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ASSESSMENT OF AFRICAN MILLET (*PENNISETUM GLAUCUM* L.) GERMPLASM IN THE ARAL SEA REGION, KAZAKHSTAN

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SUMMARY

This research aimed for an ecological evaluation of African millet (*Pennisetum glaucum* L.) genotypes. It also sought to identify the high-yielding genotypes with a complex of agronomic traits resistant to harsh salinity stress conditions. For salt tolerance index (10%–20%) and in comparison to millet standard genotype (Hashaki-1), the cultivars WRai POP, IP13150, GB 8735, Sudan POP III, IP19586, JBV 3, HHVBC Tall, Sudan POP I, IP 22269, JBV 2, Rai 171, EMSHBC, and ICMS 7704 appeared as highly resistant to salinization and exceeded the standard genotype. These cultivars exhibited the highest germination percentage, survival, and conservation rate, and set apart by highest green mass yield, surpassing the standard cultivar (Hashaki-1) by 0.1–8.4 t/ha. Correlation analysis revealed with 2.0% chloride salinity conditions, the germination intensity, the 14-day-old seedling weight, and the seminal root length positively associated with the grain weight per panicle and green mass yield. The recommendation of these traits as selection criteria is suitable for use in practical selection to evaluate an extensive set of African millet breeding material.

Keywords: African millet (*P. glaucum* L.), source material, cultivars testing, selection, salt-tolerance, drought-resistance, germination intensity, green mass yield

Key findings: Water shortage, salinization, and soil degradation necessitate a reduction in other crops and their replacement with crops that consume less water in Kyzylorda region, Kazakhstan. Ecological cultivars' testing of African millet (*P. glaucum* L.) made it possible to identify the most high-yielding and adaptive cultivars to saline soils, which are now in progressive introduction in the Kyzylorda Region, Kazakhstan.

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INTRODUCTION

African millet (*Pennisetum glaucum* L. R. Br.) is an important food and forage crop in the arid and semi-arid tropics of Africa and Asia. Moreover, with the most common micronutrients and energy sources, it is a primary cereal staple for more than 90 million people living in arid and semi-arid regions. African millet's domestication came about in the sub-Saharan region of West and Central Africa and then migrated to eastern Africa, semi-arid regions of South Asia, and other parts of the world. The ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) has the world's largest collection of 22,888 accessions of millet germplasm collected from 51 countries, including 13,185 accessions from Africa (Genesys, 2024) and 6,610 accessions from India (Upadhyaya *et al.,* 2016).

Africa and India combined account for about 98% of the world's millet cultivation. African millet cultivation on over 22 million hectares is mainly reliant on the cultivation of open-pollinated local cultivars and improved populations. However, in India, hybrids occupy about 70% (five million hectares) of African millet crop areas, and the rest (2.5 million hectares) is under traditional millet cultivars (Satyavathi, 2017).

Breeding of African millet progressed through mass selection in locally adapted material in 1930 in India; however, this method did not improve the yield significantly. Later, with the establishment of ICRISAT in the 1970s, the high-yielding millet cultivars' development transpired through population improvement using Asian and African germplasm. Producing several high-yielding cultivars, such as, WC-C75, ICMV 221, ICTP 8203, HC 4, Raj 171, JBV 2, JBV 3, HC 20, RCB 2, CZP 9802, and Pusa 266, have resulted through recurrent selection (Yadav and Rai, 2013). Modern African millet cultivars were primarily of single-purpose, bred and grown either for biomass or for grain purpose. However, solving this problem can proceed through the introduction of dual-purpose millet (Bastos *et al*., 2022).

African millet introduction for cultivation as a new forage crop has begun, cultivated for hay, silage, green fodder, and cattle grazing in the previous decade in Kazakhstan. The important biological properties of African millet are the high productiveness, resistance to diseases, high breeding ratio, and the high feed and nutritional values of the grains. It also suffers less by dry and hot winds compared with other crops and tolerates better with soil and atmospheric drought (Toderich *et al*., 2013).

Large-scale selection and improvement research on African millet has progressed in the Kazakh Research Institute of Agriculture and Plant Growing, Aktobe Agricultural Experimental Station, and Kazakh Scientific Research Institute of Rice Growing named after Zhakhaev in the Republic of Kazakhstan. In the research, the sharp difference was the salinization and atmospheric drought of the Kyzylorda Region than other regions of Kazakhstan. Other features also include the precipitation, the pathogens' racial composition, ripening time, yield, and millet cultivars' quality.

Unequal variability of various quantitative traits, depending on environmental conditions, indicate the need to study them in specific environmental conditions where the proper selection can occur. Therefore, evaluation of newly developed African millet breeding material to determine the ecological variations and stability of agronomic traits against the natural background of this region will be more effective than under artificially created conditions. This type of research will enhance the effectiveness of research project based on the genetic make-up and selection of promising African millet genotypes for Kazakhstan.

Previous studies also manifested the unequal variability of various quantitative traits based on environmental conditions, requiring the study of these millet genotypes under particular environmental conditions where selection could be efficient. The problem of stable growth in grain production, especially in risk farming areas, is solvable through developing and introducing highly adaptive millet cultivars. The solution to this concern was to use the principles and methods of ecological selection in the Republic of Kazakhstan.

