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ISSN: 0975-928X

Volume: 10

Number:2

EJPB (2019) 10(2):430-439

DOI:10.5958/0975-928X.2019.00055.3

https://ejplantbreeding.org

Electronic Journal of Plant Breeding, 10 (2): 430-439 (Jun 2019) DOI: 10.5958/0975-928X.2019.00055.3
ISSN 0975-928X

Research Article

Genetic variability and association studies in barnyard millet (*Echinochloa frumentacea* (Roxb.) Link) germplasm under sodic soil condition

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(Received: 09 Apr 2019; Revised: 27 May 2019; Accepted: 04 Jun 2019)

Abstract
Barnyard millet is one of the hardiest, climate resilient and fast growing crop that is bestowed with high nutrient content in grains. An experiment was carried out in barnyard millet under natural sodic soil condition to study the genetic variability and association for different morphological and yield contributing traits. Ninety nine barnyard millet genotypes including two commercial check varieties *viz.,* MDU1 and CO (KV) 2 were evaluated under sodic soil condition. Analysis of variance revealed significant variation for all the characters studied. High phenotypic coefficient of variation, genotypic coefficient of variation and heritability were recorded for plant height, ear width, lower raceme length, flag leaf length, flag leaf width and grain yield per plant. Association studies indicated that grain yield per plant had highly significant positive correlation with days to fifty percent flowering, days to maturity, ear width and thousand grain weight. Path coefficient analysis indicated that the highest direct and indirect effect on grain yield per plant was exhibited by days to fifty percent flowering. Thus, days to fifty percent flowering, days to maturity, ear width and thousand grain weight can be used as selection indices for increasing grain yield of barnyard millet in sodic soil.

Key words
Barnyard millet, variability, correlation, path analysis, sodic soil.

Introduction

Small millets are a group of crops that are highly climate resilient and perform well even under adverse climatic conditions. Among the millet crops, barnyard millet (*Echinochloa frumentacea*) is a fast growing hardiest crop. It is also called as Indian barnyard millet, Sawa millet, Ooda, Oodalu, jhangora and Billion dollar grass. Barnyard millet is the second most important *kharif* small millet crop next only to finger millet (Joshi, 2013). In India, it is cultivated in an area of about 1.95 lakh hectares with a production of 1.67 million tonnes and productivity of 8.57 q/ha (RashmiYadav and Vijaya Kumar Yadav, 2011). It is an herbaceous annual crop having chromosome number 2n=4x=36, and is a self pollinated. The grain is yellow or white in colour and small single seeded dry (Caryopsis) fruit (Prasad, 2005). It is grown as a multipurpose crop for food and fodder. Barnyard millet has also been used for the reclamation of sodicity, arsenic and cadmium affected soils (Sherif and Ali, 2007 and Abe *et al.,* 2011). In India, its cultivation is confined to Tamil Nadu, Andhra Pradesh, Karnataka and Uttar Pradesh (Channappagoudar *et al.,* 2008). It is a stable cereal in areas where climatic and edaphic conditions are unsuitable for rice cultivation (Yabuno, 1987). It is a fair source of protein and is an excellent source of dietary fibre with good amount of soluble and insoluble fractions (Veena *et al.,* 2005). It is a very good source of Fe content (Sampath *et al.,* 1990) ranged from 2.29 to 18.00 mg/100g (Renganathan *et al.,* 2017) and many other phytochemicals. The grain has low carbohydrate content and it is slowly digestible. Thus, it proved to be suitable for people suffering with diabetes mellitus (Ugare, 2008).

