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GROWTH, YIELD AND QUALITY OF SOME PEARL MILLET [*PENNISETUM GLAUCUM* (L.) R. BR.] GENOTYPES GROWN IN THE SEMI-ARID CLIMATE ZONE IN TÜRKİYE

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Abstract

This study was aimed to determine the performances of some pearl millet [*Pennisetum glaucum* (L.) R. Br.] genotypes that can be evaluated as roughage source in terms of forage yield and quality under second crop conditions. In this study, population number 3329, 4488, 5153, 8220, 9000, 9492, 9527, 10085 and 10467 and 'White' cultivars were used as plant material. Statistically significant differences were found among the genotypes in terms of plant height, number of stem, number of leaves on the main stem, green forage yield, hay yield, crude protein (CP), CP yield, acid detergent fiber, neutral detergent fiber and relative feed value. It was concluded that the highest agronomical productivity especially in terms of forage and CP yield was found in population number 4488.

Introduction

High temperatures, increase in arid lands and decrease in water availability resulting from climate change in recent years directly affect the cultivation of forage crops, as in other agricultural products. These adverse climatic conditions, especially in arid and semi-arid areas, shorten the vegetation period of many known forage plant species and reduce forage yield due to early flowering. It is necessary to introduce new forage plant species and varieties that are tolerant to high temperatures and drought and have high yield potential and forage quality per unit area. For this reason, the yield potential of genotypes belonging to different forage crop species should be constantly monitored. In this sense, millets constitute the plant group that has come to the fore and been studied in recent years. Pearl millet [*Pennisetum glaucum* (L.) R. Br.], which is among the millets and belongs to the Poaceae family, is one of the most climate-resistant crops due to its better adaptation to marginal environments and high nutritional value in the era of climate change (Lauriault *et al.* 2023). Pearl millet is an annual, warm-season plant widely cultivated for grain, grazing, and hay (Babiker *et al.* 2024). This plant attracts attention with its superior agro-ecological properties such as being able to grow in soils with low soil fertility and low pH, being resistant to drought, and having high tolerance to salinity and heat (Yadav *et al.* 2019, Gupta *et al.* 2022, Rashid *et al.* 2024). Moreover, pearl millet outperforms all other cereals such as wheat, maize, paddy, sorghum and barley due to its high photosynthetic efficiency, higher dry matter production capacity and lower input and higher economic returns in adverse agro-ecology (Jukanti *et al.* 2016, Satyavathi *et al.* 2021). However, pearl millet is also advantageous as a dual-purpose crop because it is an excellent animal feed both as a grain and a forage (Yadav *et al.* 2021). It has the advantage and/or potential to be evaluated as a forage plant with its important features such as high leafiness and tillering capacity, high crude protein (CP) rate and high forage yield (Lauriault *et al.* 2023), and an excellent regrowth ability that allows grazing after each cutting.

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These superior agricultural properties of pearl millet make it an alternative plant for producing the roughage required by animal husbandry in countries such as India, Bangladesh and Türkiye. However, as with many other crop plants, achieving optimum yield depends on using genotypes suitable for climate and soil conditions. Investigating the effects of genotypic factors on forage yield, quality and nutritional value, especially in forage crops, and obtaining up-to-date information in this sense is of great importance today, when climate change is experienced suddenly and rapidly. In this respect, data on the use of pearl millet, especially as a forage crop, is scarcely. The aim of this study was to determine the performance of some pearl millet (*P. glaucum*) genotypes that can be evaluated as a forage source under second crop conditions in semi-arid areas.

Materials and Methods

The field trial in the present research was carried out in the second crop growing season (July-October, 2023) in Mardin province, which has semi-arid climate conditions in Türkiye. While the average temperature value during the pearl millet vegetation period (July-October) was 27.5°C, this value was slightly higher than the long-term (1941-2023) average value of the same period 25.9°C. The total rainfall in the trial year was 5.7 mm, the long-term average was recorded as 42.8 mm. The soils where the pearl millet is grown are clayey-loamy, salt-free and neutral in character; lime content is "very calcareous", organic matter content is "low", available phosphorus (P) content is "medium" and available potassium (K) amount is "excessive". In this study, 9 pearl millet populations 3329, 4488, 5153, 8220, 9000, 9492, 9527, 10085 and 10467 were obtained from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and the Şırnak University Faculty of Agriculture collection and the 'White' control variety was obtained from Sudan were used as plant material.

