DOI 10.54596/2958-0048-2026-2-57-66
UDC 57.084
IRSTI 68.35.03, 68.35.29

COMPREHENSIVE STUDY OF PROSO MILLET GENE POOL FOR INCREASING ITS BREEDING POTENTIAL IN WESTERN KAZAKHSTAN

V.I. Tsygankov[1], A.V. Tsygankov[1], E.N. Dyussibayeva[2*], A.B. Rysbekova[2], N.V. Tsygankova[3], M.M. Abylkairova[2], K.S. Izbastina[2]
[1]Kazakh Research Institute of Horse Breeding and Fodder Production, Aktobe, Kazakhstan
[2]Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan*
[3]Federal Research Center «Nemchinovka» – Skolkovo Innovation Center, Moscow region, Russia
[*]Corresponding author: e.dyussibayeva@kazatu.edu.kz

Abstract

The aim of this research was to study the agronomic traits of common proso millet (*Panicum miliaceum* L.) used in productivity-enhancing plant breeding programs. The study was conducted in 2024-2025 on experimental field plots at the Aktobe Agricultural Experimental Station. Observations were made by using biometric measurements of plants height and morphological characteristics of their productivity. The biological material consisted of 176 proso millet genotypes of various origins; experimental data were collected for all the genotypes. Based on the results of a comprehensive assessment, the following genotypes that demonstrated superior thousand-grain weight, plant height, panicle length, growing period, and overall productivity were identified: Kormovoe 89, Yarkoe 6, Yarkoe 3, Merei (line P-1553), Shortandinskoe 7, Shortandinskoe 10, K-10343, K-10312, K-9605, K-917, K-1923, Donskoe, Saratovskoe 7, Candidum 1025. These valuable genotypes can be recommended as sources for enhancing the productive properties of proso millet.

Keywords: proso millet, gene pool, selection, variety, valuable agronomic traits, vegetation period, productivity.

БАТЫС ҚАЗАҚСТАНДА ТАРЫ ГЕНДІК ҚОРЫН КЕШЕНДІ ЗЕРТТЕУ АРҚЫЛЫ СЕЛЕКЦИЯЛЫҚ ҚОЛДАНЫЛУЫН ЖЕТІЛДІРУ

Цыганков В.И.[1], Цыганков А.В.[1], Дюсибаева Э.Н.[2*], Рысбекова А.Б.[2], Цыганкова Н.В.[3], Абылкаирова М.М.[2], Избастина К.С.[2]
[1]Қазақ жылқы шаруашылығы және жемшөп өндіру ғылыми-зерттеу институты, Ақтөбе, Қазақстан
[2]«С. Сейфуллин атындағы Қазақ агротехникалық зерттеу университеті» КеАҚ, Астана, Қазақстан*
[3]«Немчиновка» Федералдық зерттеу орталығы – «Сколково» Инновациялық орталығы, Мәскеу облысы, Ресей
[*]Хат-хабар үшін автор: e.dyussibayeva@kazatu.edu.kz

Аңдатпа

Бұл зерттеудің мақсаты өнімділікті арттыратын өсімдіктер селекциялық бағдарламалары үшін қажетті кәдімгі тары (*Panicum miliaceum* L.) бағалы ерекшеліктерін зерттеу болды. Зерттеулер 2024-2025 жылдары Ақтөбе ауыл шаруашылығы тәжірибе станциясының тәжірибелік далалық учаскелерінде жүргізілді. Бақылаулар өсімдік биіктігінің биометриялық өлшемдерін және өсімдік өнімділігінің морфологиялық сипаттамаларын қолдану арқылы жүргізілді. Биологиялық материал әртүрлі шығу тегі бар 176 тары генотипінен тұрды және барлық генотиптер бойынша тәжірибелік деректер жиналды. Кешенді бағалау нәтижелері бойынша мың дән салмағы, өсімдік биіктігі, шашақ ұзындығы, вегетациялық кезең ұзақтығы және жалпы өнімділігі бойынша келесі генотиптер анықталды: Кормовое 89, Яркое 6, Яркое 3, Мерей (Р-

1553 желісі), Шортандинское 7, Шортандинское 10, К-10343, К-10312, К-9605, К-917, К-1923, Донское, Саратовское 7, Кандидум 1025. Бұл құнды генотиптерді тары дақылының бағалы белгілерін жақсарту көздері ретінде бағдарламаларға ұсынылады.