Diversifying crops production in the Kyzylorda Region, with low water and higher salt content in the arable soil horizon, and expanding the area under non-traditional salt-tolerant grain crops are the main objectives in increasing agricultural sustainability in the region. In this regard, the selection of most adaptive crops to specific soil and climatic conditions of the Kyzylorda Region has become the prime task for scientists in this region. For the first time, particularly the study on a new crop – the African millet – has been a focus in this region, in cooperation of the ICARDA (International Center for Agricultural Research in the Dry Areas).

The studies showed African millet is resistant to soil salinization. The application of nitrogen-phosphate fertilizers enhanced the germinating ability of seeds by 2.1%–2.4%, plant survival by 4.9%–7.1%, which made it possible to obtain an increase in green mass yield with an average of 7.5%–13.7 t/ha. The crop of interest was highly drought-resistant to obtain a maximum green mass yield of 30.2–34.5 t/ha, and one irrigation per growing season was sufficient. Therefore, the latest research pursued expanding the range of African millet cultivar cultivation through ecological cultivar testing in addressing the interest and massive demand from agricultural manufacturers.

MATERIALS AND METHODS

In the presented study, 17 cultivars of African millet (*Pennisetum glaucum* L.) were samples used. The said research commenced at the Kazakh Scientific Research Institute of Rice Cultivation named after I. Zhakhaev LLP. Agricultural technology was generally acceptable for this area. Phenological observations and biometric analysis proceeded according to the VIR method (Methodological guidelines, 1981; Methods for determination of germination, 2011). Statistical processing of yield data followed the procedure according to Dospekhov (1985). The beginning of the vegetation stage became the date on which 10% of the plants correspond to it, and the full stage was when it appears in 75% of plants.

In laboratory conditions, diagnostics of salt-tolerance began by sprouting seeds in Petri dishes with NaCl salt solutions at the temperature of 24 °C±2 °C. The salt tolerant cultivar Hashaki-1 released under rice crop rotation conditions served as a control cultivar with three replications. The 50 calibrated seeds reached placement in each dish. Growing the plants continued until two weeks of age, and then bore assessment through quantitative traits. These included the selection of the 10 most aligned plants, determination of seedling length, root length, leaf area, mass of leaves and roots, and some other derived values (surface density of leaves, top-root ratio), and detection of the water-absorbing and water-holding capacity of leaves, recorded according to the VIR method (Davydova, 1979). Salt tolerance determination employed the degree of depression of each analyzed trait relative to the values of the control variant in the experiment. The calculation of the integrated salt tolerance index (ISTI %) was as according to the average for all studied parameters.

Experimental design

Evaluation of 17 African millet genotypes continued in plots of 12 m^2 (5.0 m × 2.4 m) in triplicate and randomized. A selection assessment ensued, with the samples selected according to a complex of commercial and biological traits, and then, compared with each other and with a recognized standard cultivar Hashaki-1. Plot harvesting of all cultivar samples proceeded manually, threshing used a sheaf thresher, and the yield was by the weight method (Figure 1).

Meteorological conditions

The climate of the Kyzylorda Region is sharply continental, arid, hot, dry summers, and cold winters, with unstable snow cover. The average annual air temperature was 9.8 °C. The average annual precipitation was 129 mm. In some dry years, precipitation may be only

Figure 1. Field experiments and phenological observations on the development of African millet.

40–70 mm. The soil of the experimental plot was meadow-boggy, typical for rice crop rotation in the region. The humus content was 1.73%, with a high value of solids (1.15%) (Tokhetova *et al.,* 2022). Quality of salinity – sulfate, was highly saline. Soil mechanical composition was medium-textured loam. Soil analysis transpired in the laboratory of the National Center for Expertise and Certification JSC in Kyzylorda, with accreditation Certificate No. KZT.T.12.0408, 04.11.2022 (Table 1).

The growth and development of the plant largely depends on the agrochemical parameters of the soil. Of particular importance is the amount of humus, the amount of mobile nitrogen and phosphorus, as well as, exchangeable potassium, making up the potential fertility of the soil. The study of agrochemical properties of the soil of the experimental plot showed a low amount of humus (0.87%–0.79%), and the reaction of the arable layer of soil is alkaline (pH -7.9). With the small amount of agrochemical substances in the soil, the amount of mobile and exchangeable forms of nutrient elements necessary for plant nutrition is also low (Table 2).

In the soil's arable layer of the experimental site, the amount of easily soluble forms of nitrogen did not exceed 15.3 mg/kg, mobile phosphorus (14.1 mg/kg), and exchangeable potassium (146.5 mg/kg). Analysis of water extract showed thick residue in arable layer was 1.102%–0.960% indicating higher salinity, in lower layers, moderate salinity (0.781%–0.902%), and the salinity type was chloride-sulfate.

The meteorological conditions of the study year had characteristics of elevated temperatures compared with the long-term average annual values. It should be noteworthy that in recent centuries, the average annual air temperature has systematically increased (from 7.5 °C to 9.9 °C). With the least precipitation, aridity is the distinguishing features of the region's climate.

Table 1. Characterization of the soil of the experimental plot at the Kazakh Scientific Research Institute of Rice Growing named after Zhakhaev, Kazakhstan.

