Indian Journal of Experimental Biology
Vol. 60, December 2022, pp. 918-924
DOI: 10.56042/ijeb.v60i12.36064

Phenotypic diversity and stability of early maturing Barnyard Millet (*Echinochloa* sp.) germplasm for grain yield and its contributing traits

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Received 15 October 2021: revised 18 October 2022

Barnyard millet is one of the oldest domesticated millets in the semi-arid tropics of Asia and Africa. Developing early maturing cultivars is one of the important breeding goals in barnyard millet, which can fit well when main crops fail, or during the late onset of monsoon. Thus, this study was carried out to test the phenotypic diversity, character association and path coefficients, and stability of early maturing barnyard millet accessions. The MDU 1, a slightly late-maturing (95 days) cultivar, was used to identify early maturing accessions than the control with a considerably higher yield. Diversity as revealed by D^2 analysis indicated that the trait grain yield had contributed the most towards the diversity followed by the traits such as thousand-grain weight and fodder yield per plant. The accessions IEc 350 and IEc 356 showed the highest fodder yield and grain yield per plant, and higher per day productivity than the control, MDU 1. Genotypic correlations revealed a significantly positive correlation of the grain yield with most traits investigated including days to maturity and fodder yield, and the trait fodder yield per plant showed a highly positive indirect effect on grain yield. Hence, these traits could be considered during the selection process for improving grain yield. Stability analysis identified two accessions, IEc 350 and IEc 356, and the MDU 1, as the stable high-yielding accessions. Hence, these high-yielding stable accessions can efficiently be used in barnyard millet improvement for developing early maturing varieties.

Keywords: Fodder, Nutritional security, Small millets

Barnyard millet (*Echinochloa*sp.) is one of the oldest domesticated millets in the semi-arid tropics of Asia and Africa[1]. It grows very well under rainfed dryland conditions and it is known for its high degree of tolerance against drought, salinity, and waterlogging[2]. Grains of barnyard millet are highly nutritious, and rich in protein (11%), crude fibre (13.6 g/100 g), and iron (18.6 mg/100 g) compared to rice and wheat[3] and rich in micronutrients[4,5]. In India, the cultivation of barnyard millet is over a wider range of environmental conditions and poor soils that are mainly confined to the tribal belts of Maharashtra, Odisha, Madhya Pradesh, Gujarat, Bihar, and Tamil Nadu along with the hilly regions of Uttar Pradesh. The area under barnyard millet cultivation in India is about 146,000 ha and produces 147,000 tons with an average yield of 1034 kg/ha[6].

In Tamil Nadu, cultivation is in the drylands and hilly regions by the tribal farmers in Madurai, Ramanathapuram, Theni, Virudhunagar, Dindigul, Namakkal, Salem, Villupuram, Erode, and Coimbatore districts. Barnyard millet contains a rich source of protein, fats, vitamins, and minerals and was found to have a higher nutritional profile than other staple crops like wheat, rice, and maize[7]. It provides numerous health benefits[8-11]. Because of its nutritional superiority and climate-resilient potential[12], it occupies a unique position in marginal drylands[13]. Even though the area under the crop has come down drastically in the past 50 years, survival under adverse conditions makes it a better-preferred crop during famine years and therefore identified as the best-suited crop for climate-resilient agriculture. In this study, we have tested early maturing barnyard millet accessions for diversity, traits relationship, and yield stability in three environments, to identify stable and high-yielding accessions for their use in barnyard millet improvement.

Materials and Methods

Experiment materials and environment details

The experiment consisted of twenty-nine early maturing barnyard millet accessions obtained from

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the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad. The local control used was MDU 1, a long duration (95-100 days) variety with better cooking quality in terms of white grain and high Fe content (16 mg/100 g grains), released from the Agricultural College and Research Institute (AC&RI), Madurai in 2015. The experiments were laid out in a randomized complete block design (RCBD) with three replications at three different environments. At AC&RI, Madurai, the experiment was conducted during the *kharif* season 2018 at two different dates of sowing (26 June 2018 and 18 July 2018) therefore considered as environment 1 (E1) and environment 2 (E2), and while the crop was raised in *rabi* (11 Dec 2018) season at Tamil Nadu Agricultural University (TNAU), Coimbatore was considered as environment 3 (E3). The data on 13 yield and the contributing traits on five randomly selected plants in each accession in three replications were recorded based on barnyard millet descriptors[14]. These include days to 50% flowering (days taken by 50% of plants to flower), days to maturity, plant height, inflorescence length (length of the inflorescence of the main tiller), flag leaf length, flag leaf width, length of the peduncle, stem girth (girth of the main tiller), number of basal tillers, length of the lower raceme, thousand-grain weight, fodder yield, and grain yield. The traits related to flowering and maturity were recorded at appropriate growth stages while other traits were documented at harvest/post-harvest. Agronomic practices adopted were as per the package of practices recommended by TNAU, Coimbatore.