The field experiment was set up according to the randomized block design with 4 replications. Planting was done in 4 rows with 70 cm inter-row distance and 25 cm on the row, and the plot length was kept 4 m. The sowing was done on July 7, 2023. The forage harvest of each genotype was made during the soft dough stage of the grains in the cluster. Some agronomical parameters affecting the yield, such as plant height (PH), stem number (SN) and the number of leaves on the main stem (MSLN) were measured on 10 randomly selected plants in each plot during the harvest of the plants and then the green forage yield (GFY) and hay yield (HY) of the pearl millet genotypes were determined. Dried forage samples (whole plant parts) were ground separately for each plot in order to determine the hay yield. Crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) ratios in ground plant samples were determined using the Near Infrared Reflectance Spectroscopy (NIRS) device (Brogna *et al.* 2009). Crude protein yields (CPY) were calculated by multiplying the CP ratio values with the hay yields. Relative feed value (RFV) was calculated from the estimates of dry matter digestibility (DMD) and dry matter intake (DMI) (Van Dyke and Anderson 2000): DDM % = 88.9 - (0.779 × %ADF), DMI % = 120 / %NDF, RFV = %DMD × %DMI × 0.775. Standards for RFV as a criterion to grade hay were proposed by the Hay Marketing Task Force of the American Forage and Grassland Council (Rohweder *et al.* 1978), and are presented in Table 1. The data obtained from the study were subjected to variance analysis according to the randomized block design; with respect to the differences between the groups were determined with the Least Significant Difference (LSD) multiple comparison test. In the study, principal component analysis (PCA) was performed according to 10 features obtained from 10 different genotypes. Also k-means clustering applied to the PCA results. Analyses were performed using R statistical package program.

Table 1. Quality standards of legume, grass, and legume-grass mixture.

Quality standard	CP, %DM	ADF, %DM	NDF, %DM	RFV
Top quality (prime)	> 19	< 31	< 40	> 151
1. Quality (premium-very good)	17-19	31-35	40-46	151-125
2. Quality (good)	14-16	36-40	47-53	124-103
3. Quality (fair)	11-13	41-42	54-60	102-87
4. Quality (poor)	8-10	43-45	61-65	86-75
5. Quality (reject)	< 8	> 45	> 65	< 75

Reference hay of 100 RFV contains 41% ADF and 53% NDF

Results and Discussion

Data pertaining to the growth and forage yield of pearl millet are presented in Table 2. The PH, SN and MSLN are important growth characteristics that are directly related to the productive potential of the plant in terms of forage yield. In addition, PH is closely related to photosynthetic capacity, harvest index and yield (Jing *et al.* 2023, Wang *et al.* 2023). The growth and development of leaves, are the primary tissue for both photosynthesis and feed consumption, are important in forage crops. Because leaves are richer in CP, minerals and vitamins compared to other plant organs, although they depend on growing conditions.

Table 2. Some yield parameters and forage yield of pearl millet genotypes.

Genotypes	PH (cm)	SN (No./plant)	MSLN (No.)	GFY (kg/ha)	HY (kg/ha)
3329	278.6 c	6.50 d	12.20 cde	54978 c	14789 c
4488	338.1 a	11.58 a	14.15 a	88438 a	27331 a
5153	323.3 ab	9.10 b	13.60 ab	70357 b	20085 b
8220	311.8 b	8.00 bcd	13.40 abc	62973 bc	18987 b
9000	315.4 ab	8.35 bc	12.85 bcd	63513 bc	19041 b
9492	310.8 b	8.55 bc	13.40 abc	63996 bc	19159 b
9527	330.0 ab	11.00 a	13.65 ab	70411 b	20219 b
10085	312.3 b	9.00 b	13.50 ab	69129 b	19290 b
10467	285.9 c	7.95 bcd	11.75 de	58996 c	17499 bc
White	279.8 c	7.20 cd	11.15 e	55246 c	17243 bc
CV (%)	5.53	12.48	6.68	10.17	11.39

The difference between the means shown with the same letter in the same column is not statistically significant. CV: Coefficient of variation. PH: Plant height, SN: Stem number, MSLN: No. of leaves on the main stem, GFY: Green forage yield and HY: Hay yield.