Soil sodicity is a major edaphic factor that adversely affects water and air movement in the soil which limits crop growth (Szabolcs, 1994). These soils are characterised by pH of 8.5-9.0, EC < 4.0 dS/ m, SAR > 13, ESP > 15 % (Waskom *et al.* 2003; Ogle, 2010) and imbalanced nutrition with ion toxicity. The high alkaline pH nature of sodic soil results in lesser availability of micronutrients and deteriorates the soil structure and porosity which in turn causes water logging (Rengasamy, 2002). About 37% of the world's cultivated land (1500 million hectares) is sodic which is about 560 million hectares whereas, in India, 7 million hectares are sodic land (Khan and Duke, 2001; Szabolcs, 1989; Leland and Eugene 1999; Ansari *et al.,* 1999). Due to the excess exchangeable sodium in sodic soil, it tends to become more dispersed which results in impermeable surface crusts that seriously hinders seed germination and crop growth (Pessarakli and Szabolcs, 1999). Even under these sodic soil conditions barnyard millet crop have the capacity to withstand waterlogged condition to give a considerable quantum of yield.

Genetic variability in germplasm and the detailed knowledge of association among different traits are essential for any crop improvement programme. Available information on response of barnyard millet to sodicity and related traits are very much limited. Considering the above facts, an experiment was conducted with 99 barnyard millet germplasm accessions under natural sodic soil conditions to study the genetic variability for yield and yield contributing traits and also to study the association among the traits.

Materials and Methods

The present study was carried out in natural sodic soil (pH : 9.07, EC : 0.95dS/m and ESP : 43.69%) at Anbil Dharmalingam Agricultural College and Research Institute, Trichy, Tamil Nadu during Summer 2018. The experimental material involved 97 germplasm lines of barnyard millet obtained from Indian Institute of Millets Research (IIMR), Hyderabad, Telangana and two commercial check varieties *viz.*, MDU1 and CO(KV) 2. The experiment was laid out in randomized block design with two replications and the recommended crop agronomical practices were followed. Observations were recorded on 12 biometrical traits *viz.*, days to fifty percent flowering, days to maturity, plant height (cm), number of productive tillers, number of leaves on main tiller, ear length (cm), ear width (cm), flag leaf length (cm), flag leaf width (cm), lower raceme length (cm), thousand grain weight (g) and grain yield per plant (g) as per the descriptors of barnyard millet (IPGRI, 1983). For every accession, five randomly selected plants per replication were used for recording the data, except for days to fifty percent flowering and days to maturity, which was recorded on a plot basis.

The data collected were subjected to analysis of variance (ANOVA) as per Panse and Sukhatme (1967). Phenotypic coefficient of variation (PCV) and Genotypic coefficient of variation (GCV) were calculated using the formula given by Burton *et al*. (1952). Heritability in broad sense (h^2) was assessed according to Lush (1940) and expressed in percentage. The range of heritability was categorized as low (0- 30), medium (31-60) and high (> 60) as suggested by Johnson *et al*. (1955). Genetic advance was estimated based on the formula given by Johnson *et al*. (1955) and the traits were classified as having high (>20 %), moderate (10- 20%) or low (<10%) genetic advance. All the statistical analysis was carried out using TNAUSTAT software.

Results and Discussion

Genetic variability in germplasm for the trait of interest is a prerequisite for the success of any breeding program. In the present study, ANOVA (Table 1) showed significant difference among the 99 genotypes for all the characters studied suggesting availability of sufficient variability and hence selection of superior genotypes could be possible under sodicity.

Variability based on mean and its range for different biometrical traits is given in Table 2. The barnyard millet germplasm recorded wide range of variation for all the traits under sodic soil. Days to fifty percent flowering ranged from 35 days in BAR 111 to 46 days in BAR 228. Days to maturity varied from 84 days in BAR 111 to 99 days BAR 84. For plant height two-fold variability was observed, which ranged from 31.21 cm in BAR 390 to 81.52cm in BAR 84. Similarly, ear length varied from 6.76 cm (BAR 390) to 16.29 cm (BAR 120).Wide variation was also observed for ear width, which ranged from 0.69 cm (BAR 222) to 3.64 cm (BAR 236), lower raceme length ranged from 0.72 cm (BAR 264) to 3.38 cm (BAR 382), flag leaf length ranged from 6.59 cm (BAR 390) to 22.55 cm (BAR 371) and grain yield per plant ranged from 3.1g in (BAR 198) to 41.88g (BAR 242). Similar study was carried in barnyard millet by Trivedi *et al.* (2017), Upadhyaya *et al*. (2014) and Joshi (2013). Joshi (2013) recorded wide variability among the genotypes for traits like days to fifty percent flowering, plant height, ear length, flag leaf length, flag leaf width, number of productive tillers, number of leaves on main tiller. However in the present study there was overall reduction in performance of genotypes for traits like days to fifty percent flowering, plant height, ear length, flag leaf length and flag leaf width could be due to slower cell division in the high stress condition (Schuppler *et al*., 1998)