Soilhorizon (cm)	pH	Solids (%)	Anions (%/mg-eq in 100 g of soil)			Cations (%/mg-eq per 100 g of soil)			Total salts (%)	Quality of salinity
			HCO_3	Cl	SO_4	Ca	Mg	Na		
0-20	8.1 Weakly alkaline	1.15	0.028 0.469	0.058 1.858	0.830 14.23	0.17 8.2	0.021 1.25	0.023 0.758	0.896	Sulfate highly saline
20-40	8.3 Weakly alkaline	1.18	0.031 0.342	0.067 1.902	0.835 15.95	0.18 8.41	0.024 1.82	0.028 0.802	0.848	Sulfate highly saline

Table 2. Agrochemical composition of meadow-marsh soils of the experimental plot.

Sampling depth (cm)	Humus (%)	Reaction of soil solution (pH)	Movable nitrogen (mg/kg)	Mobile phosphorus (mg/kg)	Exchangeable potassium (mg/kg)
0-20	0.87	7.9	15.3	14.1	146.5
21-40	0.79	7.8	13.8	13.4	120.0

The average annual precipitation does not exceed 100–190 mm and with uneven distribution across the seasons. Most (60%) of all precipitation occurs in the winter-spring period. The entire territory is illustrative of frequent and strong winds from the northeast with annual speed range of 3.1 to 6.0 m/s, while dust storms occur in summer.

During the crop season of 2021–2022, only 98 mm of precipitation was evident. This amount is 54.25% of the norm. In general, the temperature regime during the tillering and booting period was optimal, which had a beneficial effect on the formation of generative organs. However, during the maturity period, the weather conditions of June and July exhibited extremely high air temperatures. The normal average monthly temperature in June was 26.7 °C. However, according to observational data, the actual temperature of the said month was 29.4 °C, with a deviation from the norm (+2.7 °C). Standard precipitation rate in June is 8 mm, while the rainfall was 0 mm, and that was 0% of normal.

During the crop season of 2022–2023, and on average, 124 mm of precipitation fell. At the end of March after sowing, almost a month's rainfall poured, which had a beneficial effect on seed germination. The month of May was very dry, which accelerated the process of vegetation and ripening. In general, during this year, the ripening time was 10–15 days earlier than in the crop season of 2021–2022. Meteorological observations showed over the past five years, the air temperature has consistently exceeded the long-term average, and compared to 2017, the deviation was +1.2 (Figure 2).

RESULTS AND DISCUSSION

One of the global environmental problems is soil salinization. Thus, at present, secondary salinization is the main factor determining the level of soil fertility in the Aral Sea's rice-growing region. In the Syrdarya River, water salinity from 0.6 g/l in 1960 increased to 1.8 g/l, which exceeds all permissible norms. Salinization of irrigation water also contributes to gradual growth of desertification tendency in the Aral Sea area. According to FAO, currently in Kyzylorda oblast, out of the total land area of 22.6 million ha, almost 20.3 ha are saline, which was 85% (FAO, 2018).

The chief reason was long-term rice cultivation, which contributed to the rise of groundwater table, as well as, the emergency condition of collector-drainage and drainage network. Additionally, hot and dry climate causes high evaporation of soil moisture, which intensifies salinization processes, especially in

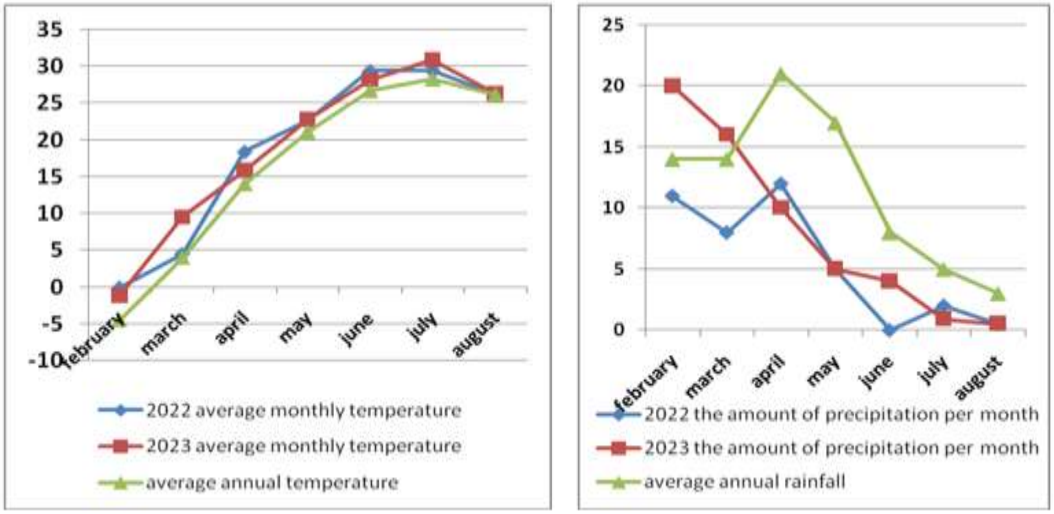

Figure 2. Agrometeorological conditions during 2022 and 2023.

case of close occurrence of mineralized groundwater. As FAO noted, agricultural lands of the region, suffering from the consequences of the Aral Sea desiccation, require close attention and investments.

The results revealed in the studied African millet (*P. glaucum* L.) cultivars, 13 appeared highly sensitive to salinization. We have identified a group of resistant genotypes, consisting of 17 samples, distinguished by a high germination rate (70%), stable seedling, and root growth. The genotypes' resistance to salinity manifested primarily by the physiological indicators, such as, water absorption capacity, leaf surface area, and root system development. These samples significantly exceeded the average resistant group of cultivars in terms of the mass of leaves and roots, which was due to their high water-holding capacity, an essential protective and adaptive function at increased osmotic pressure.

