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COMPARATIVE ASSESSMENT OF PEARL MILLET GENOTYPES UNDER ARID CONDITIONS OF SOUTHEAST KAZAKHSTAN

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SUMMARY

A comparative assessment of 14 pearl millet genotypes transpired for growth and yield traits under arid conditions of Southeast Kazakhstan. In this study, the green and dry plant biomass and grain yield of 14 pearl millet genotypes' assessment ensued under rainfed conditions in Southeast Kazakhstan. For green biomass yield, the three pearl millet genotypes Bair Bajsa, HHVBC tall, and J-6 performed better and were high yielders ranging from 39.07 to 39.94 t/ha. The accumulation of dry biomass (as hay) was different and varied widely from 3.17 to 17.36 t/ha; however, the maximum dry biomass appeared in the genotype HHVBC tall. Genotype HHVBC tall was leading for green and dry plant biomass formation and has the potential for grain yield under rainfed conditions of Southeast Kazakhstan. Drought always negatively impacted the production of fodder and grains; however, genotype HHVBC tall assures a stable plant biomass and seed production under arid conditions. In dry Southeast Kazakhstan, pearl millet, a drought-resistant crop, is a highly productive, valuable fodder and grain crop based on quality yields of biomass and grains. Subject to the cultivation technology and according to weather conditions, on average, the pearl millet genotypes form a green mass biomass yield of 40 t/ha and grain yield of 2.2 t/ha under rainfed conditions of Southeast Kazakhstan. For cultivation in the Republic, it is necessary to expand pearl millet as an annual crop, most adapted to extreme agroecological conditions.

Keywords: Pearl millet (*Pennisetum glaucum* L.), drought conditions, plant height, green and dry biomass, grain yield, Southeast Kazakhstan

Key findings: Pearl millet genotype HHVBC tall has a high potential for forming plant green and dry biomass but also showed a superior potential for grain yield under rainfed conditions of Southeast Kazakhstan. As most adapted to extreme agroecological conditions of the Republic, a need to recommend expanding the cultivation of pearl millet is a must.

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INTRODUCTION

Climate change, degrading soil and natural resources, desertification, irregular rains, drought conditions, hot weather, and inevitable decreasing natural reserves of energy raw materials threaten food security globally and nationally. The pattern of rainfall that may include an extremely high or low rate over a specific region leading to heavy or minimum rains is known as irregular rainfall. Droughts and floods cause considerable losses to life and property. Comparison of long-term mean temperatures for two successive periods, 1961–1990 and 1991–2020, indicates that the average annual temperature in the territory of Kazakhstan increased by 0.9 °C. In February and March, the temperature enhanced by 2.0 °C and 1.7 °C, respectively. The temperatures in July and December also changed a little.

The average annual precipitation over the territory remained practically unchanged; however, in some months, it increased, and the maximum rainfall was notable in February (by 15.6%), while in September and October, the rainfall decreased by 10.8% and 14.8%, respectively (UNFCCC, 2022). According to the United Nations Development Programme (UNDP), forecasts on climate change in Kazakhstan have two different scenarios, such as an annual increase in temperature by 1.7 °C –1.9 °C from 2020 to 2039 and an expected increase of 2.4 °C – 3.1 °C during the period from 2040 to 2059. Besides that, the Republic can expect a general increase in the annual precipitation. However, a significant warning in the middle of this century is an anticipated decline in summer rainfall in Kazakhstan.

Thus, agriculture continues to be one of the sectors most affected by extreme weather conditions (WMO, 2021). In 2021, Central Asia recorded a high temperature, which hurt the agricultural sector, and Kazakhstan experienced an unprecedented rise in temperature up to 46.5 °C. Abnormally high temperatures and their effect on the flow of rivers and reservoirs led to severe losses of crops and livestock (UN-OCHA, 2021). In Uzbekistan, a drought also resulted in crop losses with a limited supply of seasonal vegetables (Wong *et al*., 2021), highlighting the importance of making the agricultural sector resilient to external shocks. Various mechanisms can help to overcome these problems, such as integrated soil and watershed management to reduce soil erosion and runoff, vegetation management, and sustainable forest management. Increased agricultural productivity in arid areas will contribute to combat climate change and conserving terrestrial ecosystems (ESCAP, 2022).

