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Studies on Genetic Associations, Variability and Diversity in Pearl Millet (*Pennisetum glaucum* (L.) R. Br.)

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Abstract

The experiment was conducted among 20 genetically diverse pearl millet genotypes in randomized block experimental design with three replications at Agricultural Research Station, Bikaner (India) in 2011 for evaluating genetic associations among physiological and morphological attributes and their direct and indirect influence on the grain yield of pearl millet. Data revealed highly significant differences among the genotypes for physiological and morphological traits such as relative water content (%), total chlorophyll content, rate of photosynthesis, transpiration, stomatal conductance, internal CO_2 concentration, leaf temperature, plant height, number of productive tillers per plant, panicle diameter, panicle length, test weight, dry fodder yield, grain yield and harvest index. The genotypic and phenotypic coefficients of variation were similar for all the traits. High heritability coupled with high genetic advance as percentage of mean was observed ranging from 63.90% to 86.10% for all traits that were significantly different among the genotypes except relative water content, total chlorophyll content, transpiration rate, internal CO_2 concentration and leaf temperature, suggesting the presence of additive gene action and possibility of improving these characters through selection. Based on character association and path analysis, it is concluded that total chlorophyll content, test weight, dry fodder yield and harvest index were the most important component characters for the grain yield. On the basis of multivariate analysis, 20 genotypes were grouped into 5 clusters. This suggested the presence of high degree of divergence in the material studied. These clusters may provide promising genotypes for further improvement for the respective characters. Based on per se performance, PB-106 and HHB-197 were observed outstanding due to their high mean value of test weight, grain yield per plot, productive tillers per plant and panicle diameter and therefore, could be used as a reference variety for further breeding programme.

Key words : *Grain yield, path analysis, diversity, pearl millet, relative water content, test weight.*

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.], which is diploid (2n=14), is a staple food crop which is grown almost entirely under rain fed conditions on approximately 25 million ha of hot, drought-prone arid and semi arid regions in India, West Africa, Pakistan and Southern Asia (Yadav *et al*., 2002). India is the largest producer of pearl millet. In India, it was grown on an area of 9.33 million ha with current grain production of 9.5 million tonnes and productivity of 1044 kg ha^{-1} (Anonymous, 2011). Inter and intra seasonal variation in rainfall in these regions is often the single most important environmental factor limiting pearl millet productivity. Pearl millet is well adapted to drought, low soil fertility and high temperature and can be grown in areas where other crops can't survive (Kumar, 1989). Winkel *et al*. (2001) reported that stomata play an important role in minimizing crop water use in pearl millet at pre-anthesis stage. Recently, it has been reported that pearl millet genotypes carrying a terminal drought tolerance quantitative trait locus (QTL) have a lower rate of water loss per unit leaf area under well watered conditions. This water saving mechanism operating

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under non stressed conditions could leave water available in the soil profile for grain filling and could be beneficial for terminal stress conditions (Kholova *et al*., 2010). Stomatal regulation in response to ABA content and vapour pressure deficit has been discussed in many crops (Zhang *et al*., 2005). Several studies have reported a relationship between an enhanced ABA level and transpiration in gene-manipulated plants (Thompson *et al*., 2007).

Rajasthan is the largest pearl millet producer state in India. The local varieties of bajra impart tolerance to drought and heat stress to some extent. However, their yield potential is very low ranging from 2 to 3.60 q/ha compared to 7.5 q/ha in the state and 10.0 q/ha in the country. It has been suggested that the efficiency of breeding for stress environments could be enhanced if plant attributes that confer yield advantages in such environments could be identified and used as selection criteria (Yadav *et al*., 2004). Number of physiological parameters has been proposed as indicator of tolerance to drought stress in many crops but the information on pearl millet is meager (Kholova *et al*., 2010). Although genetic variation in the expression of certain traits in stress environments exists in the available germplasm of pearl millet, the inheritance of such variation and the interactions of its various components in determining yield in arid environment are not fully understood. The present investigation was therefore, planned to generate such morpho-physiological informations which is helpful to the breeders in planning and developing suitable varieties with good production potential in arid region.

Materials and Methods

Plant material, growth conditions and experimental treatments

Twenty genetically diverse genotypes of pearl millet were raised during *kharif* 2011 field season in a randomized block design with three replications at Agricultural Research Station, Bikaner. Each replication was divided into 20 plots, and individual plot consisted of 6 rows, each 5 m long spaced 50 cm apart. The plant-to-plant distance within a row was maintained at 15 cm by thinning at 3 leaf stages. The recommended package and practices were followed to raise a good crop.