Кілт сөздер: тары, генетикалық қор, селекция, сорт, шаруашылық-құнды белгілер, вегетациялық кезең, өнімділік.

КОПМЛЕКСНОЕ ИЗУЧЕНИЕ ГЕНОФОНДА ПРОСА ДЛЯ ПОВЫШЕНИЯ СЕЛЕКЦИОННОГО ИСПОЛЬЗОВАНИЯ В УСЛОВИЯХ ЗАПАДНОГО КАЗАХСТАНА

Цыганков В.И.[1], Цыганков А.В.[1], Дюсибаева Э.Н.[2*],
Рысбекова А.Б.[2], Цыганкова Н.В.[3], Абылкаирова М.М.[2], Избастина К.С.[2],
[1]Казахский научно-исследовательский институт коневодства и кормопроизводства, Актобе, Казахстан
[2]НАО «Казахский агротехнический исследовательский университет имени С. Сейфуллина», Астана, Казахстан*
[3]Федеральный исследовательский центр «Немчиновка» – ИЦ «Сколково», Московская область, Россия
[*]Автор для корреспонденции: e.dyussibayeva@kazatu.edu.kz

Аннотация

Целью данного исследования было изучение ценных характеристик обыкновенного проса (*Panicum miliaceum* L.), необходимых для программ селекции растений, направленных на повышение продуктивности. Исследование проводилось в 2024-2025 годах на экспериментальных полевых участках Актюбинской сельскохозяйственной экспериментальной станции. Наблюдения проводились с использованием биометрических измерений высоты растений и морфологических характеристик продуктивности растений. Биологический материал состоял из 176 генотипов проса различного происхождения; экспериментальные данные были собраны для всех генотипов. На основании результатов комплексной оценки были выявлены следующие генотипы, продемонстрировавшие превосходные показатели массы тысячи зерен, высоты растения, длины метелки, продолжительности вегетационного периода и общей продуктивности: Кормовое 89, Яркое 6, Яркое 3, Мерей (линия Р-1553), Шортандинское 7, Шортандинское 10, К-10343, К-10312, К-9605, К-917, К-1923, Донское, Саратовское 7, Кандидум 1025. Выделившиеся ценные генотипы могут быть рекомендованы в качестве источников для повышения продуктивных свойств проса.

Ключевые слова: просо, генофонд, селекция, сорт, хозяйственно-ценные признаки, вегетационный период, урожайность.

Introduction

Common or Proso millet (*Panicum miliaceum* L.) is an annual grain crop introduced into cultivation approximately 10,000 years ago in the semi-arid regions of China. It is primarily grown in India, Nigeria, Niger, and China [1]. Due to its high nutritional value and health benefits, proso millet is used as livestock and poultry feed in many countries. Recently, its high content of various minerals and amino acids, as well as the low or zero content of gluten in the grain, have attracted the attention of the industry and the scientific community. Common proso millet is used as a rotation crop in winter wheat and fallow systems due to its high water use efficiency [2]. This practice not only prevents the loss of organic matter from no-till soil but also reduces weed and disease infestations. Despite the compelling environmental and medicinal benefits of common proso millet, it remains a poorly understudied and underutilized crop [3]. Breeders worldwide strive to develop superior varieties using both classical and advanced breeding methods. However, the lack of adequate genetic resources slows the process of crop improvement [4-5]. Proso millet genetic material, representing a wide genetic diversity, is stored in gene banks maintained by several countries. The rapid growth of genomic research, along with high-throughput phenotyping, promises to accelerate proso millet breeding [6]. The development of proso millet varieties that are high-yielding, resistant to lodging and seed shattering, ready for combine harvesting, and enriched with nutrients will facilitate increased proso millet cultivation and use in the food industry [7].

The scientific novelty of this research lies in the first assessment of proso millet genotypes from the VIR and USDA collections under the environmental conditions of the region, which enabled the identification of previously uncharacterized sources of high productivity, environmental adaptability, and resistance to biotic and abiotic stresses. The obtained results expand the genetic resources available for proso millet breeding and provide a basis for the development of improved cultivars adapted to changing climatic conditions.

Research Methods

The plant material. The study was conducted in 2024-2025. The research materials were the germplasm of proso millet consisted of 176 genotypes.

