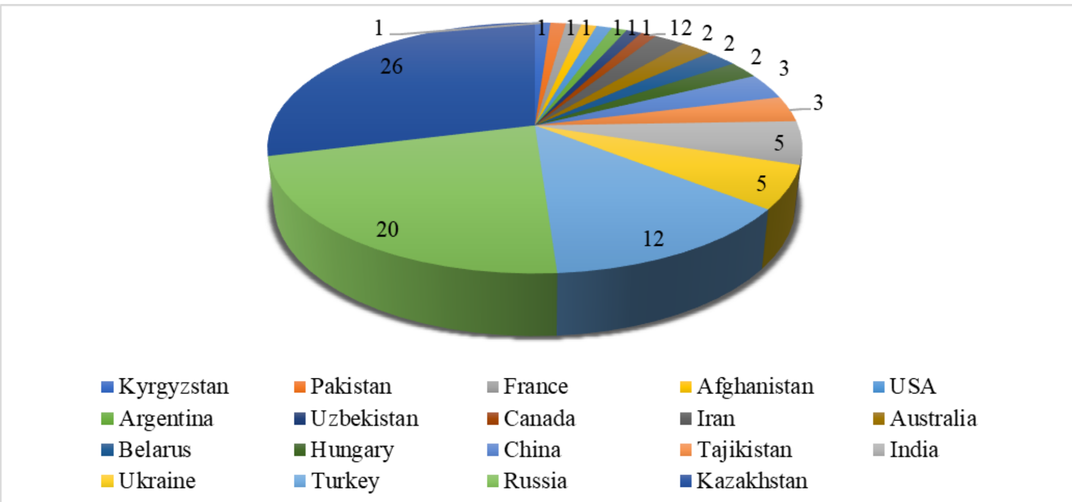


Figure 1 – Proso millet varieties and samples from different ecological and geographical origins

Field experiments were laid in the growing season of 2024 on experimental plots of two regions of the country: dry-steppe zone of Akmola region (A.I. Baraev Research and Production Centre for Grain Farming) and steppe zone of Aktobe region (Aktobe Agricultural Experimental Station).

The research was conducted according to the methodology for studying the world collection of proso millet [13]. The soils of the experimental plot were dark chestnut, the distance between plants was 10 cm, the arrangement of plots was systematic with three repetitions for each sample. Meteorological data during the growing season of the ecological trial were provided by local meteorological stations (Table 1).

Table 1 – Location and soil and climatic data of the two study regions, 2024 (June-August)

Region	Akmola region	Aktobe region
Geographical coordinates	51.41′/70.59′	50.27/57.20′
The type of soil	The chestnut dark brown (3.6-4.1% humus)	The chestnut dark and black soil (2.7% humus)
Precipitation, мм	309,1	223,1
Temperature, ºC	18,2	22,0
Max, ºC	27	28,0
Min, ºC	13,6	18,9

The meteorological conditions during the study period were characterized by a relatively uniform temperature regime compared to the long-term average data for these regions. Thus, the distribution of average daily air temperatures for 2024 for the period June-August amounted to – 18.2 ºC in Akmola region, which was almost at the level of average multiyear data of recent years. Similar temperature conditions during the growing season were observed in Aktobe region, they did not exceed 22.0 ºC. Although these regions are characterized by insufficient moisture, the precipitation is distributed unevenly both across years and within a given year. However, during the summer period, the annual precipitation exceeded long-term averages, reaching 309.1 mm and 223.1 mm, respectively. Throughout the study period, the temperature conditions and the precipitation generally ensured optimal soil moisture, promoting uniform emergence of proso millet sprouts. This, in its turn, had a significant impact on the duration of the vegetation period of the studied collection genotypes.

25 plants from each sample were selected to evaluate their qualitative and quantitative parameters for the structural analysis of productivity elements. The average values of key plant traits, including plant height (PH), number of seeds per panicle (NSPP), seed weight per panicle (SWPP, g), and productive tillering (PT) at the maturity stage, were recorded. Additionally, the weight of 1000 seeds (MTS) and productivity per square meter (Y) were measured after harvest. To ensure a comprehensive and accurate assessment of the growth and development characteristics of proso millet varieties, two groups of traits were analyzed: plant adaptation traits and productivity component traits. The plant adaptation traits included emergence to tillering duration (ETD, days), tube formation from the fifth leaf emergence to tillering (FLPI, days), flowering-to-maturity duration (FMD, days), sprouting-to-maturity vegetation duration (SMD, days), total vegetation period (VP, days), and plant height (PH, cm).