Photosynthesis and other related parameters

The rate of photosynthesis (Pn), transpiration (TR), stomatal conductance (G), internal CO_2 concentration (Ci) and leaf temperature were measured at ear emergence stage i.e. 40 days after sowing on 5 randomly selected plants in each plot using Infra Red Gas Analyser (IRGA), TPS-2, Portable Photosynthesis system, USA. These measurements were made on three plants in each plot between 10:00 to 12:00 hours.

Relative water content and total chlorophyll

Observations on Relative water content (%) and total chlorophyll (mg/g) were recorded at ear emergence stage i.e. 40 days after sowing on 5 randomly selected plants in each plot. Relative water content (RWC) of leaves was measured by the method of Slavik (1974). Leaf segments (1 cm^2) were initially weighed and floated over the distilled water for 4 hours and turgid weight was recorded. Dry weight was obtained after drying the leaf segments at 80^0C for 48 h. The RWC was calculated as RWC (%) = (Fresh weight - Dry weight) / (Turgid weight - Dry weight) x 100. Total chlorophyll content was estimated by the method Hiscox and Israelstom (1979). Sample extract was prepared from 50 mg of leaf sample placed in 5 ml of DMSO (Dimethyl sulphoxide). These samples were heated in an incubator at 65^0C for 4 h and than after cooling to room temperature, the absorbance of extracts were recorded at 663 and 645 nm. Chlorophyll content was calculated as $Chl_{Total} = [20.2 \times A_{645} + 8.02 \times A_{663}]$.

The values thus obtained are in ìg/ml of extract (solvent). Values in mg/g fresh weight were obtained by multiplying the above values with "V/W x 1000", where V is volume of extract; W is fresh weight of sample.

Growth, Development and yield attributes

At the time of harvest, observations on growth development and yield attributes were recorded. Observations for plant height (cm), productive tillers (No/plant), panicle diameter (cm), and panicle length (cm) were recorded on the same 5 randomly selected plants in each plot. On the other hand, for traits such as 1000-seed weight (g), dry fodder yield (kg/plot), and grain yield (kg/plot) were recorded on plot basis. Harvest index, a measure of dry matter partitioning to economic (grain) yield, was also computed by the formula as given by Singh and Stoskopf (1971). Harvest index was calculated using the formula as HI = (Economical yield / Biological yield) x 100. Biological yield represents total above ground biomass (grain yield plus straw yield).

Statistical analysis

Character association and path analysis were carried out as per standard procedure of Panse and Sukhatame (1984). The genetic divergence was measured by the Mahalanobis' D^2 analysis (Mahalanobis, 1936) and genotypes were grouped using Tocher's method (Rao, 1952). The grouping depends on the principle that intra-group distances should be far less than inter-group distances. A principle component analysis based on Mahalanobis' D^2 (Mahalanobis,1936) was carried out using INDOSTAT statistical software (INDOSTAT Services, Hyderabad, India) to determine the traits most effective in discriminating between accessions.

Results and Discussion

Evaluation of 20 genotypes showed significant difference for physiological and yield attributes viz. relative water content, total chlorophyll content, rate of photosynthesis, transpiration, stomatal conductance, internal CO_2 concentration, leaf temperature, plant height, productive tillers per plant, panicle diameter, panicle length, test weight, dry fodder yield per plot, grain yield per plot and harvest index suggesting the existence of significant variation among the genotypes. Similar pattern of variability in genotype evaluation of different characters were earlier reported by (Kumhar and Sharma, 2004; Shanmuganathan *et al*., 2006; Izge *et al*., 2006 and Bhagirath *et al*., 2007). In general, the phenotypic coefficients of variation (PCV) were invariably higher than that corresponding genotypic coefficient of variation (GCV), indicating higher environmental influence on expression of all traits (**Table 1 & 2**). Higher GCV and PCV were recorded for characters like transpiration rate followed by harvest index, grain yield per plot, productive tillers per plant and total chlorophyll content suggesting the scope for improvement of these characters with appropriate breeding method. Internal CO_2 concentration and leaf temperature exhibited lowest values. These results are in conformity with the report of Varu *et al*. (2005). The heritability in broad sense was observed to be high ranging from 63.90 to 86.10% for all traits which had significant differences among the genotypes except for relative water content, total chlorophyll content, transpiration rate, internal CO_2 concentration and leaf temperature suggesting that these traits are governed by additive gene action and possibility of improving these characters through selection. High heritability coupled with high genetic advance was observed for stomatal conductance, plant height and harvest index. High heritability and moderate genetic advance were observed for rate of photosynthesis, productive tillers per plant, panicle diameter, panicle length, test weight, dry fodder yield per plot and grain yield per plot whereas low heritability and low genetic advance were observed for relative water content, total chlorophyll content, transpiration rate, internal CO_2 concentration and leaf temperature. From the study of heritability and genetic advance it is inferred that simple selection among genotypes could bring about significant improvement in the grain yield and its component characters as the heritability and estimated genetic advance were high.