Data analyses

The data on 13 yield and its contributing traits were analysed for the individual year and combined three years following Residual Maximum Likelihood (REML)[15] in GenStat 19th edition (http://www.genstat.co.uk) considering accessions as random and environment as fixed effects. The significance of environments was tested using Wald's statistic and variance components due to genotype (σ^2_g), genotype × environment (σ^2_{ge}), and standard errors (SE) estimated for individual and pooled data. Best Linear Unbiased Predictors (BLUPs)[16] were obtained for all the quantitative traits for each accession for the individual environment and pooled data. The BLUPs obtained from a pooled of three environments were used for Mahalanobis's generalized distance (D^2) estimation to measure the genetic divergence among the accessions and clustering following Tocher's method[17]. The genotypic correlation between yield and its component traits[18] and the path coefficients analyses[19] were performed using GENRES software version 7[20]. For path analysis, grain yield was considered as a dependent variable while other yield-attributing traits were considered independent variables. Stability analysis was conducted using the PBTools software[21]. The GGE biplot outputs were used to identify the discrimination in environments and the correlation between the genotypes and its environment. The mean performance and the stability of the genotypes were determined by their location and proximity to the origin of the biplot.

Results and Discussion

Variance component

The variance obtained through REML analysis indicated significant genotypic variance components (σ^2_g) for all the traits in all three environments and pooled data indicated the presence of considerable variability for all the traits (Table 1). In the pooled analysis, significant variance components due to genotype and environment interaction (σ^2_{ge}) for all the traits except stem diameter, number of tillers, and thousand-grain weight were recorded, indicating the differential response of accessions to different environments.

Mean performance

Mean performance of barnyard millet accessions for different quantitative traits in different growing

Table 1 — Estimation of variation component for individual and combined of three environments following REML approach

Variable	E1	E2	E3	Pooled	
	σ^2g	σ^2g	σ^2g	σ^2g	σ^2ge
Days to flowering	65.11**	74.25**	67.71**	72.17**	4.35**
Days to maturity	75.92**	76.33**	74.81**	73.56**	1.49**
Plant height (cm)	692.31**	586.18**	193.36**	351.05**	133.14**
Inflorescence length (cm)	14.90**	14.46**	7.82**	10.44**	1*
Flag leaf length (cm)	25.25**	15.06**	33**	19.34**	3.33**
Flag leaf width (cm)	0.445**	0.38**	0.28**	0.29**	0.05**
Length of peduncle (cm)	3.94**	4.46**	3.82**	3.83**	0.19**
Stem diameter (cm)	0.175**	0.1**	0.12**	0.11**	0
No. of tillers	0.79**	1.13**	0.5*	0.69**	0.04
Length of lower raceme (cm)	0.60**	0.39**	0.42**	0.26**	0.16**
Grain yield/plant (g)	65.80**	74.1**	50.56**	60.94**	1.87**
Fodder yield/plant (g)	193.91**	185.44**	166.26**	175.38**	4.24**
Thousand grain wt. (g)	0.29**	0.36**	0.29**	0.29**	0

[σ^2g, genotypic variance component; σ^2ge Genotype × environment variance component] environments (Table 2) indicates that the trait plant height significantly differed in all three environments (68 cm in E3 to 124 cm in E1), while days to maturity was similar in all three environments (70 days E2 to 75 days in E3), and pooled of three environments (73 days) (Table 2). The number of tillers significantly differed between E1 (5) and E2 (2), both from the same location but different dates of sowing, indicating late sowing has a significant impact on the number of tillers, however similar grain yield and fodder yield per plant recorded in all three environments (14-16 g). Based on pooled data from three environments, all the accessions except MDU 1 matured earlier but none recorded a significant yield increase. Considering per-day productivity (grain yield divided by days to maturity), two accessions namely IEc 350 and IEc 356, showed higher per-day productivity (grain yield 0.45g and 0.47 g/day, respectively) than the late maturing high-yielding released cultivar MDU 1 (grain yield 0.34 g/day).