The field experiment design. The collection of proso millet was sown in 6-row, 2-meter-wide plots (each plot had an area of 1.8 m^2) in the Aktobe region. There were 14 plots in one pass of the seeding unit; between the passes there is a 30-cm-wide interplot strip. The variety "Pamyati Bersieva" was used as a standard which was selected by the AAES (Aktobe Agricultural Experimental Station); and it was sown every 19 plots. All samples were sown at the recommended seeding rate for the dry steppe zone of 2.5-2.7 million germinated seeds/ha: approximately 600 seeds per plot, in physical weight, depending on the weight of 1000 seeds (3-5 g). The seeds were sown using an SSFK-5-7 seed drill mounted on a compact T-16MG tractor with a KShK-1.5 ring-and-spur roller. The disc seeder sowed to a depth of 5-7 cm.

Methodology of field experiments. A comprehensive assessment of the genetic diversity of the studied proso millet varieties used both field and laboratory research methods. During the growing season and after harvest, the following observations and records were made: phenological data, overall phenotypic assessment (5-point scale), drought tolerance, lodging resistance, yield structure analysis, and 1 000-grain weight. During the emergence phase – the beginning of grain filling – several plants of each variety were assessed for vegetative mass development per unit area (1 m^2) to identify varieties suitable for use as green fodder. To evaluate the biological, economic, and qualitative indicators of the studied proso millet assortment, the methodology of state variety testing was applied [8].

The meteorological data for the growing experimental period 2024-2025 was gathered at the local weather station (table 1).

Table 1. Location, environment, and weather data during agronomic seasons

Site/Region	Aktobe Region	
Latitude/Longitude	50.27'/57.20'	
Soil type	black soil and dark chestnut (2.74% humus)	
Conditions	Rainfed	
Year	2024	2025
Annual rainfall for summer season, mm	167.9	120.0
Mean temperature, °C	19.9	25.3
Max temperature, °C	24.4	30.0
Min temperature, °C	13.8	19.0

Statistical processing of the obtained data. The experimental data were processed according to B.A. Dospekhov [9] and N.L. Udolskaya [10] on a PC using the AGROS-1 program (version 2.09-2.11/1993-2009; authors S.P. Martynov, N.N. Musin, T.V. Kulagina); Statist 1, Statist 2 (version 2005/2012, author I.F. Spivak-Lavrov). Heatmap data processing was based on Pearson correlation, a standard method for analyzing the strength of a linear relationship between variables.

Study Results

The collection was sown on May 19. The seedlings were observed between May 28 and 30. Field germination for most proso millet varieties was 70-80%. In 2024-2025, the duration of the period from germination to panicle emergence in proso millet varieties varied, depending on the early maturity - from 36 to 51 days; the duration of the ripening period for all forms of proso millet varied within the range of 39-51 days. Based on the data obtained from studying the vegetation of proso millet varieties and samples in the collection, we were able to conditionally divide them into 4 maturity groups: Early, Mid-season, Mid-late, and Late-season (table 2).

Table 2. Duration of proso millet growing season, days (2024-2025)

Proso millet forms	First half of the growing season (shoots – panicle growing)	Second half of the growing season (panicle emergence – ripening)	Shoots – ripening
Early-season	36	39	75
Mid-season	42	41	83
Mid late-season	47	43	90
Late-season	51	47	98

On average, under these conditions, the earliest maturing proso millet samples (up to 80-82 days) were: Yarkoe 3, Merei (line P-1553), Shortandinskoe 7, Shortandinskoe 10, K-10312 and others.

In the western region of Kazakhstan, the study of the proso millet collection including foreign and local proso millet varieties was conducted to record phenotypic variability across two different years of study, including seven of the most important traits of this crop. Based on the results of phenotypic analysis, the most valuable genotypes possessing a complex of valuable agronomic traits were selected (table 3).

Table 3. The most promising genotypes by productivity and characteristics, 2024-2025.