The genotypic correlation coefficient provides a measure of genetic association between characters and thus, help in identifying the traits, which are important and need to be considered for improvement of yield (Govindaraj *et al*., 2009). The grain yield per plot showed positive and significant correlations with total chlorophyll content and test weight (Ezeaku and Mohammed, 2006) while non-significant positive correlations were observed with productive tillers per plant and panicle diameter (**Table 3**). Negative and significant association of grain yield per plot was observed with transpiration rate, internal CO_2 concentration and panicle length. These results are in agreement with the earlier findings of Varu *et al*. (2005).

The phenotypic correlation of grain yield per plot showed positive and significant correlations with total chlorophyll content, test weight and Harvest index. Non-significant positive correlations were observed with productive tillers per plant, panicle diameter and dry fodder per plant. Negative and significant association of grain yield per plot was observed with transpiration rate, internal CO_2 concentration and panicle length.

In environmental correlations, the grain yield per plot showed positive and significant correlations with dry fodder yield per plot and harvest index. While non-significant positive correlations were observed with relative water content, total chlorophyll content, photosynthetic rate, stomatal conductance, productive tillers per plant, panicle diameter and test weight. Negative non-significant association was observed with transpiration rate, internal CO_2 concentration, leaf temperature, plant height and harvest index.

Perusal of direct and indirect effects of various characters on grain yield per plot (**Table 4**) indicated that in general there is an agreement between direction and magnitude of direct effect of various characters and correlation with grain yield per plot, i.e. the characters which had high correlations also showed high direct effect on grain yield. Relative water content, test weight, dry fodder yield per plot and harvest index had high direct effect towards grain yield. Thus, a significant improvement in grain yield can be expected through selection in the component traits with high positive direct effects.

The conclusion that is drawn from the present study is that total chlorophyll content, test weight, dry fodder yield per plot and harvest index are the most important component character for the grain yield per plot as these had high positive direct effect on grain yield. These results are in close agreement with the findings of (Maman *et al*., 2004; Yadav *et al*., 2002; Wolie and Dessalegn, 2011). In addition to these, other important characters are photosynthetic rate, stomatal conductance, productive tillers per plant, panicle diameter and panicle length, which should be considered as a selection criteria in a selection programme. All these component characters had high heritability and genetic advance and hence, these can be successfully used in improving the grain yield.

The genetic diversity gives a clear picture of actual diversity present in the genetic material used, which could be utilized in selecting desirable parents for hybridization programme as well as diversity in the material. On the basis of multivariate analysis based on Mahalanobis' D^2 statistic (Mahalanobis, 1936) 20 genotypes were grouped into 5 clusters **(Table 5)**. This suggested the presence of high degree of divergence in the material studied. Cluster I was the largest and consisted of fourteen genotypes followed by II with three genotypes. Rest of the clusters III, IV and V had single genotype in each cluster. Present study is corroborative with the findings of Rao *et al.* (2008), Savery and Parsad (1995), Tomar *et al*. (1995), Mahawar *et al.* (2004) and Vidyadhar and Devi (2007). In general, the major clusters in the above mentioned divergence analysis contained genotypes of heterogeneous origin although exact origin of genotypes used in the study was not known. Therefore, it is concluded that there was no parallelism between genetic and geographic diversity. Furthermore, there is a free exchange of seed material among different parts of country, either through direct introduction or for breeding purpose. As a consequence the character constellation that might be associated with particular region in nature, lose their individuality. Murthy (1966) suggested that genetic drift and natural selection forces operative under diverse environmental conditions within a country could cause more diversity than geographical isolation.