Statistical analysis of the obtained data was performed using Excel 2007, while primary data analysis, including correlation coefficient calculations, was conducted using R Studio (IDE) for Windows (version R 3.6.0, 2019). For the environmental test data, the following parameters were calculated: mean, minimum and maximum values, spread, and standard deviation. Correlation coefficients were used to analyze the mean values of 90 genotypes for six quantitative traits.

Results and discussion

The characterization of agronomic traits within a gene pool is a crucial step in selecting genotypes that are adaptable to various environmental conditions and possess desirable productive traits for future breeding programs aimed at developing improved varieties [14]. During the 2024 growing season, a comprehensive evaluation of 90 proso millet varieties was conducted in the Northern (A.I. Baraev Research and Production Centre for Grain Farming) and Western (Aktobe Agricultural Experimental Station) regions of the country. The assessment focused on identifying valuable agronomic traits to support breeding efforts for enhanced crop performance. The study of the world collection of proso millet including 61 foreign varieties and 29 local varieties analysed phenotypic variability between the two regions, including the important traits as plant height, productive tillering, number and weight of grains from the main panicle, weight of 1000 seeds, plant productivity and vegetation period. As a result, it was revealed that that in the current year under the prevailing soil and climatic conditions of the A.I. Barayev Research and Production Centre the average height value, varied from 92 to 154 cm, and in the Western region it was 78.7-144.7 cm, which indicates the influence of weather conditions (223.1-309.1 mm of precipitation), as in both regions the average height of proso millet plants in the past years was only 73.4±4.2 and 73.3±2.9, respectively.

For the trait of productive tillering the stable results of 1.7±0.9 was obtained in the Northern region of the country. However, in the Western region the climatic conditions did not favour the development of productive tillering and varied between 0.68 and 1.48. The number and the weight of grains from the main panicle had the most significant differences, as well as the ecological conditions of growth. Thus, observations on the experimental plots showed that there were fluctuations of 128-1392 grains from each panicle in the conditions of Northern region, which averaged 621±0.7 grains, while in the Western region the fluctuations were 102-1072 grains and the average was 429±0.5, respectively. The weight of grains from the panicle, according to the data from the experimental plots of A.I. Baraev Research and Production Centre for Grain Farming was 5.2±0.1 g, which was not a big difference comparing to the one from the Western region; this trait had a large variability between genotypes: 0.9-15 g for the Northern region and 0.26-8.82 g for the Western region (Table 2).

Table 2 – Mean values and variability of the main traits depending on the growing conditions

Traits	Units	Region*	2024	
			mean±	**variability**
Plant height	sm	Northern	124±2	92-154
		Western	106±0,4	78,7-144,7
Productive tillering	pc/1 plant	Northern	1,7±0,9	1-3,2
		Western	1,0±0,4	0,68-1,48
Number of seeds in panicle	pc	Northern	621±0,7	128-1392
		Western	429±0,5	102-1072
Weight of seeds in panicle	g	Northern	5,2±0,1	0,9-15
		Western	3,44±0,8	0,26-8,82
1000 seeds weight	g	Northern	7,73±0,3	4,5-11,5
		Western	7,01±0,8	3,9-9,93
Productivity	g/m^2	Northern	269±0,6	85-1259
		Western	289±0,4	35-636
Vegetation period	days	Northern	88,8±0,8	78-98
		Western	89,3±0,3	76-106
Note: different climatic regions of the Republic of Kazakhstan: Northern region – A.I. Baraev Research and Production Centre for Grain Farming (Akmola); Western region – Aktobe Agricultural Experimental Station (Aktobe).				