Results from the present study indicated the significant variation ($p<0.01$) among pearl millet genotypes for PH, SN and MSLN. The highest values were obtained in genotype 4488 in terms of all three parameters, genotype 9527 was statistically at par with 4488 in terms of SN (Table 2). The differences in these parameters are thought to be due to differences in the genetic structures of the genotypes. Previous studies on pearl millet genotypes emphasized significant differences among varieties/populations in terms of PH (Kumawat *et al.* 2016, Aswini *et al.* 2023), SN (Pucher *et al.* 2015, Sayğıdar *et al.* 2024) and MSLN (Hassan *et al.* 2014).

The ultimate goal in forage crop agriculture is to get the best forage yield which depends on genomic and environmental factors (Hassan *et al.* 2014) and the cultural treatments applied. The GFY and HY in pearl millet genotypes were found significantly different ($p<0.01$). The highest yields was obtained in population number 4488 (Table 2). In terms of GFY, populations 3329 and 10467 and the White variety showed the lower values, while population 3329 showed the lowest values in terms of HY. In the present study, significantly higher forage yield in population 4488 was obtained due to higher PH, SN and MSLN. As a matter of fact, it has been reported eatlier by others (Hassan *et al.* 2014, Sayğıdar *et al.* 2024) that PH and MSLN are effective on forage yield. Similar to the present research findings, significant differences in GFY and HY in pearl millet genotypes have been reported in the past by some researchers (Salama *et al.* 2020, Aswini *et al.* 2023, Sayğıdar *et al.* 2024).

Data on some forage quality of pearl millet genotypes are presented in Table 3. The crude protein content in dry matter is an important parameter affecting the palatability and digestibility of forage crops. Genotypes showed significant differences ($p<0.01$) in terms of CP content. Population number 5153 produced the highest CP rate followed by 10085, 3329, 9492 and 9000 and lowest was in 9527 (Table 3). According to Kabir *et al.* (2019) protein content is genetically controlled. Therefore, the variation among pearl millet genotypes can be attributed to the differences in their genetic structures. For all that, the amount of CP in feed rations is also important in order to meet the needs of ruminants. In this sense, Meen (2001) emphasized that the CP content in feed rations should be at least 7%. From this aspect, it was observed that the pearl millet forages were sufficient to meet the protein needs of animals in feed rations. In addition, considering the CP ratio according to the classification in Table 1, hay of poor to medium quality standards was obtained from pearl millet.

Table 3. Forage quality parameters of pearl millet genotypes.

Genotypes	CP (%)	CPY (kg/ha)	ADF (%)	NDF (%)	RFV
3329	12.48 abc	1848.5 e	30.69 ab	58.67 a	104.0 c
4488	11.43 b-e	3128.4 a	32.86 a	57.74 a	102.4 c
5153	13.61 a	2732.7 ab	28.39 bc	51.42 bc	122.1 ab
8220	10.53 de	2007.0 cde	29.98 abc	54.85 abc	111.2 bc
9000	12.09 a-d	2297.9 b-e	33.24 a	54.36 abc	108.3 bc
9492	12.41 abc	2391.2 bcd	26.73 c	49.51 c	128.7 a
9527	10.13 e	2030.5 cde	31.29 ab	56.47 ab	106.7 bc
10085	12.66 ab	2431.8 bc	30.03 abc	54.90 abc	111.2 bc
10467	10.97 cde	1913.4 de	31.44 ab	57.57 a	104.6 c
White	11.73 b-e	2033.6 cde	31.99 a	59.67 a	100.1 c
CV (%)	9.37	14.70	7.66	7.30	9.87

The difference between the means shown with the same letter in the same column is not statistically significant. CV: Coefficient of variation. CP: Crude protein, CPY: Crude protein yield, ADF: Acid detergent fiber, NDF: Neutral detergent fiber and RFV: Relative feed value.