Genotypes	Vegetation period, days	Productive tillering, pc/1 plant	Panicle length, cm	1000 seed weight, g	Grain weight per panicle, g	Number of grains per panicle, pcs	Grain yield, g/m^2
Pamyati Bersieva St.	85	1,15	20,04	8,2	4,1	494	321
Kormovoe 89	88	1,16	24,1	7,86	5,0	632	337
Yarkoe 6	89	1,07	19,72	7,85	4,2	506	353
Yarkoe 3	80	1,42	20,45	8,02	5,1	615	369
Merei (line P-1553)	82	1,13	19,87	6,47	4,7	736	338
Shortandinskoe 7	77	1,55	20,12	7,85	3,4	439	364
Shortandinskoe 10	80	1,12	21,37	7,75	3,5	487	360

K-10343	92	1,21	19,98	8,21	8,6	1058	355
K-10312	78	1,35	27,22	8,23	4,8	595	337
K-9605	86	1,00	21,57	8,19	6,8	839	349
K-917	90	1,20	19,86	7,34	5,0	645	402
K-1923	88	1,21	18,9	8,64	9,47	1094	518
Donskoe	88	1,33	19,72	7,73	4,5	525	388
Saratovskoe 7	89	1,33	19,61	8,66	5,8	599	375
Candidum 1025	85	1,26	20,5	7,60	6,58	667	483
Stat.	-	M±m= 1.193±0.03; Cv=22.0% and P=2.21%	-	M±m= 6.92±0.10; Cv =14.85; P = 1.49%	-	M±m= 330.5±14.75; Cv=44.63%; P=4.49%	M±m= 181.3±8.0; Cv=44%; P=4.43%
Note: M ± m = mean ± standard error; Cv = coefficient of variation (%); P = experimental precision (%), reflecting the relative error of the mean estimate							

Growing period of mid-late and late-ripening proso millet varieties ranged from 90 to 100 days or more: Zolotistoe kormovoe, K-8528, Zolotistoe, K-10286, Kormovoe 2020, K-3806, PI 163298, PI 163300, PI 173750, PI 177015, K-2253, K-9605, Voronezhskoe 989, Donskoe 5, Mironovskoe 51, Aktyubinskoe kormovoe, Uilskoe beloe, and others.

Productive tillering under 2025 conditions was generally insignificant and amounted to M±m=1.193±0.03 stems/plant; Cv=22.0% and P=2.21%.

According to *Number of grains per panicle* (from 500 to 800 pcs. and more) in the prevailing hydrothermal conditions of 2025, the following varieties stood out: Yarkoe 3, Yarkoe 120, Merey, Kormovoe 89, Saratovskoe 3, K-10343 Zolotistoe, Zhodinskoe, K-3751, Ilyinovskoe, k-10312, Lin. S-11/82, k-9605, k-1980, Aktyubinskoe Beloe and others with M±m = 330.5±14.75 pcs.; Cv=44.63%; P=4.49%.

The following varieties had increased *grain size* (1000 seed weight of 8-9 g or more) under 2025 conditions: Yarkoe 5, Yarkoe 7, Abakanskoe kormovoe, PI 296376, Zolotistoe kormovoe, Shortandinskoe 10, K-10343 Zolotistoe, K-2778, Zhodinskoe, K-10312, K-9373, Davskoe, PI 211058, Gorlinka, Volgogradskoe 4, Voronezhskoe 989, k-2982 with an average value of 6.92 ± 0.10 g; the variation coefficient Cv was 14.85% and P (experimental precision) was 1.49%.

Productivity. The yield for the most of the proso millet varieties under the current growing season conditions ranged from 150 g/m^2 to 250 g/m^2 with a range of variability from 50-70 to 380-440 g/m^2; the yields of standard varieties were 243 g/m^2 for Pamyati Bersieva and 294 g/m^2 for Yarkoe 6. The following varieties proved to be the most productive (+15-40% over the standard level) in 2025: Yarkoe 3, Yarkoe 120, Shortandinskoe 10, Zolotistoe, k-8528, k-2778, k-10215, k-7751, Ilyinovskoye, K-9605, K-917, K-2636, Aktyubinskoe Beloe, and several others (M±m=181.3±8.0 g/m^2; Cv=44%; P=4.43%). The yield increase over standard varieties was achieved due to better plant survival at harvest, number of grains per panicle, and size of the formed grain. The overall phenotypic score for the proso millet collection ranged from 2-2.5 to 4.0-4.3 points. The biological yield of green mass during the panicle emergence - flowering period was assessed for a number of the samples of general-purpose and forage proso millet varieties. It ranged from 1000-1600 g/m² (equivalent to 100-150 c/ha) for the following varieties: Yarkoe 120, Lin. 9/82, Zhodino, Lin. 1665, PI 222811, Shortandinskoe 10, K-9539, K-9701 Subflavum 443, PI 365844, Kormovoe 89, Uilskoe local up to 2000-2600 g/m^2 (in terms of 200-260 c/ha) - Yarkoe 3, Yarkoe 5. Yarkoe 6, Yarkoe 7, Merey, Nadezhnoe, Saratovskoe 10, Orenburgskoe 20, Danila, Liniya S-24/82, k-10352 Zolotistoe, Shortandinskoe

11, k-8503 Aktyubinskoe white, Aktyubinskoe kormovoe. After drying, the air-dry mass of these samples ranged from 250-400 to 500-600 g/m^2.