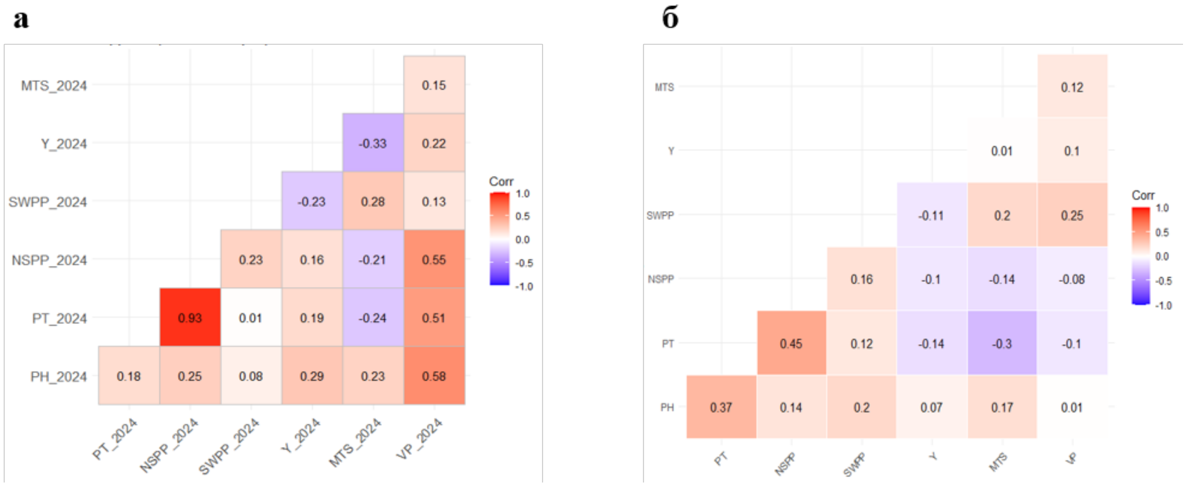
Large grain size shows the seed and food significance of the variety and determines the nutrient content, germination, food and fodder qualities of the genotype. At the same time, it is limited by the varietal characteristics of the plant, duration of its development, i.e. varietal specificity in combination with environmental conditions. Lack of productive moisture and increased temperatures during the grain filling period lead to a significant reduction in grain size [15]. Therefore, the need to determine the adaptive potential of proso millet gene pool for the 1000 seeds weight trait by testing in different conditions is an urgent task for plant breeding. During the study period from May to August, the most favourable conditions for the formation of large grain were present for the both regions of the country (7.73±0.3), when the mass of 1000 seeds of some varieties (K-10215, Pamyati Bersieva, Yarkoye 5, Shortandinskoye 7) was up to 9.9-11.5 g. Similar results of 1000 seeds weight were obtained in the conditions of Aktobe Agricultural Experimental Station, where it was 7.01±0.8 g in average and varied from 3.9 g to 9.93 g depending on the genotype. However, previous studies have shown that there were worse conditions for grain filling in the both studied regions (5.8±0.12 g) in previous years. The experimental data indicate that the evaluation of the average plant productivity (Y) of proso millet varieties showed similar productivity levels between the Northern and Western regions of the country, with an average yield of 269±0.6 g/m². The analysis of seed productivity per square meter allowed for the identification of the most productive genotypes, which demonstrated stable yields regardless of environmental conditions: K-10215 – 671.9 g/m², K-2468 – 885.3 g/m², Yarkoye 5 – 572 g/m², Shortandinskoye 7 – 548 g/m², Saratovskoye 3 – 492.6 g/m². These genotypes can serve as promising candidates for further breeding programs aimed at improving proso millet productivity.

The climate of Northern Kazakhstan is not able to ensure reliable ripening of medium-ripening and late-ripening forms of proso millet, which complicates attempts of their introduction in this region. Proso millet sprouts tolerate short-term temperature drops to +5°C. Autumn frosts below +2°C disrupt seed development and cause leaf freezing. In Akmola region May and September often have an average daily temperature below 9 ° C, and frosts can occur from early September, so, the main requirement for proso millet varieties is a short growing season. In this context, a key objective of the study was the selection and genetic evaluation of the gene pool to identify promising genotypes for the development of new proso millet varieties adapted for cultivation in the Northern region of the country.

The analysis of the vegetation period (VP) in proso millet plants revealed that the samples can be classified into three distinct groups based on their duration of vegetation: early-ripening (70-80 days); mid-ripening (81-95 days); late-ripening forms (100 days and more). The weather conditions of this region in 2024 were characterised by abundant precipitation of 223.1 mm, which led to an increase in the duration of the growing season, but it was still possible to identify 15 early-ripening genotypes, they accounted for 25% of the total foreign collection. Thus, according to the results of phenological studies in conditions of Akmola and Aktobe regions, the vegetation period was increased by almost 13 days and averaged 88.8±0.8 and 89.3±0.3, respectively.