Table 2 — Mean performance of early maturing barnyard millet at different environments, and pooled of three environments

Trait	E1	E2	E3	Pooled
Days to flowering	42^{ab}	39^{b}	45^{a}	42^{ab}
Days to maturity	73^{a}	70^{a}	75^{a}	73^{a}
Plant height (cm)	124^{a}	103^{b}	68^{c}	99^{b}
Inflorescence length (cm)	21^{a}	20^{a}	18^{b}	20^{a}
Flag leaf length (cm)	24^{a}	22^{a}	24^{a}	23^{a}
Flag leaf width (cm)	2.6^{a}	2.1^{b}	2.0^{b}	2.2^{b}
Length of peduncle (cm)	3.6^{a}	4.0^{a}	3.7^{a}	3.8^{a}
Stem diameter (cm)	1.3^{a}	1.0^{b}	1.2^{a}	1.2^{a}
No. of tillers	5^{a}	2^{b}	5^{a}	5^{a}
Length of lower raceme (cm)	3.0^{a}	2.6^{b}	2.7^{ab}	2.8^{ab}
Grain yield per plant (g)	16^{a}	14^{a}	14^{a}	15^{a}
Fodder yield per plant (g)	32^{a}	30^{a}	30^{a}	31^{a}
Thousand-grain weight (g)	2.84^{a}	2.84^{a}	2.80^{a}	2.80^{a}

[Mean followed by the same letters is not significant at $P \leq 0.05$; but followed by different letters is significant at $P \leq 0.05$]

Phenotypic divergence

D^2 statistics serve as an important tool for plant breeders to classify the accessions into different groups based on the genetic divergence between them[22]. Based on D^2 analysis, all thirty accessions were grouped into eight clusters. The distribution of accessions into eight clusters based on D^2 values is presented in Table 3. Cluster I had the maximum number of twelve accessions, followed by cluster II and cluster VII with 5 and 4 accessions, respectively; while clusters III, IV, V, and VI had two accessions each. Cluster VIII had only one accession indicating a higher divergence of this accession to others. Cluster mean values for different traits based on D^2 values are presented in Table 3. Cluster I had accessions that scored low mean values for many of the traits, such as early flowering, with short plant height (81.59 cm), short inflorescence length (17.33 cm), flag leaf length (19.67 cm), flag leaf breadth (1.93 cm), stem girth (0.96 cm), and low fodder yield (23.05 g/plant) and grain yield (10.09 g/plant). Cluster II contains the accessions that had moderate mean values for plant height (100.34 cm), flag leaf length (25.01 cm), flag leaf breadth (2.49 cm), days to 50% flowering (41.11 days), and days to maturity (76.32 days). Cluster III contains the accessions that had the low mean value for the number of tillers (4.06) and thousand-grain weight (1.99 g). The accessions with the higher mean value for the lower raceme length were found in cluster V. Cluster VI contained the accessions that had the highest mean values for plant height (129.63 cm) and thousand-grain weight (3.39 g). Cluster VI had the accessions that had the highest mean value for peduncle length (6.06 cm) and the lowest mean value for lower raceme length. Cluster VIII containing the solitary accession MDU 1 had the highest mean values for inflorescence length (24.28 cm), flag leaf length

Table 3 — Distribution of 30 barnyard millet accessions into different clusters based on D^2 values for quantitative traits, and traits' mean values based pooled of three environments