Average intra and inter-cluster D^2 values among 20 genotypes **(Fig. 1)** revealed that cluster I (23.68) followed by cluster II (12.68) showed maximum intra-cluster D^2 value. Cluster II and V showed maximum inter-cluster D^2 value (94.77) followed by cluster IV and V (91.57), and cluster II and III (67.88) revealing thereby existence of diverse genotypes in these clusters.

Cluster V had genotypes having their desirability for characters like total chlorophyll, stomatal conductance, productive tillers per plant, panicle diameter (cm), test weight, grain yield, and harvest index (%). Cluster IV had desirable value for relative water content and internal CO_2 concentration. Similarly, other clusters like I, II and III were also having genotypes good for different character combinations **(Table 6)**. Thus, these clusters may provide promising genotypes for further improvement for the respective characters. It was observed that the contribution of characters like panicle length (30.0%), panicle diameter (27.37%), harvest index (8.42%), test weight (7.89%), dry fodder yield (7.89%) and seed yield per plant (7.37%) was very high towards the genetic divergence.

Based on per se performance, PB-106 and HHB-197 were observed outstanding due to their high mean value of test weight, grain yield per plot, productive tillers per plant and panicle diameter and therefore, could be used as a reference variety for further breeding programme.

Table 1 : Mean, variance, coefficient of variation, heritability and expected genetic advance for relative water content, total chlorophyll, rate of photosynthesis, transpiration, stomatal conductance, internal CO_2 concentration and leaf temperature in diverse pearl millet genotypes

Bajra Genotypes	Relative water content (%)	Total chl. (mg/g)	Photosynthesis (μ mol $m^{-2}s^{-1}$)	Transpiration (m mol $m^{-2}s^{-1}$)	Stomatal conductance (m mol $m^{-2}s^{-1}$)	Internal co_2 conc. (ppm)	Leaf temperature (^0C)
GHB-558	78.08	2.15	11.44	5.93	248.22	230.33	37.89
RHB-173	76.51	2.81	11.61	3.80	134.66	258.89	38.00
RHB-121	71.83	2.06	9.16	4.76	128.22	251.44	37.78
PB-106	78.57	3.10	7.44	3.34	129.44	242.33	38.00
ICMH-356	77.75	3.13	10.68	5.33	364.11	215.78	37.56
GHB-744	77.72	3.03	6.98	4.58	128.33	232.78	38.22
GHB-732	73.42	2.41	6.52	3.59	130.56	265.55	37.89
NANDI-61	84.08	2.21	5.78	4.64	169.56	254.55	37.78
HHB-197	75.21	3.21	9.74	5.44	239.11	247.11	38.11
HHB-223	79.72	2.16	13.09	6.48	266.33	210.89	37.78
PUSA-23	85.77	2.54	7.80	4.55	163.78	256.22	39.11
HHB-67 IMPROVED	79.98	3.02	7.89	5.63	231.89	255.33	38.44
GHB-538	79.54	2.69	10.49	5.87	234.07	258.45	37.78
RAJ-171	79.17	2.68	6.88	5.46	250.00	229.22	38.44
PUSA-383	77.38	2.41	10.69	6.68	236.44	249.44	38.33
JBV-2	81.52	2.48	6.53	6.86	376.56	215.89	39.11
ICMH-221	64.62	1.98	10.91	4.20	182.33	245.67	39.00
PUSA-266	79.94	2.43	11.81	4.83	253.22	291.56	38.22
ICMH-8203	77.15	1.63	7.18	5.45	172.22	267.67	38.55
CZP-9802	79.94	2.52	8.07	5.56	222.67	238.00	39.11
Grand mean±SEm	77.89±4.60	2.53±0.39	9.03±1.22	5.15±0.82	213.09±23.16	245.86±27.70	38.26±0.68
Variance	19.86	0.19	4.77	1.00	3180.02	346.96	0.25
Coefficient of Genotype	13.12	22.09	15.50	33.16	0.92	0.37	0.37
variation Phenotype	22.92	27.63	24.99	35.73	13.83	2.20	2.20
Heritability	22.60	32.80	63.90	38.50	86.10	00.40	02.90
Genetic advance	2.98	0.39	3.29	1.02	135.09	0.31	0.05
Genetic advance expressed as % of mean	3.83	15.42	36.43	19.81	63.40	0.13	0.13