PCV and GCV in conjunction with heritability and genetic advance as per cent mean for the traits helps in deciding the breeding program to be adopted for crop improvement. In the present study (Table 2), High PCV value was observed for grain yield per plant (48.99) followed by lower raceme length (35.17), flag leaf width (33.05), ear width (31.33), flag leaf length (27.31), number of productive tillers (25.32) and plant height (21.59). Similarly, Arunachalam and Vanniarajan (2012) obtained high PCV value for grain yield per plant in barnyard millet. High GCV values were observed for grain yield per plant (47.88) followed by lower raceme length (31.47), flag leaf width

(29.78), ear width (27.54), flag leaf length (22.80) and plant height (20.39). High PCV and GCV value was observed for grain yield per plant followed by lower raceme length, flag leaf width, ear width, flag leaf length, number of productive tillers and plant height indicated stable nature of these characters. The difference between GCV and PCV were observed to be narrow suggesting the predominance of genetic control of the traits studied (Majumdar *et al.,* 1974). Anuradha *et al.* (2017) obtained similar narrow difference between PCV and GCV in little millet. Low PCV and GCV were observed for days to fifty percent flowering, days to maturity and thousand grain weight suggests that the genetic improvement through selection for these traits may not be always effective (Renganathan and Vanniarajan, 2018). In rice, Sabesan *et al.* (2009) observed low PCV and GCV for days to fifty percent flowering and days to maturity under coastal saline low land.

Heritability of any trait of interest determines the success of selection for its improvement. Among the traits studied (Table 2), high heritability was observed for seven characters *viz.,* grain yield per plant (95.51), plant height (89.22) , flag leaf width (81.22), lower raceme length (80.10), ear width (77.30), ear length (71.85) and flag leaf length (69.72). This also indicated the predominant genetic influence in the inheritance of the traits and hence selection for improvement of the traits could be effective. This is in accordance with the findings of Sood *et al.* (2015); Renganathan and Vanniarajan, (2018) in barnyard millet; Vetriventhan and Upadhayaya, (2018) in proso millet. Moderate heritability was observed for the characters days to fifty percent flowering (54.06), days to maturity (56.17), number of leaves on main tiller (45.97), thousand grain weight (43.35) and number of productive tillers (39.69).

High genetic advance as percentage of mean was observed for the traits *viz.,* grain yield per plant (96.39), lower raceme length (58.03), flag leaf width (55.29), ear width (49.88), plant height (39.68), flag leaf length (39.22), ear length (29.97) and number of productive tillers (20.70). High heritability accompanied with high genetic advance for a trait indicates the preponderance of additive gene action in its inheritance and for such of those traits, selection may be effective in crop improvement. Among the traits studied, grain yield per plant, plant height, lower raceme length, flag leaf width, ear width had high heritability and genetic advance and hence selection method of breeding could be employed for improvement of these traits in barnyard millet. This result is in conformity with the reports of Arunachalam *et al*. 2012, Sood *et al*. (2015) in barnyard millet. In rice, Yadav *et al.* (2017) noted similar results for plant height and grain yield per plant under sodic soil condition. Days to fifty percent flowering and days to maturity recorded moderate heritability and low genetic advance (Table 2) which indicated that these characters are influenced by environment effects and hence, selection would be ineffective.