Cluster No.	No. of accessions	Accessions in the cluster	Mean values of different traits of a give cluster												
			DFF	DTM	PH	IL	FLL	FLB	LOP	STG	NOT	LLR	TWT	FYPP	GYPP
C I	12	IEc# 71, 82, 85, 106, 107, 108, 109, 154, 157, 158, 159, 161	36	68	82	17	20	1.9	4.9	1.0	5.1	2.6	2.93	23	10
C II	5	IEc# 231, 239, 240, 291, 296	41	76	100	20	25	2.5	1.8	1.3	4.5	2.6	2.66	31	14
C III	2	IEc# 385, 387	44	73	113	22	26	2.4	2.6	1.5	4.1	3.0	2.00	43	19
C IV	2	IEc# 386, 396	44	77	116	21	28	2.2	0.8	1.4	4.3	2.8	2.83	39	18
C V	2	IEc# 350, 356	49	70	123	22	26	2.5	2.9	1.4	5.5	3.6	3.34	54	32
C VI	2	IEc# 397, 399	45	75	130	24	29	2.6	3.6	1.5	4.2	3.2	3.39	33	17
C VII	4	IEc# 389, 391, 656, 793	43	74	98	20	24	2.1	6.1	1.1	4.4	2.6	2.44	23	10
C VII	1	MDU 1	73	105	124	24	31	3.4	1.1	1.7	6.3	3.4	3.36	61	36

[DFF, Days to 50% flowering; DTM, Days to maturity; PH, Plant height (cm); IL, Inflorescence length (cm); FLL, Flag leaf length (cm); FLB, Flag leaf breadth (cm); LOP, Length of peduncle (cm); STG, Stem girth (cm); NOT, No. of tillers; LLR, Length of lower raceme (cm), TWT, Thousand grain wt. (g); FYPP, Fodder yield/plant (g); GYPP, Grain yield/plant (g)]

(31.36 cm), flag leaf breadth (3.40 cm), stem girth (1.73 cm), number of tillers (6.26), fodder yield (60.85 g/plant) and grain yield (35.71 g/plant). This accession was also found late maturing (104.52 days) type which had taken more days (72.80) for fifty per cent flowering indicating that the late-maturing accessions are high yielding[23]. Similar high inter-cluster distances were also reported in barnyard millet.

Inter and intra D^2 cluster distances were highest between clusters I and VIII (D=35.680) (Table 4). Among the thirteen quantitative traits studied, grain yield per plant was the most important trait that contributed the maximum to the genetic divergence with 46.67%, followed by thousand-grain weight (15.17%) and fodder yield per plant (14.94%). The results indicated that to select genetically diverse accessions, one should categorize the materials based on traits such as grain yield per plant, fodder yield per plant, and thousand-grain weight as they showed maximum contribution towards divergence. The maximum intra-cluster distance observed was in cluster I (D=12.149). This implies that these clusters have accessions with varied genetic architecture[26].

The individual traits were given ranks based on their contribution to total genetic divergence. The trait grain yield per plant contributed the maximum towards genetic diversity (46.67 %) followed by thousand-grain weight (15.17%) and fodder yield (14.94%). Length of the peduncle (10.11%) and days to maturity (4.83%) contributed moderately while other traits namely number of tillers, length of the lower raceme, and days to 50 per cent flowering had relatively less contribution towards genetic divergence whereas the traits namely plant height, inflorescence length, flag leaf length, and flag leaf breadth showed very low contribution to the genetic divergence (Table 5). Thus, based on phenotypic traits, the most superior diverse accessions could be identified and utilized in breeding programs.

Table 4 — Inter (above diagonal) and Intra (diagonal) D square cluster distances of barnyard millet accessions based on pooled over three environments

	C I	C II	C III	C IV	C V	C VI	C VII	C VIII
C I	12.149	15.181	17.687	17.329	21.250	15.486	13.711	35.680
C II		11.268	12.174	9.719	19.104	12.066	14.244	28.037
C III			5.115	9.676	15.753	13.094	14.145	26.163
C IV				6.191	15.505	9.948	15.933	23.854
C V					6.713	14.193	20.962	25.194
C VI						8.108	13.504	24.929
C VII							10.707	31.252

Traits associations and path analysis

Correlation coefficients

Grain yield is a complex trait and is influenced by many environmental factors, knowledge of the correlation between yield and its constituent characters may be helpful for selecting an appropriate plant type. Grain yield per plant had a highly significant positive correlation with all the traits including fodder yield per plant (0.97), days to 50% flowering (0.80), inflorescence length (0.64), days to maturity (0.59), and thousand seed weight (0.36), except length of the peduncle (–0.60) (Table 6). Similarly, positive associations of traits like plant height, number of tillers, peduncle length, inflorescence length, flag leaf length, and thousand-grain weight with grain yield per plant were reported by other researchers in barnyard millet[2,24,25] and finger millet. The association of fodder yield per plant with grain yield per plant was also reported[2]. Hence, primary selection for these traits given importance may obtain cultivars with increased grain yield. Significant positive correlation of most of the component traits on grain yield and inter-correlation between component traits indicated that an increase in any one of them would lead to improvement of other traits, and ultimately the grain yield.