It is typical that the leaf area and the dynamics of its formation are one of the main indicators of photosynthetic activity of crop plants. Numerous studies reported the positive effect of leaf surface area on yield. However, under the salinization and drought conditions, such direct proportionality did not show. It largely depends on the intensity of the confirmatory in field conditions, which makes it possible to reject samples under laboratory physiological properties of individual cultivars. One of these crucial indicators is water-holding capacity, which is a key integral physiological indicator of the water regime and functional state of crop plants. The indicator displayed a close relation to metabolism, and its slight decrease signifies the resistance of plants to stress conditions. Salinity-resistant cultivars were distinctive with high water-holding capacity at increased osmotic pressure and the ability to use a minimum amount of moisture during the formation of generative organs.

Some African millet cultivars were inferior in leaf surface area than the standard cultivar Hashaki-1, found noticeably superior for the leaves and root mass. This may be due to their high water-holding capacity, which is an important protective and adaptive function at increased osmotic pressure. According to water-holding capacity, 13 millet cultivars were notable in comparison with the standard cultivar Hashaki-1 (Table 3).

The observations further showed in the group of resistant African millet genotypes, laboratory germination on a salt background was not considerably different from germination rate both in the control (distilled water) and in the field experiment (resistance coefficient > 80%). The effectiveness of laboratory diagnostics has also been conditions and focus on screening promising breeding material under field conditions. The genotypes found resistant to salinization at the early stages of ontogenesis had high productiveness in field conditions of the Kyzylorda Region, Kazakhstan (Table 4). These millet cultivars under field conditions also maintained the highest germination, survival, and conservation of plants, and were superior by the maximum green mass yield, exceeding the standard Hashaki-1 by an average of 0.1–8.4 t/ha.

Table 3. Physiological indicators of African millet cultivars under salinization conditions in the laboratory experiment (NaCl – 2.0%).

No.	Millet cultivars	14-day seedling phase				
		TWC (%)	WC (%)	MDS (g)	ISTI (%)	LSA (cm^2)
1	Hashaki 1 (Standard)	80.9	38.0	1.84	100	5.32
2	WRai POP	+2.2	+1.52	+0.09	+10	+0.34
3	IP13150	+2.5	+1.48	+0.18	+15	+0.42
4	GB 8735	+2.0	+1.42	+0.31	+10	+0.32
5	Dauro Genepod	-0.12	-1.10	-0.24	-10	-0.46
6	Sudan POP III	+2.0	+1.32	+0.12	+15	+0.07
7	IP19586	+1.0	+1.28	+0.14	+20	+0.18
8	JBV 3	+1.3	+1.22	+0.12	+15	+0.25
9	HHVBC Tall	+1.3	+1.81	+0.25	+14	+0.28
10	Sudan POP I	+2.0	+1.41	+0.19	+15	+0.24
11	IP 22269	+1.1	+1.21	+0.21	+11	+0.28
12	JBV 2	+0.9	+1.03	+0.14	+12	+0.14
13	Rai 171	+1.8	+1.33	+0.12	+13	+0.25
14	ICMV 155	-0.05	-1.00	-0.08	-10	-0.24
15	EMSHBC	+0.9	+1.07	+0.12	+13	+0.19
16	MC 94C2	-0.10	-1.07	-0.22	-10	-0.38
17	ICMS 7704	+0.9	+1.04	+0.17	+10	+0.18

Note: TWC - total water content; WC – water-holding capacity; MDS – mass of dry seedlings; ISTI – integral salt tolerance index; LSA – leaf surface area.

Table 4. Salt-tolerant parameters of the best African millet genotypes under laboratory and field conditions (averaged for 2022–2023).

No.	Millet cultivars	Laboratory experiment (NaCl-2.0%)		Field experiment (Solids 1.15%)		
		Germination *X*±% (%)	ISTI (%)	Germination *X*±% (%)	ISTI (%)	Green mass Yield (t/ha)
1	Hashaki 1 (Standard)	86.5	100	68.7	100	38.0
2	WRai POP	87.7	110	78.0	120	44.6
3	IP13150	87.0	115	76.2	120	43.0
4	GB 8735	86.8	110	74.5	115	42.1
5	Dauro Genepod	86.5	90	69.0	100	39.2
6	Sudan POP III	87.0	115	68.8	115	40.2
7	IP19586	88.5	120	80.2	120	46.4
8	JBV 3	86.0	115	76.5	120	45.2
9	HHVBC Tall	87.9	114	78.5	120	45.5
10	Sudan POP I	88.6	115	79.2	120	45.7
11	IP 22269	88.0	111	74.2	115	44.7
12	JBV 2	88.0	112	74.6	115	45.0
13	Rai 171	88.1	113	74.8	120	45.1
14	ICMV 155	87.0	90	68.0	100	38.0
15	EMSHBC	87.0	113	70.5	115	40.8
16	MC 94C2	86.7	90	66.7	100	37.7
17	ICMS 7704	87.4	110	68.9	115	38.4

The results revealed nonsignificant differences among the African millet cultivars for quantitative traits reflecting the formative process. The laboratory diagnostics verification had the cultivars emerging in early ontogenesis provided the highest productiveness under field conditions. Rashid *et al.* (2024) also concluded salt stress significantly reduced the various morphological, associated, and biochemical characteristics of pearl millet cultivars. Their studies identified salinity tolerant cultivars, viz., YBS-93, YBS-94, YBS-95, and YDR-8-1, which exhibited better shoot length, root length, and plant biomass production. Further genetic and molecular studies envisaged the mechanisms of salt tolerance and signaling pathways in the salt-tolerant species (Khan *et al.,* 2006; Kapoor and Pande, 2015).