As a result of ecological testing of the proso millet collection, the early-ripening and high-yielding samples (up to 1200 g/m^2) with vegetation period of 67-82 days suitable for cultivation in the conditions of dry-steppe and steppe zone of the Republic of Kazakhstan were selected.

Correlation analysis related to the climatic conditions of proso millet gene pool has been studied insufficiently in comparison with the main agricultural crops (Figure 2).



Note: PH – plant height (cm), NSPP – number of seeds per panicle (pcs), SWPP – seed weight per panicle (g), PT – productive tillering (pcs/1 plant), MTS – 1000 seeds weight (g), Y – grain yield per square metre (g/m2), VP – vegetation eriod (day). Highlights: red is positive correlation and blue is negative correlation ($p < 0.05$).

Figure 2 – The correlation coefficient (r) between valuable agronomic traits under specific conditions of A.I. Baraev Research and Production Centre for Grain Farming (Akmola): a – domestic collection; b – foreign collection.

In this study, the correlation coefficients between key agronomic traits of proso millet varieties were analyzed to assess their interrelationships. This analysis provides valuable insights into trait associations, aiding in the selection of genotypes with desirable characteristics for plant breeding programs. Thus, in the conditions of Akmola region, the data obtained in the current year indicate that productivity of local genotypes of proso millet Y is not related to weight of 1000 seeds MTS and weight of grains per panicle SWPP (r=-0.23, -0.33).

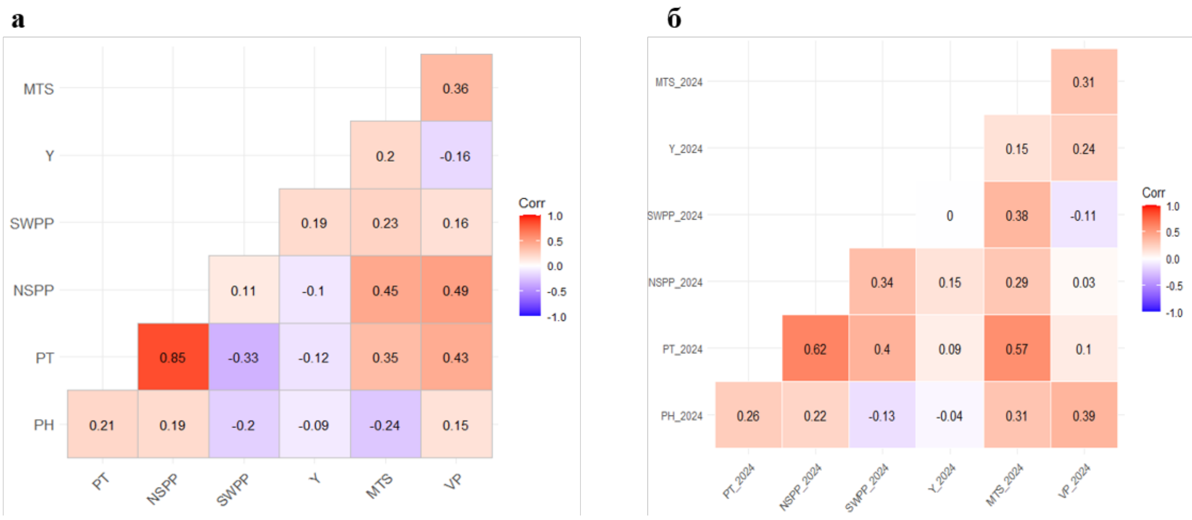
For the domestic collection, a positive correlation was observed between productive tillering PT and number of seeds per panicle NSPP (r=0-0.93). Less stable positive correlation was found for number of seeds per panicle NSPP and vegetation period VP; productive tillering PT and vegetation period VP; plant height PH and vegetation period VP, their correlation was 0.55, 0.51 and 0.58, respectively.

For the foreign collection under conditions of A.I. Baraev Research and Production Centre for Grain Farming, a positive correlation was revealed for multiple traits (r=0.14-0.45). Nevertheless, a significantly stable correlation was revealed between the traits of plant height PH and productive tillering PT (r=0,37); and between number of grains per panicle NSPP and plant height PH (r=0,45).