Compared with the standard cultivar Pamyati Bersieva (321 g/m^2), all selected genotypes demonstrated higher grain yield, with increases ranging from 5.0 to 61.4%. The best results were recorded for K-1923 (518 g/m^2, +61.4%), Candidum 1025 (483 g/m^2, +50.5%), K-917 (402 g/m^2, +25.2%), and Donskoe (388 g/m^2, +20.9%). The yield advantage of K-1923 was primarily associated with a substantially higher grain number per panicle (1094 vs. 494 grains in the standard) and grain weight per panicle (9.47 vs. 4.1 g). Similarly, Candidum 1025 combined higher grain weight per panicle (6.58 g) with a higher grain number per panicle (667 grains), resulting in a marked increase in productivity. In contrast, Shortandinskoe 7 and Yarkoe 3 exhibited superior productive tillering, exceeding the standard by 34.8% and 23.5%, respectively, indicating alternative mechanisms contributing to yield formation.

Based on the results of comprehensive studies of agronomic traits of proso millet in 2024-2025, valuable genotypes were identified: Kormovoe 89, Yarkoe 6, Yarkoe 3, Merei (line P-1553), Shortandinskoe 7, Shortandinskoe 10, K-10343, K-10312, K-9605, K-917, K-1923, Donskoe, Saratovskoe 7, Candidum 1025.

Correlation analysis related to climatic conditions of proso millet germplasm are understudied comparing to the major crops. In our research, correlation coefficients between the main valuable agronomic traits of proso millet varieties were studied. The table represents Pearson correlation coefficients (r). Statistically significant correlations are marked with * ($p < 0.05$) and ** ($p < 0.01$) (table 4).

Table 4. Significant correlations between climatic variables and agronomic traits of proso millet genotypes.

Variables	r	p-value
Amount of precipitation (APR) – plant height (HT)	0.66	<0.01
Amount of precipitation (APR) – seed weight per panicle (SWMP)	0.56	<0.05
Amount of precipitation (APR) – number of seeds per panicle (NSMP)	0.55	<0.05
Amount of precipitation (APR) – grain yield (GY)	0.53	<0.05
Year (YR) – plant height (HT)	-0.66	<0.01
Year (YR) – grain yield (GY)	-0.53	<0.05

Thus, under the western conditions, the data obtained in 2024-2025 indicate that the yield of proso millet genotypes GY is not related to year conditions YR (r=-0.53) and average temperature AMT (Figure 1).