Based on the correlation study in 21 traits for growth indicators at the early stages of ontogenesis under salinity conditions (2.0% NaCl), the most informative traits were the germination intensity, 14-day-old seedlings weight, and seminal roots length. They had an average positive correlation with the green mass yield. These traits have further recommendations as selection criteria for use in practical selection by evaluating an extensive set of the breeding material.

According to the salt tolerance index values and resistance to salinity, three genotype groups received classification as a) highly resistant (13 samples), b) medium-resistant (3), and c) non-resistant to salinity (1). Similar findings came from the work by Bano *et al.* (2019).

Thus, the sharp continental nature of the soil and climatic conditions of the Kyzylorda Region, Kazakhstan, leads to a significant variation in biotic and abiotic environmental factors. These define the constant search for new African millet cultivars adapted to local environmental conditions. The effectiveness of introducing crop cultivars results from the degree of their study for agronomic characters and biotic properties. The presented research showed one of the approaches to reduce the time required for screening the cultivars is laboratory diagnostics, making it possible to evaluate cultivars in a fairly short time for resistance to stress factors (drought, low temperatures, soil salinization, and pathogen infestation).

Phenological observations based on the growth and development of African millet showed the studied cultivars differed in growth intensity and the germination period. In African millet cultivars grown for green fodder, the harvest time could be the time when 50% of the heads emerged. However, standard cultivar Khashaki-1 of Uzbekistan selection (used as control cultivar) was ready to harvest for green fodder in 56 days, while other millet cultivars matured at different times. Based on this indicator, conditionally dividing the studied cultivars could be into three groups.

Previous studies have shown a wide range of diversity in agronomic traits, stress tolerance, and nutritional properties in African millet populations (Bashir *et al*., 2014; Sy *et al.,* 2015*;* Pucher *et al.,* 2015; Sattler *et al*., 2018), and in Asian germplasm (Yadav, 2008; Kumari *et al.*, 2016). It is also similar in the millet accessions bred at the ICRISAT (Shanmuganathan *et al*., 2006; Khairwa *et al.,* 2007). These studies emphasized that phenotypic characterization was the first step toward assessment, characterization, and classifying the germplasm to enhance their use in African millet breeding. The early ripening group includes cultivars producing 50% of the pods in 56–70 days, the medium-ripening group with cultivars producing 50% of the pods in 73–78 days, and the late-ripening group (millet cultivars producing 50% of the pods in 93–108 days).

According to this classification, the first early ripening group included six strains, namely, Hashaki 1 (56), NNVBC Tall (61), JBV 2 (65), ICMV 155 (66), MC 94C2 (68), and GB 8735 (70). The second group comprised five cultivars with medium-ripening period, such as, IP13150 (73), Rai 171 (73), WRai POP (75), Sudan POP III (77), and IP19586 (78). The third late-ripening group included four millet cultivars, i.e., ICMS 7704 (93), Sudan POP I (98), Dauro Genepod (108), and IP 22269 (108).

Phenological observations showed although sowing the seeds of the investigated cultivars were at the same time, however, their germination and the subsequent development stages were different. As a result, the duration of the germination period turned out to be varied. In the Aral Sea Region of Kazakhstan, 50% of the nine millet cultivars belonging to the late-ripening group produced the spikes in September, which means these cultivars were fully ripe and do not set grains under the conditions of the region.

The pearl millet yields in India increased by 3.0% per year during 1990–2017 by using heterotic effects through the development of hybrids (Yadav *et al.*, 2019). However, in contrast, the millet productivity on the African continent has not changed significantly over the past three decades from 1988 (691 kg/ha) to 2018 (718 kg/ha), although the cultivated area increased from 15.8 to 22.1 million hectares (Babatunde and Dipo, 2009). Therefore, it is necessary to develop new high-yielding cultivars using genetic diversity, and most importantly, to study them in a wide ecological area to identify their adaptability to stressful environmental conditions.

Based on the field germination, dividing the pearl millet cultivars could be into groups, with 45% of the studied samples characterized by average seed germination (51%–80%). Classifying the samples into groups totaled 35.2% with high (81%–90%) and very high (91%–100%) field germination. The proportion of samples with low seed germination ability was 19.8%. The survival rate of pearl millet plants averaged at 84.5%. In contrast to the field seed germination, nonsignificant differences occurred among genotypes for plant survival (V = 5.6%). According to this trait, the samples' distribution into groups confirmed the high adaptability of pearl millet genotypes to the changing environmental conditions. More than half (56%) of the studied samples showed the maximum (84%–90%) and very high (91%–96%) plant survival (Table 5). Survival within the range of 51%–80% was the characteristic of 42.5% of the samples, and only a small part (1.5%) turned out as unstable to adverse factors during the growing season. By determining the green mass yield in pearl millet, the ultimate green mass yield (34.5-48.0 t/ha) resulted from the millet genotypes HHVBC Tall, GB 8735, Sudan POP I, IP 22269, WRai POP, IP13150, and IP19586. The determination of the green mass yield was at the onset of the middle of the heading phase of each cultivar individually from the studied set of the genotypes.