Path coefficient analysis

To get the actual contribution of each trait to yield, it is necessary to partition the correlation into direct and indirect effects through path analysis. Thus, correlation in combination with path analysis would help in identifying suitable criteria for yield improvement. In the present study, grain yield per plant was taken as a dependent variable and the direct and indirect effects of yield contributing traits on

Table 5 — Contribution of each character to divergence, based on pooled of three environments

Trait	No. of times ranked first	% contribution
Days to 50 % flowering	7	1.61
Days to maturity	21	4.83
Plant height	0	0.00
Inflorescence length (cm)	4	0.92
Flag leaf length (cm)	0	0.00
Flag leaf breadth (cm)	2	0.46
Length of peduncle (cm)	44	10.11
Stem girth (cm)	1	0.23
Number of tillers	21	4.83
Length of lower raceme (cm)	1	0.23
Thousand-grain weight (g)	66	15.17
Fodder yield per plant (g)	65	14.94
Grain yield per plant (g)	203	46.67
Total		100.00

Table 6 —Genotypic correlation coefficient of yield and yield attributing traits, based on combined of three environments

Trait	PH	IL	FLL	FLB	LOP	STG	NOT	LLR	DFF	DTM	TWT	FYPP	GYPP
PH	1	0.91**	1.00**	0.78**	-0.58**	0.89**	-0.41*	0.72**	0.73**	0.58**	-0.03	0.70**	0.70**
IL		1	0.96**	0.80**	-0.47**	0.88**	-0.47**	0.69**	0.66**	0.57**	0.14	0.67**	0.64**
FLL			1	0.85**	-0.64**	0.96**	-0.50**	0.57**	0.79**	0.76**	-0.03	0.67**	0.64**
FLB				1	-0.65**	0.97**	-0.33	0.41*	0.77**	0.81**	0.1	0.71**	0.65**
LOP					1	-0.72**	0.25	-0.18	-0.53**	-0.62**	-0.04	-0.68**	-0.60**
STG						1	-0.41*	0.51**	0.81**	0.74**	0.08	0.82**	0.75**
NOT							1	0.15	0.02	-0.11	0.3	-0.04	0.12
LLR								1	0.39*	0.13	0.05	0.36*	0.48**
DFF									1	0.89**	0.08	0.76**	0.80**
DTM										1	0.05	0.62**	0.59**
TWT											1	0.29	0.36*
FYPP												1	0.97**
GYPP													1

[*Significance at $P \leq 0.05$; PH, Plant height (cm); IL, Inflorescence length (cm); FLL, Flag leaf length (cm); FLB, Flag leaf width (cm); LOP, Length of peduncle (cm); STG, Stem girth (cm); NOT, No. of tillers; LLR, Length of lower raceme (cm); GYPP, Grain yield/plant (g); FYPP, Fodder yield/plant (g); TWT, Thousand-grain wt.; DFF, Days to 50% flowering; DTM, Days to maturity]

Table 7 — Direct (diagonal) and indirect effects (above and below diagonal) of different yield attributing traits with grain yield, based on combined of three environments