Yield, being a complex trait, could be indirectly improved by selecting for characters that are highly correlated with yield. The estimated phenotypic and genotypic correlation coefficients among the characters studied are presented in Table 3. For all the traits studied, the genotypic correlation was higher than phenotypic correlation signifying low environmental influence in the inheritance of traits and relative stability of the genotypes. The results of the analysis indicated that grain yield per plant exhibited highly significant positive correlation with thousand grain weight (0.472), days to fifty percent flowering (0.445), days to maturity (0.443) and ear width (0.213) indicating the importance of these traits in yield improvement of barnyard millet. Similar relationships were recorded by Arunachalam *et al*. (2012); Gupta *et al*. (2009); Upadhyaya *et al*. (2014); Sood *et al.* (2015); Joshi *et al.* (2015) and Arya *et al.* (2017) in barnyard millet. Days to fifty percent flowering and days to maturity showed highly significant positive genetic correlation with grain yield, which indicated that selecting late maturity types could result in better yield improvement. This is in accordance with the findings of Arunachalam *et al.* (2012), who concluded based on their study in barnyard millet that early maturing genotypes were poor yielders and *vice versa.* This is supported by the study of Sood *et al.* (2016).

Path coefficient analysis (Dewey and Lu, 1959) was carried out to split the correlation coefficients in to measures of direct and indirect effects. The calculated coefficients were then categorized as negligible, low, moderate, high and very high based on the scales suggested by Lenka and Mishra (1973). Among the traits studied (Table 4), Days to 50 percent flowering was observed to have maximum direct effect on yield (3.938) implying that selection of longer duration types could result in better yield. The better performance of late types is attributable to the high indirect effect through ear length (0.852) and thousand grain weight (0.315). The character days to maturity was observed to have high negative direct effect on grain yield (-3.083), but the direct correlation was highly significant (0.443). This could be because of high indirect effect of days to 50 percent flowering (3.862) and ear length (0.908) through days to maturity. Ear length was also observed to have very high positive direct effect (1.617) with yield

(Prakash and Vanniarajan, 2015). The high direct effect was observed to be influenced indirectly by days to 50% flowering (2.075). Although plant height had negative direct effect (-0.798), its positive correlation with yield is due to the indirect contribution of days to 50 percent flowering (2.366), ear length (1.411) and thousand grain weight (0.251). Thus the direct and indirect contribution of days to fifty percent flowering on yield could be due to the increased duration of the crop resulting in increased biomass production which could reflect in yield. However this is contrary to the findings of Eric *et al.* (2016), who concluded based on their study in finger millet that late maturing accessions have lower 1000 grain weight and yield due to limited moisture at the grain filling stage and excessive shading due to high leafiness. The high residual value (0.55) indicates that 45 percent of total variability of grain yield has been accounted for in the study. Higher residual value is also indicative of the fact that some more traits could be included to increase the precision of the study.

Sodicity had a considerable effect on the mean values of all the twelve quantitative traits that were studied. The traits *viz.*, days to fifty percent flowering, days to maturity, plant height and grain yield per plant had narrow difference between PCV and GCV indicating less environmental influence on inheritance of the traits. High heritability and genetic advance for plant height, ear length, ear width, lower raceme length, flag leaf length, flag leaf width and grain yield per plant indicated that these traits are predominantly governed by additive gene action and hence, could be improved by simple selection method of breeding. Indirect selection for yield based on traits namely thousand grain weight, days to fifty percent flowering and days to maturity will be beneficial under sodic conditions as they were positively correlated whereas, days to fifty percent flowering proved to be the most important trait as it had high direct and indirect effect on yield.

Acknowledgement

The authors are very much grateful to IIMR, Hyderabad, Telangana for providing seed materials of Barnyard millet germplasm accessions for carrying out the present study.