Thus, based on the ecological cultivar testing of 50 pearl millet cultivars on the saline soil of the Aral Sea Region, numerous genotypes gained identification, based on individual characteristics and the complex of traits. From the current crop season results, the distinguished millet cultivars were WRai POP, IP 13150, GB 8735, Dauro Genepod, Sudan POPIII, IP 19586, JBV 3, HHVBC Tall, Sudan POPI, IP 22269, JBV 2, Rai 171, ICMV 155, EMSHBC, MC 94C2, and ICMS 7704, with a plant height above the 235 cm. A significant increase in the green mass yield received validation mainly by the number of plants before harvesting, due to the highest field germination, resistance to salinity and drought in the early stages of ontogenesis, and in general, having agronomic resistance to stress factors of the Aral Sea environment, Kazakhstan (Figure 3).

Breeders should pay attention to the economically valuable traits of crop plants, which least vary under the influence of environmental factors. It is precisely for these characteristics that during the selection process, it was possible to develop the superior cultivars, and highly varying traits needs regulation by agro-technical methods. Analysis of the data on the variability of quantitative traits helped identify three groups of traits, i.e., a) low-variable = number of roots, number of leaves, and leaf area, b) Moderate variable = germination, root thickness, and top-root ratio, and c) highly variable = length of 14-day-old seedlings and seminal roots, weight of seedlings and seminal roots. Attention is necessary to the high variable traits, such as, the length of 14-day-old seedlings and seminal roots, indicating a wide range of genotypic variability. Therefore, it is essential to conduct targeted selection of genotypes with high rates of these traits.

Table 5. Germination and survival of the African millet cultivars under the Aral Sea conditions, Kazakhstan (averaged for 2022–2023).

No.	Millet cultivars	Germination (%)	Number of plants (pcs/ha)	Plant height before harvesting (cm)	Productive tillering (pcs/plant)
1	WRaiPOP	85.7	169700	294.3	7
2	IP 13150	84.2	168500	262.5	7
3	GB 8735	89.8	164800	268.7	10
4	Dauro Genepod	88.3	167100	247.0	5
5	Sudan POP III	87.5	166800	302.4	7
6	IP 19586	86.3	173400	295.2	7
7	JBV 3	83.8	166300	294.7	7
8	HHVBC Tall	84.1	165900	287.6	11
9	Sudan POP I	83.8	164500	320.1	5
10	IP 22269	89.6	161200	245.3	5
11	JBV 2	84.5	164700	266.7	7
12	Rai 171	82.3	168300	238.3	6
13	ICMV 155	85.7	165800	239.5	10
14	EMSHBC	88.8	169600	120.8	7
15	MC 94C2	83.6	168900	205.4	5
16	ICMS 7704	84.8	168800	215.7	5
17	Hashaki 1 (Standard)	82.9	160300	235.6	6
	LSD_{05}	0.95			

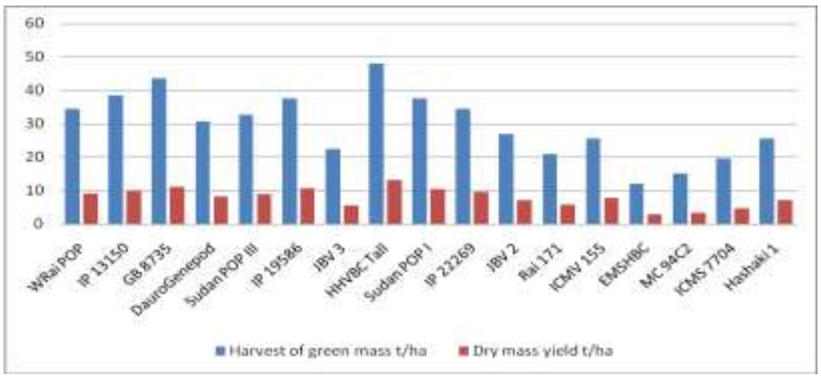

Figure 3. Green and dry mass yield of pearl millet cultivars (averaged for 2022–2023).

Effective breeding programs require optimal allocation of resources, which is highly dependent on the components of genetic variability, their interaction with the environment, and residual variability (Rajв *et al.,* 2005; Gordillo and Geiger, 2008). Thus, these quantitative genetic parameters need investigating at the beginning of the hybrid-breeding program. Studying the relationship between grain yield and other agro-morphological and phenological traits is also necessary to understand the adaptation mechanisms better (Tokhetova *et al.,* 2022).