Drought is one of the foremost abiotic stresses for crop plants worldwide and will intensify due to global climate change, rising temperatures, and fluctuating weather patterns. However, drought is always one of the main limiting factors in agricultural production, hindering plant growth, development, and productivity (Nethra *et al*., 2014; Ulaganathan and Nirmalakumari, 2015; Widyawan *et al*., 2018). In this regard, the current situation with global climate change necessitates the development and introduction of new drought-resistant crop genotypes in cultivation (Ziki *et al.,* 2019), such as African millet (pearl millet), which has wide distribution throughout the world and vital in developing and producing arid pasture and forage for livestock and birds (Gurinovich *et al.,* 2020). Its biomass is beneficial as feed for many animals, and its seeds serve as poultry and human food. Among warm-season cereals, millet is the most heat- and drought-tolerant crop (Gupta *et al.,* 2015).

Pearl millet (*Pennisetum glaucum* L.) is of tropical origin with C4 metabolism and is also resistant to moderate water stress and high temperatures; however, it is primarily grown for grain production in Asia and sub-Saharan Africa. According to FAOSTAT (2020), the annual sown area under millet crops was

33 million ha, with pearl millet (*Pennisetum glaucum* L.) sharing 85% of the land (Gurinovich *et al.,* 2020). The chief producing countries of pearl millet are India (11 million ha with 9.5 million t of grains), Central, Northeast, and West Africa, such as, Nigeria, Niger, Mali, Sudan, Burkina Faso, Ethiopia, Senegal, and Chad (16 million ha with 13.3 million t of grains).

Recently, pearl millet has gained enhanced attention as a multi-cut fodder crop for producing fresh fodder and forage in the arid and semi-arid tropics. In Central Asia, studies on pearl millet were mainly on saline, including Kazakhstan (Zhapayev *et al.,* 2015a, b; Toderich *et al.,* 2018). There are also no past data on the distribution of this highly productive crop in new marginal conditions, especially those subject to high salinity and drought. Besides, pearl millet is a non-traditional crop for Kazakhstan and other Central Asian countries, which meets all crop requirements, i.e., drought resistance, high nutritional value, two cuts per year, and high yield of green mass. It can also serve as a stubble crop after harvesting early winter grain crops. Moreover, the great potential for biomass output and seed productivity is of interest as a feed resource for livestock and birds in the arid conditions of Southeast Kazakhstan.

Cultivating intensive genotypes adapted to the area’s environmental conditions is essential for obtaining a high yield of good quality, especially in arid and changing climates. The timing of plant maturation, the passage of phenological phases, resistance to adverse weather conditions, and diseases and pests also depend on the correct choice of crop genotypes. As a result, all these together allow breeders to get a high yield of good quality at a lower cost. Thus, the early introduction of producing especially drought-resistant highly productive crops, such as pearl millet, capable of growing throughout the country, is the most effective solution to the problem.

MATERIALS AND METHODS

Plant material

Introducing new genotypes of non-traditional crops is imperative to obtain feed for livestock in Kazakhstan. Therefore, selecting drought-resistant and productive genotypes is becoming increasingly valuable. Evaluating the source material based on its ability to withstand environmental stress conditions is the foremost prerequisite for selecting new genotypes characterized by a reduction in costs per unit of crop with drought resistance and high yielding is the most effective solution to the problem of climate change and reduced precipitation (Zhapayev *et al.,* 2023).

Field experiments on evaluating 14 pearl millet genotypes transpired in rainfed conditions of Southeast Kazakhstan. The role of such crops is enhancement with severe unfavorable weather conditions (Komarov *et al.,* 2013). In this regard, it became necessary to introduce an unconventional drought-resistant crop, like pearl millet. Assessing several sorghum genotypes to select promising lines ensued; however, studies on pearl millet genotypes to isolate high-yielding genotypes under the environmental conditions of South and Southeast Kazakhstan were inadequate (Zhapayev *et al.,* 2015a, b; Kunypiyaeva *et al.,* 2018). Therefore, for the rainfed situations of Southeast Kazakhstan, there is a way to evaluate the highly productive genotypes of pearl millet, which have a high yield of green and dry biomass, multipurpose capabilities, and good adaptability to adverse environmental factors.

Fourteen pearl millet genotypes (Hashaki 1, IP 6104, GB 8735, ICMV 221, Raj 171, Sudan POP III, Bair Bajsa, ICTP 8203, MC94 C2, HHVBC tall, J-6, JBV-2, Guerinian 4/2, and IP 19586) served as the research material achieving evaluation under rainfed conditions of Southeast Kazakhstan. Seeds came from the International Crops Research

Table 1. Phenological phases of plant development of pearl millet genotypes during the crop season 2021.