In forage crops, the CPY obtained from unit area is as important as the CP ratio. In this context, CPY, which is the result of multiplying the HY and CP ratio, varied significantly ($p<0.01$) according to the genotypes. In this study CPY among the genotypes varied between 1848.5 and 3128.4 kg/ha; population 4488 with high HY caused the highest CPY (Table 3). In previous studies conducted in different ecologies, it was reported that CPY in pearl millet plant varied between 360 and 1511 kg/ha according to genotypes and that the effect of genotypes on CPY was found significantly consistent with present research findings (Singh *et al.* 2012, Kumawat *et al.* 2016, Shekara *et al.* 2021).

The ADF ratio, which is an indicator of total digestible nutrients in forages, and the NDF ratio, which is related to ruminant feed consumption, are important criteria that determine the quality of forage plants. It is desired that the ADF and NDF ratios in forage plants are low. The lowest values for both parameters were determined in population number 9492 (Table 3). Despite the statistically significant variability ($p<0.05$) among genotypes, the feed quality standards were taken into account (Table 1). It was observed that pearl millet genotypes produced feed ranging from “top quality” to “very good” in terms of ADF ratio and from “good” to “moderate” quality standards in terms of NDF ratio.

Statistically significant variation was observed among the genotypes in terms of RFV at $p<0.05$ level. The highest RFV was determined in population number 9492 with 128.7; while the lower RFV was determined in populations number 4488 (102.4), 3329 (104.0) and 10467 (104.6) and White (100.1) variety, which are statistically in the same group (Table 3). When the RFV averages calculated for pearl millet hay are evaluated on the scale given in Table 1. It is understood that the feeds obtained from pearl millet genotypes are in the feed group between "medium" and "very good" quality in terms of RFV.

In PCA, the number of variables is reduced to linear functions called principal components (PC) which accounts for most of the variation produced by the characters under study. The direction and amount of contribution of each feature used in this study to the PCs are given in Table 4. The shares of these PCs in the total variation and their cumulative contribution margins are given in Table 5 together with their Eigen values. The study identified 3 PCs with Eigen value greater than 1.00 which accounted for 83.3% of the total variation for discriminating the lines. From PCA, PC1 showed the highest amount of variance (46.2%) which mostly related to traits like CPY (0.4026), GFY (0.3915), and HY (0.3783). As a result, the first component mainly identifies the characters responsible for yield. PC2 showed second highest amount of variance (27%) with cumulative variance (73.2%) with mostly related to traits like RFV (-0.5065), ADF (0.4955), and NDF (0.4538). Therefore, the PC2 mainly identifies the characters related with fiber ratio and feed value. PC3 showed third highest amount of variance (10%) with cumulative variance (83.3%) with mostly related to traits like CP (0.7850), and CPY (0.4454), therefore the PC3 mainly identifies the characters which are related with CP (Tables 4 and 5).

Correlation matrix of 10 traits plotted against the five principal components is presented in Fig. 1 and biplot between PC1 and PC2 for 10 characters of 10 genotypes is presented in Fig. 2. From correlation matrix the red dots show the positive relationship between the respective characters with components and blue dot shows the negative relationship. As can be seen from the graph, the highest positive relationship with PC1 was found between CPY, GFY and HY. The highest negative relationship with PC1 was found between NDF. It may be assumed that there is a strong negative relationship between PC2 and RFV, but also a strong positive relationship with ADF and NDF (Fig. 1). From biplot analysis it was revealed that genotypes are diverse for the characters under PC1 and PC2. PC1 components showed negative relationship with NDF and ADF. PC2 had negative relationship with traits like RFV and CP and both components showed positive relation with SN, HY, GFY, PH, and CPY (Fig. 2).

Table 4. Values of principal component analysis.