In this regard, to increase the efficiency of selection using the correlation analysis method, we have determined the interdependence of various biological and economically valuable parameters. The close contingency of traits enables to evaluate indirectly the parameters of one based on the other. The study established under saline soil conditions of rice systems of the Kazakhstan Aral Sea region, the highest positive relationship appeared between the plant height and the green mass yield (r = 0.77), the number of grains in a panicle and the grain

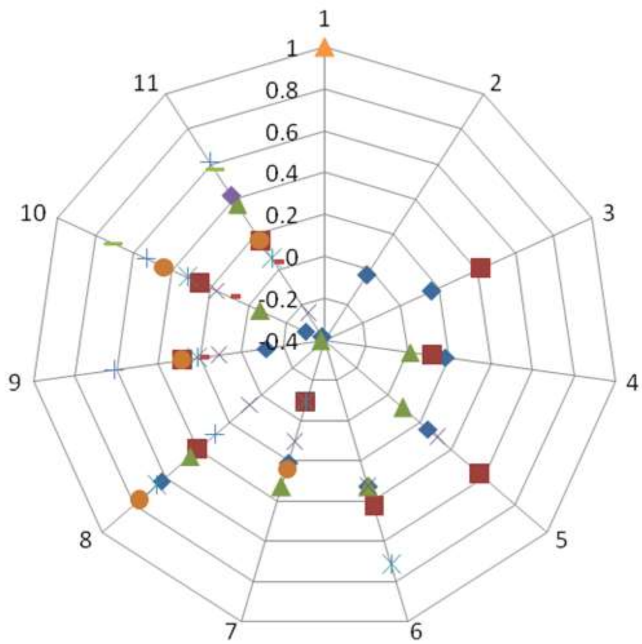

Figure 4. Correlation coefficients between productive and morpho-biological traits of pearl millet: 1-number of ears per 1 m², 2-plant height, 3-length of the upper internode, 4-ear length, 5-number of grains in an ear, 6-weight of grain per ear, 7-yield of green mass, 8-weight of grain per 1 m², 9-intensity of germination in saline solution, 10-total weight of 14-day-old seedlings, and 11-length of embryonic roots. Note: critical r values at 99% significance level = 0.3.

weight per panicle (r = 0.72), and the number of grains in a panicle and grain weight per one m² (r = 0.66). Average correlation with positive values were evident between the number of spikes per one m² and the green mass yield and the plant height and the number of grains in a panicle (Figure 4).

The analysis of the studied African millet cultivars further showed a high positive relationship among the plant height, number of spikes per one m^2, and green mass yield. Therefore, one can assume these traits can be effective as main factors in increasing yields under unfavorable ecosystems of the Kazakhstan Aral Sea Region. Thus, based on the correlation study of 21 traits for growth indicators at the early stages of ontogenesis under salinity conditions (2.0% NaCl), the most informative traits were the germination intensity, the total weight of 14-day-old seedlings, and the length of seminal roots. They gave an average positive correlation with the green mass yield and the grain weight per panicle. These traits were recommendable as selection criteria for use in practical selection by evaluating African millet breeding materials (Zhapayev *et al*., 2023; Muzzayyanah *et al*., 2024).

CONCLUSIONS

The laboratory diagnostics confirmed African millet (*P. glaucum* L.) cultivars emerging in early ontogenesis provided the highest productivity under field conditions. Thirteen millet cultivars have shown distinction as highly resistant to salinization, exceeding the standard cultivar Hashaki-1 for salt tolerance index (10%–20%), i.e., WRai POP, IP13150, GB 8735, Sudan POP III, IP19586, JBV 3, HHVBC Tall, Sudan POP I, IP 22269, JBV 2, Rai 171, EMSHBC, and ICMS 7704. These cultivars maintained the maximum germination, survival, and conservation of plants, and were also superior by the utmost green mass yield, exceeding the standard cultivar Hashaki-1 by 0.1–8.4 t/ha. Correlation analysis under salinity conditions showed the germination intensity, the total weight of 14-day-old seedlings, and the length of the seminal roots positively correlated with the green mass yield and grain weight per panicle. The study recommends these traits as most suitable criteria for practical selection in evaluating African millet breeding materials.

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REFERENCES

Babatunde M, Dipo B (2009). Global economic slowdown and the African Continent: Rethinking export-led growth. *Int. J. Afr. Stud.* ISSN 1451-213X Issue. 2: 47-73.

Bano DA, Singh K, Waza SA, Singh NP (2015). Effect of cowpea *Bradyrhizobium* (RA-5) and *Burkholderia cepacia* (RRE-5) on growth parameters of pigeonpea under salt stress conditions. *J. Pure Appl. Microbiol.* 9: 2539-2546.

Bashir EM, Melchinger AE, Parzies HK, Haussmann BI (2014). Characterization of Sudanese pearl millet germplasm for agro-morphological traits and grain nutritional values. *Plant Genet. Resour. Charact. Util.* 12: 35-47.

Bastos LM, Faye A, Stewart ZP, Akplo TM, Min D, Vara Prasad PV, Ciampitti IA (2022). Variety and management selection to optimize pearl millet yield and profit in Senegal. *Eur. J. Agron.* 139: 126-565.

Davydova GV (1979). Methodological guidelines for determining the salt resistance of grain crops for germination and survival of seeds in saline solutions. *N.I. Vavilov Institute of Plant Science*. Leningrad: VIR, 1979: 11.

Dospekhov BA (1985). Methods of field experiment. *Moscow Kolos:* 350. http://padaread.com/?book=51452.

FAO (2018). Handbook for Saline Soil Management, FAO, ISBN 978-92-5-130141-8, www.fao.org/publications.

Genesys (2024). Plant Genetic Resources for Food and Agriculture (PGRFA) conserved in genebanks worldwide, Pearl millet, *Genesys*, 2024, https://www.genesys-pgr.org/c/pearlmillet.

Gordillo G, Geiger H (2008). Alternative recurrent selection strategies using doubled haploid lines in hybrid maize breeding. *Crop Sci*. 48: 126-132. 10.2135/cropsci2007.04.0223.