Pearl millet genotypes	Sowing date	Seedling date	Phase 10-12 leaves	Full ripeness phase	Vegetation period (days)
Hashaki 1	May 08	May 20	July 18	September 19	134
IP6104	May 08	22nd of May	July 22	September 21	136
GB 8735	May 08	May 20	July 18	September 20	135
ICMV 221	May 08	May 20	July 18	September 21	136
Raj 171	May 08	22nd of May	July 22	September 21	136
Sudan POP 111	May 08	May 20	July 18	September 21	136
Bair Baisa	May 08	May 24	July 20	October 2	147
ICTP 8203	May 08	May 24	July 20	September 20	135
MC94 C2	May 08	22nd of May	July 22	September 30th	145
HHVBC tall	May 08	22nd of May	July 18	September 30th	145
J-6	May 08	22nd of May	July 20	September 30th	145
JBY-2	May 08	May 20	July 15	October 2	147
Guerinian 4/2	May 08	May 20	July 18	September 20	135
IP 19586	May 08	22nd of May	July 15	October 4	149

Institute for the Semi-arid Tropics (ICRISAT), Hyderabad, India. Field experiments in the crop season 2021 were in triplicate, with a randomized placement of plots. Sowing proceeded manually on May 1, with a simultaneous introduction of 150 kg of ammophos on the plot area of 14 m^2 (2.8 m × 5 m). Selecting the local millet cultivar Hashaki 1, released in Uzbekistan, became the check for comparison. The basis for the optimum planting date of pearl millet was usually on air and soil temperatures. Lemus (2015) reported that the optimal growth of pearl millet occurs at 32.78 °C to 35.00 °C, with the best sowing time from May to June.

For Southeast Kazakhstan, the optimal sowing time is the third day of April to the first day of May, depending on the weather conditions of that crop season. Phenological observations showed that the onset of growth and development phase of the studied millet genotypes took place within a wide range; hence, the whole ripening stage of the grain occurred from the second day of September to the first day of October 2021. At the same time, for studied genotypes, the growing season was 134–149 days. Early-maturing genotypes include Hashaki 1, GB 8735, ICTP 8203, and Guerinian 4/2, while late-maturing were IP 19586, Bair Bajsa, and JBY-2, with the remaining genotypes of mid-season (Table 1). Thus, selecting and introducing highly productive drought-resistant genotypes of pearl millet in Central Asia will provide an opportunity for adaptation and mitigation of the effects of global climate change.

Description of the study area

Rainfed lands of Southeast Kazakhstan are characteristics of increasing aridity. The rainfed land in the region is around 1.4 million ha of the total area. Performing the tasks consisted of laying and conducting field experiments under semi-arid (from 280 to 400 mm) and non-irrigated lands of Southeast Kazakhstan in the stationary laboratory of agriculture, Kazakh Research Institute of Agriculture and Plant Growing, Republic of Kazakhstan.

The soil cover of the experimental plot was piedmont, light chestnut soil, and according to the mechanical composition of the earth, it belongs to coarse silty medium loam, containing physical clay at 39%–42%, coarse dust (45%–51%), and silt (12%–17%). The provision of the soil with easily hydrolyzable nitrogen was medium, with low mobile phosphorus and medium exchangeable potassium. The upper horizon contains humus (2.02%) and gross nitrogen (0.12%–0.14%). Groundwater, located more than 10 m deep, does not affect the soil-forming process.

Table 2. Weather conditions for the growing season 2021 at the Almalybak Weather Station, KazRIAPG.

Months	Atmospheric precipitation (mm)		Air temperature (℃)		Relative humidity (%)
	2021	Long-term average	2021	Long-term average	2021
April	56.3	56.5	12.4	10.4	66
May	81.6	61.6	19.4	16.4	63
June	20.9	53.9	23.1	21.2	50
July	22.8	26.6	26.9	24.1	41
August	27.2	21.2	24.0	22.1	50
September	1.6	15.9	20.5	16.0	50

Meteorological conditions

In the crop season 2021, the meteorological conditions differed significantly from the long-term average values and had great diversity (Table 2). According to the weather data, the spring of 2021 was more humid (by 88.9 mm) and warmer than long-term averages, especially in March, characteristic of an excess of long-term indicators by 3.4 degrees. Precipitation that fell on April 1 contributed to sufficient accumulation of moisture in the soil to obtain friendly seedlings of crop plants. According to the temperature background, the summer months were hotter (except August) than the average long-term indicators by 1.9 °C–2.7 °C, with the precipitation observed below the norm by 30.8 mm. According to the agrometeorological conditions, such summer was extremely dry and hot. In general, according to the weather conditions in 2021, for the growth and development of pearl millet plants, the said crop season was unfavorable due to lack of moisture from a hot summer climate.