	PH	IL	FLL	FLB	LOP	STG	NOT	LLR	DFF	DTM	TWT	FYPP	GYPP
PH	**0.131**	-0.023	-0.027	0.097	0.049	-0.214	-0.018	0.013	0.358	-0.199	-0.003	0.492	0.70**
IL	0.114	**-0.027**	-0.027	0.101	0.041	-0.211	-0.022	0.013	0.331	-0.199	0.013	0.490	0.64**
FLL	0.119	-0.024	**-0.030**	0.108	0.055	-0.222	-0.023	0.011	0.392	-0.262	-0.002	0.481	0.64**
FLB	0.094	-0.020	-0.024	**0.135**	0.056	-0.227	-0.016	0.008	0.382	-0.285	0.010	0.510	0.65**
LOP	-0.071	0.012	0.018	-0.083	**-0.091**	0.174	0.012	-0.004	-0.275	0.227	-0.004	-0.506	-0.60**
STG	0.111	-0.022	-0.026	0.121	0.062	**-0.252**	-0.019	0.009	0.402	-0.262	0.007	0.588	0.75**
NOT	-0.045	0.011	0.013	-0.040	-0.020	0.092	**0.053**	0.003	0.006	0.041	0.027	-0.028	0.12
LLR	0.078	-0.016	-0.015	0.048	0.014	-0.108	0.007	**0.022**	0.176	-0.037	0.005	0.228	0.48**
DFF	0.089	-0.017	-0.022	0.098	0.047	-0.192	0.001	0.007	**0.527**	-0.329	0.008	0.571	0.80**
DTM	0.070	-0.014	-0.021	0.104	0.056	-0.178	-0.006	0.002	0.468	**-0.370**	0.005	0.470	0.59**
TWT	-0.004	-0.004	0.001	0.013	0.003	-0.017	0.014	0.001	0.041	-0.020	**0.100**	0.221	0.36*
FYPP	0.085	-0.017	-0.019	0.090	0.060	-0.195	-0.002	0.007	0.395	-0.229	0.029	**0.761**	0.97**

[Residual effect= 0.1046914. *, ** Significance at $P \leq 0.05$ and 0.01, respectively; PH, Plant height (cm); LLR, Length of lower raceme (cm); IL, Inflorescence length (cm); DFF, Days to 50% flowering; FLL, Flag leaf length (cm); DTM, Days to maturity; FLB, Flag leaf breadth (cm); TWT, Thousand-grain wt. (g); LOP, Length of peduncle (cm); FYPP, Fodder yield/plant (g); STG, Stem girth (g); GYPP, Grain yield/plant (g); NOT, No. of tillers. The numbers in bold represents the direct effect of the corresponding trait towards the grain yield per plant]

grain yield are given in Table 7. Among the traits studied, seven traits were found to have positive direct effects while the other five traits had negative direct effects on plant yield. Fodder yield per plant (0.761) had the highest positive direct effect followed by days to 50% flowering (0.527), flag leaf breadth (0.135), plant height (0.131), thousand-grain weight (0.100), the total number of tillers (0.053) and length of lower raceme (0.022). The influence of the component traits on grain yield through other traits indicated that most of the component traits had a high indirect effect on grain yield through fodder yield, which included the traits such as stem girth (0.588), days to 50 % flowering (0.571), flag leaf breadth (0.510), plant height (0.492), inflorescence length (0.490), flag leaf length (0.481), days to maturity (0.470), length of lower raceme (0.228) and thousand-grain weight (0.221). This indicates that an increase in straw yield per plant would increase the grain yield as well. Similar findings were reported in finger millet[26]. The other traits like days to maturity (0.468), stem girth (0.402), fodder yield per plant (0.395), flag leaf length (0.392), flag leaf breadth (0.382), plant height (0.358), inflorescence length (0.331) and length of lower raceme (0.176) contributed high indirect effect on grain yield through days to 50 % flowering. The traits like plant height, number of tillers, flag leaf breadth[2] and thousand-grain weight were reported to exhibit low to a moderate direct effect on grain yield. Thus, the present study puts forth the major traits that contribute to genetic diversity, their association with grain and fodder yield is considered essential while

Table 8 — Stability analysis through GGE biplot for 30 accessions

Character	Closer ideal accessions	Nature of stability	Proximal ideal accessions	Nature of stability
Days to 50% flowering	MDU 1 (G30)	S	None	None
Days to maturity	MDU 1 (G30)	S	None	None
Plant height	IEc 350 (G18) IEc 356 (G19) IEc 399 (G27) MDU 1 (G30)	PS PS PS PS	IEc 386 (G21) IEc 387 (G22) IEc 389 (G23) IEc 396 (G25)	PS PS PS S
No. of tillers	MDU 1 (G30)	S	IEc 106 (G4) IEc 108 (G6) IEc 107 (G5) IEc 350 (G18) IEc 82 (G2)	PS PS PS PS S
Thousand seed weight	IEc 161 (G12)	S	IEc 399 (G27) IEc 350 (G18) MDU 1 (G30) IEc 157 (G9)	PS S PS S
	IEc 350 (G18)	S	IEc 291 (G16) IEc 159 (G11) IEc 71 (G1) IEc 656 (G28)	PS PS S S
Fodder yield/plant	MDU 1 (G30)	S	IEc 350 (G18) IEc 356 (G19) IEc 385 (G20)	S PS S
Grain yield/plant	MDU 1 (G30)	S	IEc 350 (G18) IEc 356 (G19)	S S