Kapoor N, Pande V (2015). Effect of salt stress on growth parameters, moisture content, relative water content and photosynthetic pigments of fenugreek variety RMt-1. *J. Plant Sci.* 10: 210-221.

Khairwa lIS, Yadav SK, Rai KN, Upadhyaya HD, Kachhawa D, Nirwan B, Bhattacharjee R, Rajpurohit BS, Dangaria Srikant CJ (2007). Evaluation and identification of promising pearl millet germplasm for grain and fodder traits. *J. SAT Agric. Res*. 5: 1-6.

Khan M, Shirazi M, Ali M, Mumtaz S, Sherin A, Ashraf A (2006). Comparative performance of some wheat genotypes growing under saline water. *Pak. J. Bot.* 38: 1633-1639.

Kumari J, Bag MK, Pandey S, Jha SK, Chauhan SS (2016). Assessment of phenotypic diversity in pearl millet [*Pennisetum glaucum* (L.) R. Br.] germplasm of Indian origin and identification of trait-specific germplasm. *Crop Past. Sci.* 67: 1223.

Methodological guidelines for the study of the world millet collection. (1981). *N.I. Vavilov Institute of Plant Science*. Leningrad: VIR: 30.

Methods for determination of germination (2011). The interstate standard 12038-84. Moscow Standartinform: pp. 31 https://files.stroyinf.ru/Data2/1/4294838/4294838875.pdf.

Muzzayyanah PN, Suwarno WB, Ardie SW (2024). Gene action and heritability estimates in F_2 populations of Foxtail millet (*Setaria italica* L.). *SABRAO J. Breed. Genet.* 56(1): 65-75. http://doi.org/10.54910/sabrao2024.56.1.6.

Pucher A, Sy O, AngarawaiII, Gondah J, Zangre R, Ouedraogo M, Sanogo MD, Boureima S, Hash CT, Haussmann B (2015). Agro-morphological characterization of West and Central African pearl millet accessions. *Crop Sci.* 55: 737-748.

Rajв A, Abrahaв N, Ali A, Obilana AB, Jonesв R (2005). Topcross hybrids as an entry into commercial seed production of pearl millet in Eastern Africa. *Exp Agric.* 41: 335-356. 10.1017/S001447970500267X.

Rashid M, Noreen S, Hussain KS, Waqar R (2024). Morphological and biochemical variations caused by salinity stress in some varieties of *Pennisetum glaucum* L. *J. King Saud Univ. Sci.* 36(1): 102994. https://doi.org/10.1016/j.jksus.2023.102994.

Sattler FT, Sanogo MD, KassariI A, AngarawaiII, Gwadi KW, Dodo H, Haussmann BIG (2018).

Characterization of West and Central African accessions from a pearl millet reference collection for agro-morphological traits and Striga resistance. *Plant Genet. Resour. Charact. Util.* 16: 260-272.

Satyavathi CT (2017). Review of Pearl Millet Research, Project Coordinator Review, 52nd Annual Group Meeting, PAU Ludhiana. April 28–30, AICRP on Pearl millet, Jodhpur, Rajasthan, India, pp. 125-132.

Shanmuganathan M, Gopalan A, Mohanraj K (2006). Genetic variability and multivariate analysis in pearl millet. *J. Agric. Sci.* 2: 73-80.

Sy O, Fofana A, Cisse N, Noba K, Diouf D, Sane D, Kane A, Kane NA (2015). Study of the agromorphological variability of the national collection of local mils of Senegal. *J. Appl. Biosci.* 87: 8030-8046.

Toderich K, Akinshina N, Zhapaev R, Nurgaliyev N, Tautenov I, Gupta Sh, Srinivasa R (2013). Sorghum and pearl millet for crop diversification. Improved Crop-Livestock Productivity and Farmers Livelihood in Central Asia. International Center for Agricultural Research in the Dry Areas (ICARDA). PFU-CGIAR Office in Tashkent, 26-29 August 2013.

Tokhetova LA, Makhmadjanov SP, Savin TV, Baimbetova GZ (2022). Combining ability analysis in spring barley (*Hordeum vulgare* L.) for yield traits. *SABRAO J. Breed. Genet*. 54(4): 710-721. http://doi.org/10.54910/sabrao2022.54.4.3.

Upadhyaya HD, Reddy K, Ramachandran S, Kumar V, Ahmed MI (2016). Adaptation pattern and genetic potential of Indian pearl millet named landraces conserved at the ICRISAT gene bank. *Indian J. Plant Genet. Resour*. 29: 97-113.

Yadav OP (2008). Collection, characterization and evaluation of genetic diversity in pearl millet landraces from arid and semi-arid regions of Rajasthan. *Ann. Arid Zone 47*: 33-39.

Yadav OP, Rai KN (2013). Genetic improvement of pearl millet in India. *Agric. Res.* 2: 275-292.

Yadav OP, Singh DV, Dhillon BS, Mohapatra T (2019). India's evergreen revolution in cereals. *Curr. Sci.* 116: 1805-1808.

Zhapayev RK, Kunypiyaeva GT, Mustafaev FM, Bekzhanov SZh, Nurgaliev AK (2023). Comparative assessment of pearl millet genotypes under arid conditions of Southeast Kazakhstan. *SABRAO J. Breed. Genet*. 55(5): 1678-1689. http://doi.org/10.54910/sabrao2023.55.5.20.