RESULTS AND DISCUSSION

Pearl millet is a drought-resistant and high-yielding crop with better green and dry biomass and one of the most valuable annual fodder grasses that contribute to their rapid introduction and production. As part of several international research -projects, high-yielding and salt-tolerant genotypes of pearl millet, sorghum, and other crops underwent screening in nurseries. This research aimed at developing agrotechnical methods for cultivating new valuable crops for the economic and sustainable development of arid fodder production and animal husbandry. Sorghum is a well-adapted crop to semi-arid and arid regions due to its tolerance to abiotic stresses such as drought and salinity.

In most studies involving multiple conditions, the maximum variability occurs in the environments (Mohammadi *et al*., 2009). Pearl millet can withstand high temperatures and drought, especially in marginal soils with limited water and nutrient retention capacity (Kapadia *et al*., 2016). In addition, it is an early-ripening crop (65–90 days), which allows for a double harvest in various regions. It has a vast yield potential and can provide more fodder than sorghum and maize. Therefore, it is an attractive crop for inefficient agriculture to deal with environmental problems, such as global warming, unstable weather conditions with water shortages, and other abiotic stresses.

Also notably, the response and tolerance of plants to stress varies depending on their genotypes and environments, which has reference to biological differences between the genotypes, plant growth, and stress conditions, and even short-term drought or salinity stress affects the plant tolerance, which ultimately leads to decreasing plant growth, development, and yield (Muscolo *et al*., 2014). With improved feed supplies, the farmers will surely benefit from the growing demand for livestock products, which will be enhanced expectedly (Delgado *et al*., 1999). Water stress affects crop productivity during the vegetative and final growth stages (Shivhare and Charu, 2019). Additionally, improved cultivars developed for dual purposes can benefit the farming community by meeting local feed and food requirements (Yadav *et al*., 2021).

Therefore, one of the non-traditional crops can be pearl millet, which can serve as an economically viable alternative and an often repeated-grain crop for developing rainfed lands in the Central Asian region. Furthermore, it is very critical for agricultural production to know which genotypes to sow in arid soils. In this regard, the study and introduction of various genotypes in the dry lands of Southeast Kazakhstan will help increase agricultural productivity and significantly improve the farming community's income. Moreover, the study and adoption of non-traditional crops, such as pearl millet in the face of climate change, will contribute more to advancing the entire agricultural sectors, such as livestock and poultry, by using green and dry biomass and grains, respectively.

Nowadays, the pearl millet has lesser use in Kazakhstan. The main factors limiting the production potential of pearl millet are limited collection samples, with breeding work to develop new domestic cultivars and hybrids not carried out, and insufficient knowledge of this crop in Kazakhstan. Other countries, such as South America and Korea, are experimenting with pearl millet as a new forage crop, and the United States has a new interest in cultivating pearl millet as a grain crop due to its drought tolerance and high quality (Kumar *et al*., 2020). It is worth noting that any crop improvement program to succeed depends on the presence of genetic diversity maintained within the genotype (Kumar *et al*., 2016). The pearl millet genotype exhibits extensive variations in several traits, including yield and nutritional properties. Availability, assessment, and use of genetic diversity aid in new cultivars' development (Singh and Gupta, 2019).

Regarding the above, one of the ways is to run a comparative assessment of highly productive genotypes of pearl millet, which have a high yield of green and dry biomass, multipurpose functions, and good adaptability to adverse environmental conditions. Previous descriptions of agronomic differences among pearl millet genotypes have ensued, which can guide selection based on the cultivation purpose, such as forage and grain (Dewey *et al*., 2009).