[S, Stable; PS, Partially stable]

Table 9 — 'What-won-where' biplot for 30 accessions in three environments

Character	E1	E2	E3
Days to 50% flowering	MDU 1 (G30)	IEc 387 (G22) MDU 1 (G30)	IEc 396 (G25)
Days to maturity	MDU 1 (G30)	None	IEc 396 (G25) IEc 240 (G15) MDU 1 (G30)
Plant height (cm)	IEc 356 (G19) IEc 399 (G27) IEc 397 (G26)	IEc 656 (G28) MDU 1 (G30)	IEc 350 (G18) IEc 240 (G15) IEc 396 (G25) IEc 356 (G19) IEc 399 (G27) IEc 397 (G26)
No. of tillers	IEc 108 (G6) IEc 107 (G5)	None	MDU 1 IEc 107 (G5) IEc 108 (G6)
Thousand grain weight (g)	None	IEc 399 (G27)	IEc 350 (G18) IEc 161 (G12) IEc 399 (G27)
Fodder yield/plant (g)	IEc 159 (G11)	IEc 350 (G18) IEc 356 (G19) MDU 1 (G30)	IEc 350 (G18) IEc 356 (G19) MDU 1 (G30)
Grain yield per plant (g)	MDU 1	IEc 350 (G18) IEc 356 (G19)	IEc 350 (G18) IEc 356 (G19) MDU 1 (G30)

formulating the selection criteria for barnyard millet improvement.

Stability analysis through GGE biplot

The results of the stability analysis for maturity and grain yield are depicted in Suppl. Fig S1& S2, respectively. (*All supplementary data are available only online along with the respective paper at NOPR repository at http://nopr.res.in*). For a better understanding, the same is furnished in Table 8. From the table, it is evident that MDU 1 was closer to ideal accession for most of the traits such as days to 50 % flowering, days to maturity, plant height, the number of tillers, and grain yield per plant. The accessions IEc 350 and IEc 356 were proximal to the idealaccession for yield attributing traits such as fodder yield per plant and grain yield per plant. All these accessions exhibited stable performance except IEc 356 which exhibited partial stability for fodder yield per plant which indicates that it possesses some potential and could be exploited for the future crop improvement program. Altogether, IEc 350, IEc 356, and MDU 1 were identified as stable performing accessions for yield attributing traits. The utility of GGE biplot in ascertaining the relationships among the genotypes (G), environments (E), and the G×E interactions are well documented[27].

What-won-where biplot

From an environmental point of view, certain accessions respond well to a particular environment. The accessions that were suitable for its favourable environment are furnished in Table 9. As far as yield is concerned, IEc 159 and MDU 1 were the most suitable accessions in E1 for fodder yield and grain yield, respectively. In E2, IEc 350, IEc 356, and MDU 1 were ideal accessions for fodder yield, and IEc 350 and IEc 356 for grain yield. In E3, IEc 350, IEc 356, and MDU 1 were the most ideal accessions for both fodder yield and grain yield. From the stability analysis, it could be confirmed that the accessions MDU 1, IEc 350, and IEc 356 were the stable and high-yielding accessions in all three environments and these accessions could be exploited in developing early maturing cultivars.

Conclusion

In the present study, twenty-nine early maturing barnyard millet accessions were identified and used to study their phenotypic diversity, character association, and path coefficients and stability. MDU 1, a slightly late maturing (95 days) was used as the control. D^2

analysis revealed that the traits grain yield, thousand-grain weight, and fodder yield per plant had contributed the most toward the diversity. The trait grain yield showed a positive genotypic correlation with almost all the traits investigated and the trait fodder yield per plant contributed a high positive indirect effect on grain yield. IEc 350 and IEc 356 showed the highest fodder yield and grain yield per plant and also possessed higher per-day productivity than the control, MDU 1. The stability analysis revealed that the accessions IEc 350 and IEc 356 and MDU 1 were stable and high yielding and hence these accessions can be effectively utilized further for the development of early maturing barnyard millet varieties.

Conflicts of interest

Authors declare no competing interests.

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