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Table 1. Analysis of Variance of yield and yield components of barnyard millet genotypes under sodic soil

Source of variations	df	Mean squares											
		Days to fifty per cent flowering	Days to maturity	Plant height	Ear length	Ear width	Lower raceme length	Flag leaf length	Flag leaf width	Number of leaves on main tiller	Number of productive tillers	Thousand grain weight	Grain yield/plant
Replications	1	0.611	2.909	47.295	4.649	0.128	0.843	11.709	0.014	7.681	1.136	0.002	4.809
Genotypes	98	12.587**	34.540**	220.220**	7.260**	0.596**	0.653**	20.542**	0.358**	1.125**	2.206**	0.141**	67.855**
Error	98	3.754	9.694	12.551	1.189	0.076	0.072	3.664	0.037	0.416	0.952	0.055	1.557

**Significant at 1% level

Table 2. Variability for morphological traits and genetic parameters in barnyard millet germplasm under sodic condition

S.No	Characters	Mean ± SE	Range	Coefficient of variation (%)		Heritability (h^2) %	GA as percent of mean (5% level)
				PCV	GCV		
1	Days to fifty percent flowering	37± 1.37	35 (BAR 111) - 46 (BAR 228)	7.65	5.62	54.06	8.52
2	Days to maturity	89 ± 2.2	84 (BAR 111) - 99 (BAR 84)	5.29	3.96	56.17	6.12
3	Plant height (cm)	49.97 ± 2.51	31.21 (BAR 390) - 81.52 (BAR 84)	21.59	20.39	89.22	39.68
4	Ear length (cm)	10.15 ± 0.77	6.76 (BAR 390) - 16.29 (BAR 120)	20.25	17.16	71.85	29.97
5	Ear width (cm)	1.85 ± 0.2	0.69 (BAR 222) - 3.64 (BAR 236)	31.33	27.54	77.30	49.88
6	Lower raceme length (cm)	1.71 ± 0.19	0.72 (BAR 264) - 3.38 (BAR 382)	35.17	31.47	80.10	58.03
7	Flag leaf length (cm)	12.74 ± 1.35	6.59 (BAR390) - 22.55 (BAR 371)	27.31	22.80	69.72	39.22
8	Flag leaf width (cm)	1.35 ± 0.14	0.73 (BAR 390) - 3.59 (BAR 295)	33.05	29.78	81.22	55.29
9	Number of leaves on main tiller	5 ± 0.46	4 (BAR 193) - 7 (BAR 154)	18.4	12.47	45.97	17.42
10	Number of productive tillers	5 ± 0.69	3 (BAR 278) - 8 (BAR 160)	25.32	15.95	39.69	20.70
11	Thousand grain weight (g)	2.13 ± 0.17	1.2 (BAR 278) - 3.06 (MDU 1)	14.71	9.69	43.35	13.14
12	Grain yield/plant (g)	12.03 ± 0.88	3.1 (BAR 198) - 41.88 (BAR 242)	48.99	47.88	95.51	96.39

Barnyard millet accession numbers are given within parenthesis.

SE : Standard error
PCV: Phenotypic coefficient of variation
GCV: Genotypic coefficient of variation
h^2 : Heritability (broad sense)
GA : Genetic Advance

Electronic Journal of Plant Breeding, 10 (2): 430-439 (Jun 2019) DOI: 10.5958/0975-928X.2019.00055.3
ISSN 0975-928X

Table 3. Genotypic (rG) and Phenotypic (rP) correlation coefficient of yield and yield components in barnyard millet genotypes