A comparative assessment of the 14 pearl millet genotypes progressed according to the agrobiological characteristics, i.e., plant height, green and dry biomass, and grain yield. The studied pearl millet genotypes grown under rainfed conditions showed nonsignificant differences in plant height ranging, from 170 to 240 cm (Figure 1). However, the millet genotypes, i.e., Sudan POP III, Guerinian 4/2, and ICMV 221, their plant heights varied from 170 to 185 cm, genotypes ICTP 8203 and IP 19586 were considerably tall (240 cm), with the rest of the genotypes showing intermediate plant heights ranging from 200 to 220 cm.

In addition to drought tolerance and tolerance to low soil fertility, pearl millet's dual role in agropastoral agriculture is particularly essential for its biomass (i.e., above-ground biomass other than grain), commonly used as animal feed, and its grain used for human consumption (Hassan *et al*., 2021). Modern pearl millet cultivars are primarily single-purpose, bred, and grown for either biomass (i.e., livestock feed) or grain (Serba *et al*., 2020). This difference in end-use leads farmers to plant different cultivars with different cultivation requirements. Lately, due to its high thickness and growth capacity (Shekara *et al*., 2020), dual-purpose pearl millet has been highlighted as a potential crop for biomass and grain production. Uneven rainfall patterns that characterize the semi-arid Sahel region can lead to feed shortages and conflicts between crop and livestock farmers, which can achieve mitigation through the broad adoption of dual-purpose pearl millet (Satyavathi *et al*., 2021).

The results further revealed that the yield of green and dry biomass could benefit as screening and selection criteria for drought tolerance among the studied genotypes of pearl millet. In screening the genotypes for output of green biomass, millet genotypes, viz., Bair Bajsa, HHVBC tall, and J-6, gave 39.07–39.94 t/ha (Figure 2). The least significant yield of green biomass (12.68–19.82 t/ha) emerged in the genotypes Sudan POP III, Guerinian 4/2, and GB 8735. The remaining millet genotypes showed intermediate green biomass yield. In the

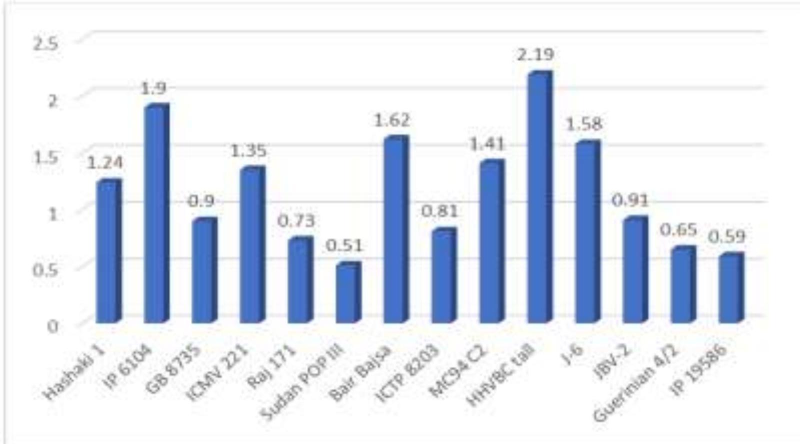

Figure 1. Performance of pearl millet genotypes for plant height (cm).

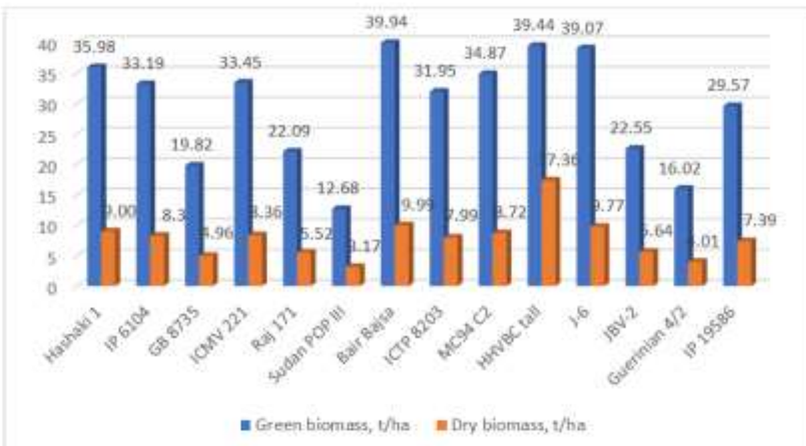

Figure 2. Performance of pearl millet genotypes for green and dry biomass (t/ha).