For the domestic and foreign collection, there was negative relationship between number of grains per panicle NSPP and plant productivity per square metre Y (r=-0.11-0.23); productive tillering PT and weight of 1000 seeds MTS (r=-0.24-0.3).

According to the results of the research in the conditions of Aktobe Agricultural Experimental Station (Western region), positive relationships were found between the traits: plant height PH and productive tillering PT; productive tillering PT and number of seeds per panicle NSPP; number of seeds per panicle NSPP and seed weight per panicle SWPP, number of seeds per panicle NSPP and weight of 1000 seeds MTS, productive tillering PT and weight of 1000 seeds MTS, weight of 1000 seeds MTS and vegetation period VP, productive tillering PT and vegetation period VP. The coefficient for these traits was r=0.11-0.85 for the domestic varieties, while the foreign samples showed 0.1-0.62.

In general, productive tillering was significant at seed filling phase and impacted both the number of grains per panicle and the weight of 1000 seeds. However, it was evident from the study that plant height PH did not affect productivity (Figure 3) as reported in the other similar crop breeding studies [16-18].



Note: PH – plant height (cm), NSPP – number of seeds per panicle (pcs), SWPP – seed weight per panicle (g), PT – productive tillering (pcs/1 plant), MTS – 1000 seeds weight (g), Y – grain yield per square metre (g/m2). Highlights: red is positive correlation and blue is negative correlation ($p < 0.05$).

Figure 3 – The correlation coefficient (r) between valuable agronomic traits under specific conditions of Aktobe Agricultural Experimental Station (Aktobe): a – domestic collection; b – foreign collection.

According to the research data, duration of vegetation period in the Western region insignificantly influenced the yield: the longer were the interphase periods of samples, the better productivity they showed (r=0.05-0.24). Also, the vegetation period affects the trait of 1000 seed weight. Thus, the conducted correlation analysis allowed to identify the traits affecting the overall productivity of proso millet genotypes depending on environmental factors.

Conclusion

According to the results of ecological testing of the proso millet collection of domestic and foreign selection, weak relationship between genotype and environment was revealed, as no significant differences between correlations were observed. Statistical processing of experimental data confirmed the interaction of individual valuable traits, with a significant relationship established for the pair of traits of productive tillering and number of grains per panicle (r=0.45-0.93). Thus, the analyses of proso millet in two regions (Northern and Western parts of Kazakhstan) significantly differing in bioclimatic potential allowed to highlight the varieties K-10215, K-2468, Yarkoye 5, Shortandinskoye 7, Saratovskoye 3 as productive and possesing high adaptive capacity for their introduction and expansion of the sowing area.

Acknowledgement

The work was carried out within the AP22785049 “ Improvement of the breeding process based on chemical mutagenesis to obtain early-ripening mutant forms of millet (*Panicum miliaceum* L.)” framework of young scientists grant financing on scientific and (or) scientific technical projects for the years 2024-2026.