Characters	Correlation coefficient	Days to fifty per cent flowering	Days to maturity	Plant height	Ear length	Ear width	Lower raceme length	Flag leaf length	Flag leaf width	Number of leaves on main tiller	Number of productive tillers	Thousand grain weight	Grain yield/plant
Days to fifty per cent flowering	rG	1.000	0.981**	0.601**	0.527**	0.615**	0.438**	0.625**	0.457**	0.854**	0.229*	0.394**	0.445**
	rP	1.000	0.935**	0.403**	0.295**	0.411**	0.285**	0.418**	0.267**	0.347**	-0.026	0.185	0.319**
Days to maturity	rG		1.000	0.570**	0.562**	0.593**	0.361**	0.663**	0.513**	0.843**	0.153	0.358**	0.443**
	rP		1.000	0.383**	0.312**	0.394**	0.217*	0.437**	0.293**	0.367**	-0.057	0.145	0.315**
Plant height	rG			1.000	0.873**	0.630**	0.659**	0.839**	0.494**	0.775**	0.366**	0.314**	0.101
	rP			1.000	0.751**	0.546**	0.578**	0.694**	0.452**	0.571**	0.252*	0.234*	0.091
Ear length	rG				1.000	0.643**	0.661**	0.863**	0.603**	0.688**	0.103	0.142	0.125
	rP				1.000	0.544**	0.535**	0.661**	0.538**	0.488**	0.096	0.219*	0.122
Ear width	rG					1.000	0.502**	0.701**	0.587**	0.550**	0.092	0.236*	0.213*
	rP					1.000	0.463**	0.544**	0.520**	0.338**	0.063	0.138	0.173
Lower raceme length	rG						1.000	0.530**	0.242*	0.421**	0.318**	0.278**	0.058
	rP						1.000	0.456**	0.241*	0.257*	0.168	0.141	0.063
Flag leaf length	rG							1.000	0.710**	0.905**	0.165	0.422**	0.142
	rP							1.000	0.597**	0.520**	-0.030	0.260**	0.105
Flag leaf width	rG								1.000	0.666**	-0.074	0.404**	0.139
	rP								1.000	0.411**	-0.030	0.263**	0.126
Number of leaves on main tiller	rG									1.000	0.156	0.243*	0.197
	rP									1.000	0.233*	0.185	0.130
Number of productive tillers	rG										1.000	0.464**	-0.097
	rP										1.000	0.238*	-0.057
Thousand grain weight	rG											1.000	0.472**
	rP											1.000	0.328**
Grain yield/plant	rG												1.000
	rP												1.000

*Significant at 5% level **Significant at 1% level

Table 4. Path analysis of different morphological traits in barnyard millet germplasm under sodic condition

Characters	Days to fifty per cent flowering	Days to maturity	Plant height	Ear length	Ear width	Lower raceme length	Flag leaf length	Flag leaf width	Number of leaves on main tiller	Number of productive tillers	Thousand grain weight	Grain yield/plant
Days to fifty per cent flowering	**3.938**	-3.024	-0.479	0.852	-0.101	-0.344	0.002	-0.183	-0.426	-0.106	0.315	0.445**
Days to maturity	3.862	**-3.083**	-0.455	0.908	-0.097	-0.283	0.002	-0.205	-0.421	-0.070	0.286	0.443**
Plant height	2.366	-1.759	**-0.798**	1.411	-0.103	-0.517	0.002	-0.197	-0.386	-0.169	0.251	0.101
Ear length	2.075	-1.731	-0.696	**1.617**	-0.105	-0.519	0.002	-0.241	-0.343	-0.047	0.114	0.125
Ear width	2.423	-1.830	-0.503	1.040	**-0.164**	-0.394	0.002	-0.235	-0.274	-0.042	0.189	0.213*
Lower raceme length	1.726	-1.113	-0.526	1.068	-0.082	**-0.785**	0.001	-0.097	-0.210	-0.147	0.222	0.058
Flag leaf length	2.463	-2.044	-0.670	1.396	-0.115	-0.416	**0.003**	-0.284	-0.452	-0.076	0.337	0.142
Flag leaf width	1.798	-1.582	-0.394	0.976	-0.096	-0.190	0.002	**-0.400**	-0.332	0.034	0.323	0.139
Number of leaves on main tiller	3.363	-2.600	-0.618	1.112	-0.090	-0.330	0.002	-0.266	**-0.499**	-0.072	0.194	0.197
Number of productive tillers	0.903	-0.471	-0.292	0.166	-0.015	-0.249	0.000	0.030	-0.078	**-0.462**	0.371	-0.097
Thousand grain weight	1.553	-1.105	-0.251	0.230	-0.039	-0.219	0.001	-0.162	-0.121	-0.214	**0.799**	0.472**

Bolded values indicate direct effects Residual effect: 0.5518 *significant at 5% level **significant at 1% level

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