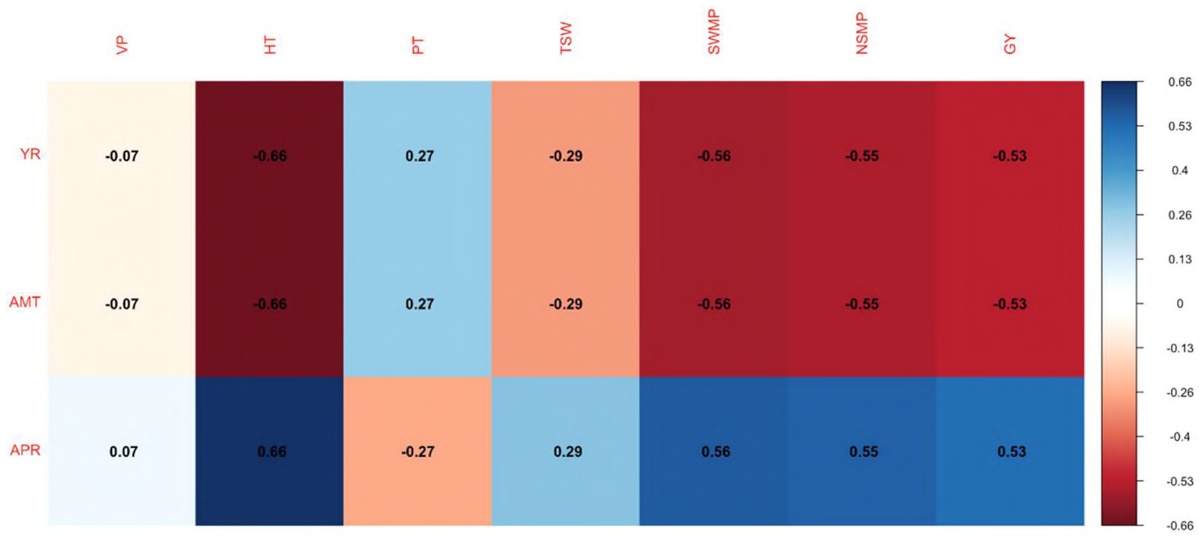

Figure 1. Correlation coefficients among the agronomic traits in the conditions Aktobe region:
*VP - vegetation period, HT – Plant height, PT - productive tillering, TSW - 1000 seed weight, SWMP - seed weight per panicle, NSMP - Number of seeds per panicle, GY – yield per square meter, YR - year, AMT - average temperature, APR - amount of precipitation. Note: Correlations with $p < 0.05$ are highlighted in colour. The colour indicates either positive (blue) or negative (red) correlation.

Negative correlation was also observed between plant height HT and year YR, average temperature AMT; number of seeds per panicle NSMP and seed weight per panicle SWMP with year YR, average temperature AMT, r consisted -0.55-0.66. In this study, no relationship was observed between productive tillering PT – year YR and productive tillering PT – average temperature AMT (r=-0.27); 1000 seed weight TSW – amount of precipitation APR (r= -0.29). Plant height HT and amount of precipitation APR (r=0.66); seed weight per panicle SWMP and amount of precipitation APR (r=0.56); number of seeds per panicle NSMP and amount of precipitation APR (r=0.55); yield GY and amount of precipitation APR (r=0.53) showed high trait dependence among all varieties.

Discussion

The evaluation of 176 proso millet genotypes under the environmental conditions of Western Kazakhstan revealed substantial variation in productive tillering, seed number per panicle, seed weight per panicle, and 1000 seed weight. Similar levels of phenotypic diversity have been reported in proso millet germplasm collections evaluated in India, Africa, and Mediterranean environments, where broad genetic variation was considered a prerequisite for effective breeding and adaptation to diverse agroecological conditions. Vetriventhan and Upadhyaya (2019) identified wide phenotypic diversity for productivity and nutritional characteristics in a global collection of proso millet germplasm. The ranges of variation recorded in the Western Kazakhstan collection for productive tillering, seed number per panicle, seed weight per panicle, and thousand-seed weight are consistent with the magnitude of diversity reported in these studies. The presence of highly productive accessions within the evaluated material indicates that the collection possesses valuable genetic resources comparable to those identified in major international germplasm collections and can serve as an important source of breeding material for improving yield potential and environmental adaptation [11].

The significant positive association observed between precipitation and both seed number and seed weight per panicle is consistent with previous studies demonstrating that water availability during flowering and grain filling is a major determinant of proso millet productivity. Researchers in semi-arid regions of India and Sub-Saharan Africa have likewise reported that reduced rainfall during reproductive stages leads to a decrease in grain set and panicle productivity, whereas favorable moisture conditions increase grain number and grain weight. These findings suggest that precipitation is one of the principal environmental factors affecting yield formation across contrasting proso millet-growing regions [12, 13].

The superior agronomic performance observed during the 2024–2025 growing seasons, particularly for productive tillering and panicle productivity traits, may be explained by the environmental conditions prevailing during the experimental years. Similar responses have been reported in Mediterranean and continental climates, where seasonal differences in rainfall distribution significantly influenced yield components and genotype ranking. Therefore, the observed variation among years highlights the importance of evaluating germplasm under multiple environmental conditions to identify stable and broadly adapted genotypes.

Differences in maturity groups also deserve consideration. Studies conducted in India and North Africa have shown that early-maturing genotypes often exhibit greater drought avoidance, whereas medium- and late-maturing forms may achieve higher yield potential under favorable moisture conditions. The diversity of maturity groups represented in the present collection may therefore contribute to the observed variability in productivity and adaptation traits. Similarly, Calamai et al. (2020), who evaluated 80 accessions of proso millet under Mediterranean conditions, reported substantial variation in grain productivity and yield-related traits among accessions [14, 15].