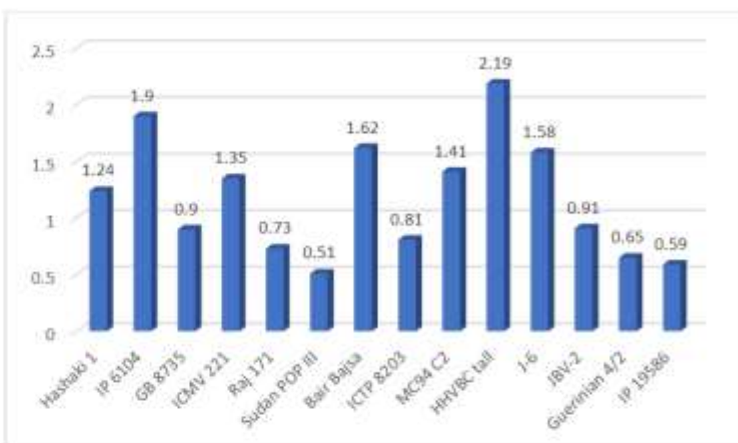

Figure 3. Performance of pearl millet genotypes for grain yield (t/ha).

experiments, the accumulation of dry biomass (as hay) differed and varied within a range of 3.17–17.36 t/ha. However, the massive dry biomass formation came from the millet genotype HHVBC tall, which was also similar in its panicle size and seed output.

Among pearl millet genotypes, the differences in biomass production can refer to the influence of genetic characteristics of crop genotypes (Saifullah *et al*., 2011). Previous studies have shown that the main drivers of pearl millet productivity under water-limited conditions are drought tolerance rather than high yield potential. Therefore, evaluation studies with contrasting genotypes conducted under drought and non-drought conditions suggest cross-genotype-environment interactions (Van-Oosterom *et al*., 2003). In studies by Toderich *et al*. (2018), pearl millet genotypes IP 19856 and HHVBC tall showed approximately 30% more dry feed yield and 25% more seeds compared with the local cultivar Khashaki1. Additionally, improved pearl millet lines showed that genotype significantly affected (64.4%) plant green biomass yield.

The 14 pearl millet genotypes indicated a grain yield range of 0.51–2.19 t/ha (Figure 3). However, the highest grain yield resulted in the genotype HHYB tall, with a significant increase in seed yield associated with panicle size and seed weight. Meanwhile, the minimum grain yield appeared from two genotypes, i.e., Sudan POP III (0.51 t/ha) and IP 19586 (0.59 t/ha). Genotype HHVBC tall has a high potential for forming plant green and dry biomass but also showed promising grain yield in the rainfed conditions of Southeast Kazakhstan. Thus, a high capacity of biomass output and seed productivity is of great interest as a feed resource for livestock and birds, respectively, under the arid conditions of Southeast Kazakhstan.

The high potential for biomass production and seed productivity immensely provide a feed supply for livestock and birds in Southeast Kazakhstan’s dry environments. Drought during flowering reduces pollen tube growth and fertilization, resulting in less seed setting, and stress during grain filling results in decreased grain yield. Previous studies documented grain yield losses of 65% for pearl millet under severe drought conditions in Niger (Yadav *et al*., 2002). Similarly, on average, across all nine genotypes over two years, a 53% decrease in grain yield was evident under rainfed conditions. In addition, the speed and duration of seed filling affect the seed weight, which is a major component of total seed yield (Yang and Zhang, 2006).

Since drought negatively impacted fodder production and grain productivity, pearl millet genotype HHVBC tall will guarantee stable plant green and dry biomass and grain production in arid conditions. Interestingly, the crop season 2021 was unfavorable and dry; therefore, the most suitable genotypes were distinguishable, which, even under drought conditions, form a stable production of green and dry fodder and grains.

Reduced grain yield under water stress may also be linkable with above-ground biomass, with lower straw yield indicating a negative impact on assimilate production, resulting in reduced yield with pearl millet under terminal drought conditions and a decrease of 7.5%–55.2% in straw yield (Yadav *et al*., 2002). In addition, terminal drought and heat stress reduced plant photosynthetic rates in growth chambers (Prasad *et al*., 2011) and field conditions (Sehgal *et al*., 2017). Feed production revealed a strong correlation (r = 630) between straw and grain yield. However, the loss of millet grain yield may also be attributable to decreasing panicle number (Yadav *et al*., 2012). A positive correlation occurred in plant height and leaf area and green mass yield of pearl millet (Imran *et al*., 2007).