Литература

1. Zargar M., Dyussibayeva E., Orazov A., Zeinullina A., Zhirnova I., Yessenbekova G., Rysbekova A. Microsatellite-Based Genetic Diversity Analysis and Population Structure of Proso Millet (*Panicum miliaceum* L.) in Kazakhstan // Agronomy. – 2023, – №13(10), – P.1-14.
2. Lu H., Zhang J., Liu K.-b., Wu N., Li Y., Zhou K., Ye M., Zhang T.; Zhang, H., Yang X. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. Proc. Natl. Acad. Sci. USA 2009, 106, 7367–7372.
3. Xiao-Han Wang, Myung-Chul Lee, Yu-Mi Choi, Seong-Hoon Kim, Seahee Han, Kebede Taye Desta, Hye-Myeong Yoon, Yoon-Jung Lee, Mi-Ae Oh, Jung-Yoon Yi, Myoung-Jae Shin. Phylogeography and Antioxidant Activity of Proso Millet (*Panicum miliaceum* L.) // Plants. – 2021, – №10(10), – P.21-12. https://doi.org/10.3390/plants10102112.
4. Habiyaremye C., Matanguihan J.B., D’Alpoim Guedes J., Ganjyal G.M., Whiteman M.R., Kidwell K.K., Murphy K.M. Proso millet (*Panicum miliaceum* L.) and its potential for cultivation in the Pacific Northwest, US: A review // Front. Plant Sci. – 2017, – №7, P.1-17.
5. Adekunle A., Ellis-Jones J., Ajibefun I., Nyikal R., Bangali S., Fatunbi A., Ange A. Agricultural Innovation in Sub-Saharan Africa: Experiences from Multiple Stakeholder Approaches / Forum for Agricultural Research in Africa (FARA): Accra, Ghana, 2013.
6. Kalinova J. Nutritionally important components of proso millet (*Panicum miliaceum* L.) // Food. – 2007, – №1, P.91–100.
7. Электронный ресурс. – http://www.kazakh zerno.kz/novosti/populyarnye-novosti/239908-urozhajnost-zernovykh-v-kazakhstane-nerastet-polveka. дата обращения:12.02.2025.
8. Домбровская Ю.В. Экологическое испытание сортов яровой мягкой пшеницы в условиях акмолинской области // Растениеводство и кормопроизводство. – 2020, – №3(93), – С.48-52.
9. О.П. Кибальник, И. М. Богапов, Д.С. Семин, И.Г. Ефремова, У.М. Сагалбеков Экологическое испытание сортов сахарного сорго в агроклиматических условиях России и Казахстана // Аграрный вестник Урала №04 (233), 2023 г.
10. Иванисов М. М., Марченко Д.М, Некрасов Е.В., Рыбась И.А. Сравнительная оценка сортов озимой мягкой пшеницы в межстанционном испытании по показателям качества // Зерновое хозяйство России. – 2020, – №4(70), – С. 14-18. doi: 10.31367/2079-8725-2020-70-4-14-18.
11. Коробейников Н.И. Корреляционный анализ признаков продуктивности яровой мягкой пшеницы и его использование в практической селекции // Повышение эффективности селекции и семеноводства сельскохозяйственных растений: доклады и сообщения VIII генетико-селекционной школы. Новосибирск, 2001. – С. 62-72.
12. Головоченко А. П. Особенности адаптационной селекции яровой мягкой пшеницы в лесостепной зоне Среднего Поволжья / Кинель, – 2001. – 380 с.
13. Dyussibayeva E., Abylkairova M., Tsygankov V., Zhirnova I., Zeinullina A., Yessenbekova G., Orazov A., Tsygankov A., Dolinnyc Y., Rysbekova A. Evaluation of the agronomic traits and correlation analysis of phenotypes of proso millet (*Panicum miliaceum* L.) germplasm in Kazakhstan // Brazilian Journal of Biology. – 2024, – №84, P.1-12.
14. Calamai A., Masoni A., Marini L., Dell’acqua M., Ganugi P., Boukail S., Benedettelli S., Palchetti E. Evaluation of the Agronomic Traits of 80 Accessions of Proso Millet (*Panicum miliaceum* L.) under Mediterranean Pedoclimatic Conditions. Agriculture 2020, 10, 578. https://doi.org/10.3390/agriculture10120578

15. Шоева О. Ю., Глаголева А. Ю., Кукоева Т. В. Влияние локуса Blp1, контролирующего синтез меланина в колосе ячменя, на размер и вес зерна // Труды по прикладной ботанике, генетике и селекции. – 2021, – № 182(2), – С. 89–95. DOI: 10.30901/2227-8834-2021-2-89-95.

16. Eric M.O., Pangirayi T., Paul S., Mwangi G., Abhishek R. Correlations, Path Coefficient Analysis and Heritability for Quantitative Traits in Finger Millet Landraces. Philipp. J. Sci. 2016, 145, 12.

17. Nandini K.M., Sridhara S. Performance of foxtail millet (*Setaria italica* L.) genotypes to sowing dates in Southern transition zone of Karnataka. J. Pharmacogn. Phytochem. 2019, 8, 2109–2112.

18. Anuradha N., Tara T., Bharadwaj C., Sankar S.M., Thalambedu L. Association of agronomic traits and micronutrients in pearl millet. Int. J. Chem. Stud. 2018, 6, 181–184.

References

1. Zargar M., Dyussibayeva E., Orazov A., Zeinullina A., Zhirnova I., Yessenbekova G., Rysbekova A. (2023) Microsatellite-Based Genetic Diversity Analysis and Population Structure of Proso Millet (*Panicum miliaceum* L.) in Kazakhstan // Agronomy. №13(10), P.1-14.

2. Lu H., Zhang J., Liu K.-b., Wu N., Li Y., Zhou K., Ye M., Zhang T.; Zhang, H., Yang X. (2009) Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. Proc. Natl. Acad. Sci. USA. №106, P.7367–7372.