Overall, the results confirm findings from previous international studies: broad germplasm collections constitute an essential source of alleles for improving yield stability, stress tolerance, and adaptation to climate variability. At the same time, the present study provides new information on the performance of VIR and USDA accessions under the specific soil and climatic conditions of Western Kazakhstan, thereby expanding knowledge on their breeding value and regional adaptability.

Conclusion

Thus, despite promising traits that may confer resistance to environmental stress, *P. miliaceum* remains a minor cereal crop, grown primarily in arid and semi-arid agricultural regions with low resource inputs as a subsistence crop for local populations. This study presents data from a two-year field experiment evaluating the valuable traits of proso millet accessions in the Western regions of Kazakhstan. The results made it possible to identify valuable varieties and samples of proso millet. This data can be used in future proso millet breeding programs to develop new and improved genotypes adaptable to arid zones and with desirable productivity traits. The evaluated proso millet germplasm demonstrated considerable variability in agronomic and productivity traits, allowing the identification of promising donor genotypes for specific breeding objectives.

For plant breeding aimed at increasing grain yield, the most valuable genotypes were K-1923 (518 g/m^2), Candidum 1025 (483 g/m^2), K-917 (402 g/m^2), and Donskoe (388 g/m^2), all of which substantially exceeded the standard cultivar Pamyati Bersieva. As sources of high grain weight per panicle, K-1923 (9.47 g), K-10343 (8.6 g), K-9605 (6.8 g), and Candidum 1025 (6.58 g) are recommended for use in breeding programs targeting enhanced yield potential. For improving grain number per panicle, K-1923 (1094 grains), K-10343 (1058 grains), K-9605 (839 grains), and Merei (736 grains) represent valuable donor material. Early maturity, an important trait for arid environment, was observed in Shortandinskoe 7 (77 days), K-10312 (78 days), and Yarkoe 3 and Shortandinskoe 10 (80 days). These genotypes may be useful for developing early-ripening cultivars adapted to unstable moisture conditions. The highest productive tillering was recorded in Shortandinskoe 7 (1.55 shoots per plant), Yarkoe 3 (1.42), K-10312 (1.35), Donskoe (1.33), and Saratovskoe 7 (1.33), indicating their potential value as donors of enhanced plant productivity and stand density. Based on the combination of traits, K-1923, Candidum 1025, K-917, and Donskoe are recommended for grain-oriented breeding programs, whereas Shortandinskoe 7, Yarkoe 3, and K-10312 may be valuable for forage and dual-purpose breeding due to their early maturity and high tillering ability. Genotypes combining high grain productivity with favorable yield components, particularly K-1923 and Candidum 1025, should be prioritized for further breeding and multi-environment testing in Western Kazakhstan.

During the preparation of this manuscript, the authors used artificial intelligence tools (e.g., ChatGPT, Gemini, Claude, NoteBook LLM, Groq, DeepSeek) to assist with text editing or translation (specifying the sections of the article). All scientific interpretations were carried out by the authors. AI tools were not used for data collection or statistical analysis. All content has been checked and verified by the authors, who bear full responsibility for the content and originality of the manuscript.

Acknowledgments: The work was performed within the program financing by the Ministry of Agriculture of the Republic of Kazakhstan under the budget program 267, BR22885305 «Breeding and genetic technology for the development of systems for long-term storage, restoration, monitoring and rational use of agrobiodiversity, as the basic basis for improving breeding programs of RK».

References:

1. Lu H., Zhang J., Liu K.B., Wu N., Li Y., Zhou K. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago // Proceedings of the National Academy of Sciences of the United States of America. - 2009. - № 106(18). – P. 7367-7372. DOI: NA

2. 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). – 2615. DOI: 10.3390/agronomy13102615

3. Rysbekova A., Abylkairova M., Orazov A., Zeinullina A., Hu Y.G., Ydyrys A., Zargar M., Dyussibayeva E. Application of Inter-Simple Sequence Repeat Markers in Genetic Variance Detection of Proso Millet (*Panicum miliaceum* L.) Germplasm Cultivated in Kazakhstan // ES Food Agrofor. - 2025. – № 20. - 1471. DOI: 10.30919/faf1471