Correlation analysis among the main agrobiological characteristics ensued among plant height, green and dry biomass, and grain yield; between the green biomass and grain yield; and between the dry biomass and grain yield. The analysis showed the linear dependence of the coefficient of determination between green biomass and grain yield (0.581), and the coefficient of determination between dry biomass and grain yield was 0.665, which authenticated that green and dry biomass also contribute an increase in grain yield of the studied pearl millet genotypes, i.e.,

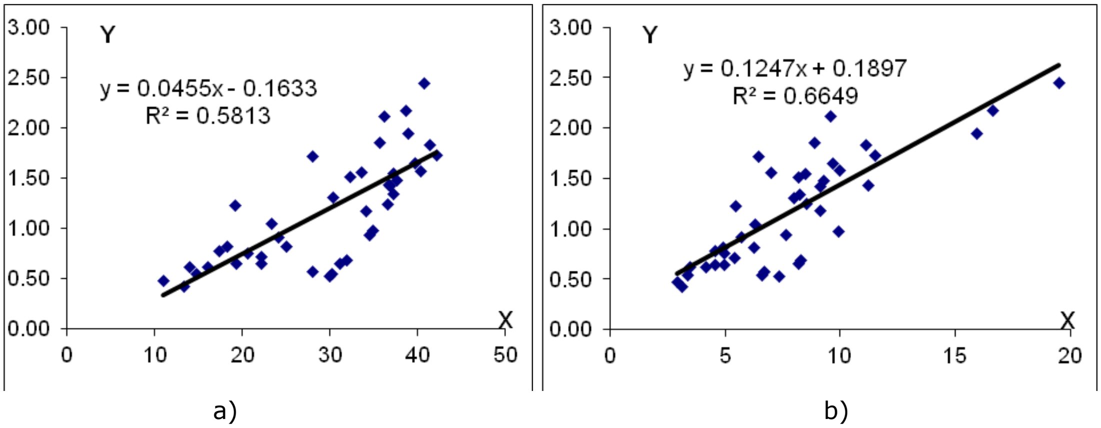

Figure 4. The correlation coefficient of 14 pearl millet genotypes: (a) between the green biomass and grain yield, (b) between dry biomass and grain yield.

analysis of the regression equation - medium and above average (Figure 4). As for the plant height on the accumulation of plant biomass and grain yield, a weak correlation was distinct under rainfed conditions of Southeast Kazakhstan.

In the analysis of variance, the years of study were significant for all the traits, and the genotypes' characteristics also varied significantly over the years. Years accounted for 70%–75% of the variation in biomass, highlighting the high degree of environmental variation in the dryland pearl millet growing area, and some characteristics, such as the number of panicles per square meter and panicle length were largely stable, with 60% per genotype and 75% of the total phenotypic number of variation (Bidinger and Raju, 2000). Grain yield had a significant positive correlation with panicle number (r = 0.690), indicating a substantial benefit to genotypes with the ability to produce more panicles. More panicles provide developmental plasticity under drought conditions (Van-Oosterom *et al.*, 2003).

Grain number had a high positive correlation with panicle yield but showed a negative correlation with seed size. The panicle yield index had a significant and positive relationship with grain yield (r = 0.670), reflecting the ability of genotypes to fill grain under moisture-deficit conditions, and, therefore, its positive relationship with grain and in later flowering genotypes negatively affected panicle yield (Yadav and Bhatnagar, 2001). Biomass yield had a significant positive relationship with crop yield. Biomass variation accounted for 81%, while 15% of the variations in grain yield. Additionally, it has been a statement that biomass rather than grain yield should serve as a measure of drought adaptation (Bidinfer and Yadav, 2009). In addition, harvest depends on the selection of genetic material; thus, drought-adapted pearl millet landraces produced higher biomass; however, they provided a lower yield index, while elite improved cultivars had lower biomass with a much higher yield index (Yadav, 2008).

CONCLUSIONS

Field screening of 14 pearl millet genotypes showed that the studied genotypes formed a reasonably high fodder and grain productivity under dry conditions. It was also evident that under the conditions of Southeast Kazakhstan, pearl millet, as a drought-resistant plant, proved highly productive by providing high yields of green and dry biomass and grains. Subject to the cultivation technology, the formation of a green mass yield of up to 40 t/ha and grains of up to 2.2 t/ha occurred. For cultivation in the Republic, its recommendation centers on expanding the cultivation of pearl millet as an annual crop that primarily adapts to extreme agroecological conditions.

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