3. Xiao-Han Wang, Myung-Chul Lee, Yu-Mi Choi, Seong-Hoon Kim, Seahee Han, Kebede Taye Desta, Hye-Myeong Yoon, Yoon-Jung Lee, Mi-Ae Oh, Jung-Yoon Yi, Myoung-Jae Shin. (2021) Phylogeography and Antioxidant Activity of Proso Millet (*Panicum miliaceum* L.) // Plants. №10(10), P.21-12. https://doi.org/10.3390/plants10102112.

4. Habiyaremye C., Matanguihan J.B., D'Alpoim Guedes J., Ganjyal G.M., Whiteman M.R., Kidwell K.K., Murphy K.M. (2017) Proso millet (*Panicum miliaceum* L.) and its potential for cultivation in the Pacific Northwest, US: A review // Front. Plant Sci. №7, P.1-17.

5. Adekunle A., Ellis-Jones J., Ajibefun I., Nyikal R., Bangali S., Fatunbi A., Ange A. (2013) Agricultural Innovation in Sub-Saharan Africa: Experiences from Multiple Stakeholder Approaches / Forum for Agricultural Research in Africa (FARA): Accra, Ghana, – 51 p.

6. Kalinova J. (2007) Nutritionally important components of proso millet (*Panicum miliaceum* L.) // Food. №1, P.91–100.

7. Electronic resource. – http://www.kazakh zerno.kz/novosti/populyarnye-novosti/239908-urozhajnost-zernovykh-v-kazakhstane-nerastet-polveka. Data obrashenya:12.02.2025. (In Russian)

8. Dombrovskaya Yu. V. (2020) Ekologicheskoe ispitanie sortov yarovoi myagkoi pshenici v usloviyah akmolinskoi oblasti [Ecological testing of spring soft wheat varieties in the conditions of the Akmola region] // Plant growing and forage production. №3(93), P.48-52. (In Russian)

9. Kibalnik O. P., Bogapov I. M., Semin D. S., Efremova I. G., Sagalbekov U. M. (2023) Ekologicheskoe ispitanie sortov saharnogo sorgo v agroklimaticheskih usloviyah Rossii i Kazahstana [Ecological testing of sweet sorghum varieties in the agroclimatic conditions of Russia and Kazakhstan] // Agrarian Bulletin of the Urals. №4 (233). (In Russian)

10. Ivanisov M. M., Marchenko D. M., Nekrasov E. V., Rybas I. A. (2020) Sravnitelnaya ocenka sortov ozimoi myagkoi pshenici v mejstancionnom ispitanii po pokazatelyam kachestva [Comparative evaluation of varieties of winter soft wheat in an inter-station test for quality indicators] // Grain Economy of Russia. №4(70), P. 14-18. doi: 10.31367/2079-8725-2020-70-4-14-18. (In Russian)

11. Korobeynikov N.I. (2001) Korrelyacionnii analiz priznakov produktivnosti yarovoi myagkoi pshenici i ego ispolzovanie v prakticheskoi selekcii [Correlation analysis of productivity traits of spring soft wheat and its use in practical breeding] // Increasing the efficiency of breeding and seed production of agricultural plants: reports and communications of the VIII genetic and breeding school. Novosibirsk. – P. 62-72. (In Russian)

12. Golovochenko A. P. (2001) Osobennosti adaptacionnoi selekcii yarovoi myagkoi pshenici v lesostepnoi zone Srednego Povoljya [Features of adaptive selection of spring soft wheat in the forest-steppe zone of the Middle Volga region] / Kinel. – 380 p. (In Russian)

13. Dyussibayeva E., Abylkairova M., Tsygankov V., Zhirnova I., Zeinullina A., Yessenbekova G., Orazov A., Tsygankov A., Dolinnyc Y., Rysbekova A. (2024) Evaluation of the agronomic traits and correlation analysis of phenotypes of proso millet (*Panicum miliaceum* L.) germplasm in Kazakhstan // Brazilian Journal of Biology. №84, P.1-12.