4. Cygankov A.V., Cygankov V.I., Rysbekova A.B., Dyusibaeva E.N., Cygankova N.V. Ispol'zovanie geneticheskogo raznoobraziya kul'tury prosa pri sozdanii adaptivnyh zasuhoustojchivyh sortov v usloviyah Zapadnogo Kazahstana // Sb. nauch. statej v 2-h tomah. Tom 1. Zadachi sel. i sem. zernovyh kul'tur po mat. Mezhd. nauch. konf., posv. 300-letiyu RAN. – Moscow: FIC «Nemchinovka», 2024. - S. 223-241 [in Russian]. DOI: NA

5. Dyussibayevaa E., Abylkairova M., Tsygankov V., Zhirnova I., Zeinullina A., Yessenbekova G., Orazov A., Tsygankov A., Dolinny 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. - e287947. DOI: /10.1590/1519-6984.287947 P. 1-12

6. Dipak K. Santra, Rituraj Khound, Saurav Das. Proso Millet (*Panicum miliaceum* L.) Breeding: Progress, Challenges and Opportunities // Advances in Plant Breeding Strategies: Cereals. - 2019.- № 5(1). - P. 223-2027. DOI: NA

7. Bortesi L, Fischer R. The CRISPR/Cas9 system for plant genome editing and beyond.Biotechnol.Adv. - 2015. - 33(1). – P. 41–52. DOI: 10.1016/j.biotechadv.2014.12.006

8. Metodika gosudarstvennogo sortoispytaniya sel'skohozyajstvennyh kul'tur. -Almaty: KGI MSH RK, 2002. – 378 s. [in Russian]. DOI: NA

9. Dospekhov B.A. Metodika polevogo opyta. - M.: Agropromizdat, 1985. - 352 s. [in Russian]. DOI: NA

10. Udol'skaya N.L. Vvedenie v biometriyu. – Alma-Ata, 1976. – 84 s. DOI: NA

11. Vetriventhan M., Upadhyaya H.D. Variability for Productivity and Nutritional Traits in Germplasm of Kodo Millet, an Underutilized Nutrient-Rich Climate Smart Crop // Crop Sci. - 2019. – № 59. - P.1095-1106. DOI: 10.2135/cropsci2018.07.0450
12. Sood S., Khulbe R.K., Agrawal P.K., Upadhyaya H.D. Barnyard millet global core collection evaluation in the submontane Himalayan region of India using multivariate analysis // Crop J. - 2021. – № 3. - P.517-525. DOI: 10.1016/j.cj.2015.07.005
13. Sanon M., Hoogenboom G., Traoré S.B., Sarr B., Garcia A.G.Y., Somé L., Roncoli C. Photoperiod sensitivity of local millet and sorghum varieties in West Africa // NJAS Wagening. J. Life Sci. - 2014. - № 68. – P. 29-39. DOI: 10.1016/j.njas.2013.11.004
14. Craufurd P., Mahalakshmi V., Bidinger F. Adaptation of sorghum: characterisation of genotypic flowering responses to temperature and photoperiod // Theor Appl Genet. - 1999. – № 99. – P.900-911. DOI: 10.1007/s001220051311
15. 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. – P.578. DOI: 10.3390/agriculture10120578

Information about the authors

V.I. Tsygankov – Candidate of Agricultural Sciences, Corresponding Member of the National Academy of Agrarian Sciences of the Republic of Kazakhstan, Head of the Department of Selection and Primary Seed Production, Kazakh Research Institute of Horse Breeding and Fodder Production, Aktobe, Kazakhstan; e-mail: zigan60@mail.ru;
A.V. Tsygankov – Master of Agronomy, Senior Researcher, Kazakh Research Institute of Horse Breeding and Fodder Production, Aktobe, Kazakhstan; e-mail: mirestnonesdes1@mail.ru;
E.N. Dyussibayeva – corresponding author, PhD, associate professor, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan; e-mail: e.dyussibayeva@kazatu.edu.kz;
A.B. Rysbekova – Candidate of biological sciences, associate professor, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan; e-mail: aiman_rb@mail.ru;
N.V. Tsygankova – Candidate of Agricultural Sciences, Head of the Laboratory of the Federal Research Center «Nemchinovka» – Skolkovo Innovation Center, Moscow region, Novoivanovskoye settlement, Russia; e-mail: tzugnatali@yandex.ru;
M.M. Abylkairova – doctoral student of S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan; e-mail: margarita.abkv@gmail.com.
K.S. Izbastina – PhD, associate professor, S.Seifullin Kazakh Agro Technical Research University, Astana, Kazakhstan; e-mail: izbastina.k@gmail.com.