Parameters	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
PH	0.3716	0.1304	-0.2040	-0.5093	0.2135	-0.2126	-0.6724	0.0204	0.0204	-0.0141
SN	0.3356	0.2021	-0.301	-0.0355	-0.7954	-0.4344	0.1439	-0.0443	-0.0170	-0.0090
MSLN	0.3737	-0.0288	-0.2578	-0.5239	0.0565	0.4056	0.5695	0.1604	-0.0246	0.0119
GFY	0.3915	0.2659	-0.0042	0.2470	0.1682	0.1986	0.4795	-0.8001	-0.0493	-0.0495
HY	0.3783	0.2723	0.0032	0.4248	0.1104	0.1073	-0.6138	0.4159	-0.0335	0.6330
ADF	-0.1479	0.4955	0.1051	-0.1217	0.4382	-0.5511	0.3828	0.0498	-0.2464	-0.0353
NDF	-0.2462	0.4538	0.1857	-0.1656	-0.2653	0.4522	-0.2207	0.0612	-0.5835	-0.0608
CP	0.1329	-0.2905	0.7850	-0.3242	0.0107	-0.0580	0.3166	-0.1656	-0.0585	0.3759
CPY	0.4026	0.0631	0.4454	0.2031	0.0971	0.0819	-0.2177	0.3530	0.0972	-0.6661
RFV	0.2259	-0.5065	-0.1759	0.1863	0.0789	-0.1798	0.2350	0.0246	-0.7623	-0.0810

Table 5. Descriptive statistics of selected PCs.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Eigen value	2.149	1.644	1.002	0.810	0.691	0.575	0.387	0.230	0.078	0.041
Proportion of variance	0.462	0.270	0.100	0.066	0.048	0.033	0.015	0.005	0.001	0.000
Cumulative proportion of variance	0.462	0.732	0.833	0.898	0.946	0.979	0.994	0.999	0.999	1.000

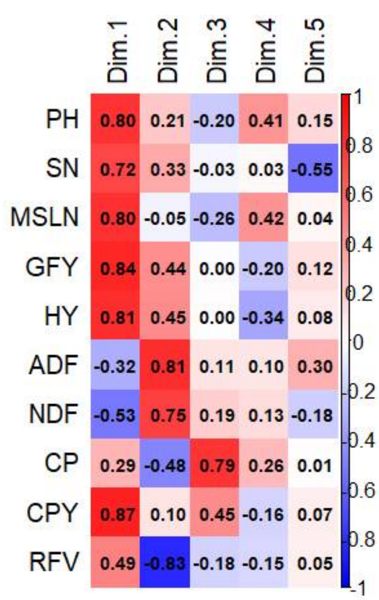

Fig. 1. Correlation plotted against different characters with first five PCs.

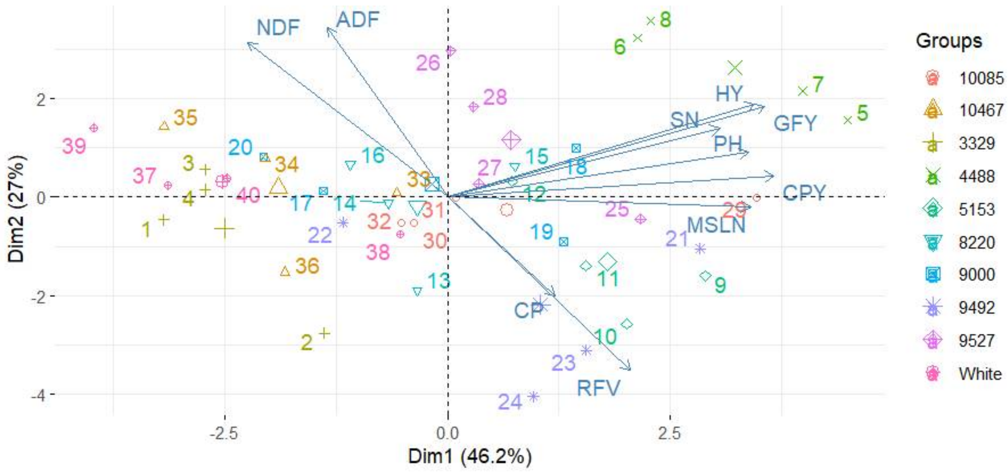

Fig. 2. Biplot against PC1 and PC2 for studied characters of 10 genotypes.

Pearl millet genotypes have the potential to be successfully grown to meet the quality roughage needs of livestock farming in second crop conditions in Mardin province and in similar ecologies. As a result of PCA, it was seen that CPY, GFY and HY traits were determinant in PC1 and PC2 principal components and these traits highlighted genotype number 4488. For this purpose, population number 4488, which has the highest agronomical productivity especially in terms of forage and crude protein yield, can be evaluated under semi-arid or arid climate conditions. Moreover, populations that stand out in terms of forage yield and quality have the potential to be evaluated as important materials for breeding studies.

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