14. Calamai A., Masoni A., Marini L., Dell'acqua M., Ganugi P., Boukail S., Benedettelli S., Palchetti E. (2020) Evaluation of the Agronomic Traits of 80 Accessions of Proso Millet (*Panicum miliaceum* L.) under Mediterranean Pedoclimatic Conditions. Agriculture. №10, P.1-15. https://doi.org/10.3390/agriculture10120578

15. 10. Shoeva O. Yu., Glagoleva A. Yu., Kukoeva T. V. (2021) Vliyanie lokusa Blp1_ kontroliruyuschego sintez melanina v kolose yachmenya_ na razmer i ves zerna [Effect of the Blp1 locus, which controls melanin synthesis in barley ears, on grain size and weight] // Works on applied botany, genetics and breeding. № 182(2), P. 89–95. DOI: 10.30901/2227-8834-2021-2-89-95.

16. Eric M.O., Pangirayi T., Paul S., Mwangi G., Abhishek R. Correlations, Path Coefficient Analysis and Heritability for Quantitative Traits in Finger Millet Landraces. Philipp. J. Sci. 2016, 145, 12.

17. Nandini K.M., Sridhara S. Performance of foxtail millet (*Setaria italica* L.) genotypes to sowing dates in Southern transition zone of Karnataka. J. Pharmacogn. Phytochem. 2019, 8, 2109–2112.

18. Anuradha N., Tara T., Bharadwaj C., Sankar S.M., Thalambedu L. Association of agronomic traits and micronutrients in pearl millet. Int. J. Chem. Stud. 2018, 6, 181–184.

Авторлар туралы мәлімет

Рысбекова Айман Бөкенқызы (жауапты автор) – Биология ғылымдарының PhD докторы, С. Сейфуллин атындағы ҚАТУ-дың Ауыл шаруашылығы және өсімдік шаруашылығы кафедрасының қауымдастырылған профессоры (Астана, Қазақстан, e-mail: a.rysbekova@kazatu.edu.kz).

Дюсибаева Эльмира Наврузбекқызы – PhD, С. Сейфуллин атындағы ҚАТУ-дың Ауыл шаруашылығы және өсімдік шаруашылығы кафедрасының қауымдастырылған профессоры (Астана, Қазақстан, e-mail: e.dyussibayeva@kazatu.edu.kz).

Әбілқайырова Маргарита Маратқызы – PhD докторанты, С. Сейфуллин атындағы ҚАТУ-дың Ауыл шаруашылығы және өсімдік шаруашылығы кафедрасы (Астана, Қазақстан, e-mail: margarita.abkv@gmail.com).

Зейноллина Айым Ерболқызы – С. Сейфуллин атындағы ҚАТУ-дың Ауыл шаруашылығы және өсімдік шаруашылығы кафедрасының оқытушысы (Астана, Қазақстан, e-mail: a.zeinullina@kazatu.edu.kz).

Оразов Айдын – PhD, Астана Халықаралық Университетінің Жаратылыстану ғылымдары мектебінің қауымдастырылған профессоры (м.а.), «NatureLaB» Қоршаған ортаны зерттеу ғылыми-зерттеу зертханасының жетекшісі (Астана, Қазақстан, e-mail: orazov1994aidyn@gmail.com).

Authors information

Rysbekova Aiman Bokenovna (corresponding author) – PhD in Biological Sciences, Associate Professor of the Department of Agriculture and Plant Growing at S. Seifullin KATRU (Astana, Kazakhstan, e-mail: a.rysbekova@kazatu.edu.kz);

Dyusibayeva Elmira Navrusbekovna – PhD, Associate professor of the Department of Agriculture and Plant Growing at S. Seifullin KATRU (Astana, Kazakhstan, e-mail: e.dyussibayeva@kazatu.edu.kz);

Abylkairova Margarita Maratovna – PhD student of the Department of Agriculture and Crop Growing at S. Seifullin KATRU (Astana, Kazakhstan, e-mail: margarita.abkv@gmail.com);

Zeinullina Aiym Erbolkyzy – lecturer of the Department of Agriculture and Plant Growing at S. Seifullin KATRU (Astana, Kazakhstan, e-mail: a.zeinullina@kazatu.edu.kz);

Orazov Aidyn – PhD, Acting Associate Professor of the School of Natural Sciences at Astana International University, Head of the "NatureLaB", Research Laboratory of Environmental Studies (Astana, Kazakhstan, e-mail: orazov1994aidyn@gmail.com).

Поступила 18 ноября 2024 года
Принята 10 марта 2025 года