Table 2 : Mean, variance, coefficient of variation, heritability and expected genetic advance for yield and yield attributing characters in diverse pearl millet genotypes

Bajra Genotypes	Plant height (cm)	Productive tillers (No/plant)	Panicle diameter (cm)	Panicle length (cm)	1000-seed Weight (g)	Dry Fodder yield (kg/plot)	Grain yield (kg/plot)	Harvest Index
GHB-558	164.67	2.60	2.53	20.13	9.27	4.72	1.18	24.90
RHB-173	171.00	2.27	1.77	22.20	7.10	5.87	1.20	20.68
RHB-121	162.67	2.67	1.53	18.53	7.37	3.87	0.84	21.71
PB-106	147.67	2.53	2.53	20.67	10.63	4.78	1.76	36.98
ICMH-356	147.33	2.53	2.17	16.67	9.87	4.12	1.19	28.82
GHB-744	172.00	2.80	1.93	17.73	9.03	5.11	1.41	27.74
GHB-732	141.33	2.47	1.83	18.47	6.93	4.94	1.28	25.97
NANDI-61	162.33	2.87	2.43	19.40	6.67	6.61	0.73	11.10
HHB-197	152.33	5.07	2.17	21.60	10.60	3.09	1.51	49.11
HHB-223	149.00	2.80	1.97	18.13	8.63	3.60	1.05	29.12
PUSA-23	160.00	4.20	1.90	21.13	9.07	4.12	1.35	32.81
HHB-67 IMPROVED	166.33	3.27	2.97	20.73	9.70	5.10	1.18	23.33
GHB-538	160.00	3.00	2.03	17.60	8.10	4.23	1.19	27.93
RAJ-171	174.33	3.33	1.80	24.27	9.50	4.93	1.40	28.07
PUSA-383	177.00	3.60	1.83	26.93	6.67	3.60	0.66	18.19
JBV-2	169.67	3.20	1.97	25.73	7.93	5.09	0.77	15.29
ICMH-221	162.33	1.20	2.27	18.57	8.87	3.60	1.28	36.96
PUSA-266	177.33	3.20	1.63	25.60	8.40	4.57	0.67	14.54
ICMH-8203	140.00	1.80	2.23	19.07	8.10	3.00	0.62	20.95
CZP-9802	154.67	2.47	1.43	20.27	8.37	4.29	1.21	28.30
Mean±SEm	160.55±6.13	2.89±0.40	2.05±0.12	20.67±1.41	8.54±0.48	4.46±0.49	1.12±0.16	26.13±3.16
Variance	132.00	0.67	0.14	8.66	1.46	0.81	0.10	77.07
Coefficient of Genotypic	6.63	26.52	17.80	13.40	13.56	18.59	29.23	32.50
variation Phenotypic	8.41	31.44	19.30	15.78	15.20	23.01	31.45	35.72
Heritability	66.80	71.20	85.10	72.10	79.60	69.60	65.30	82.80
Genetic advance	17.91	1.33	0.69	4.85	2.13	1.38	0.51	15.91
Genetic advance expressed as % of mean	11.16	46.02	33.66	23.46	24.94	30.94	11.43	60.89

Table 3 : Phenotypic (P), genotypic (G) and environmental (E) correlation coefficient between different characters in diverse pearl millet genotype

Characters		Relative water content (%)	Total chlorophyll (mg/g)	Photosyn-thesis (µ mol $m^{-2}s^{-1}$)	Transpiration (m mol $m^{-2}s^{-1}$)	Stomatal conductance (m mol $m^{-2}s^{-1}$)	Internal CO_2 conc. (ppm)	Leaf temperature (^0C)	Plant height (cm)	Productive Tillers (No/plant)	Panicle diameter (cm)	Panicle length (cm)	Test weight (g)	Grain yield (kg/plot)	Dry Fodder yield (kg/ plot)
Total chlorophyll	P	0.097													
(mg/g)	G	0.435*													
	E	-0.030													
Photosynthesis	P	-0.129	-0.043												
(µ mol $m^{-2}s^{-1}$)	G	-0.485*	-0.100												
	E	0.105	0.006												
Transpiration	P	0.145	-0.136	0.123											
(m mol $m^{-2}s^{-1}$)	G	0.553**	-0.177	0.325											
	E	-0.026	-0.115	-0.081											
Stomatal	P	0.176	0.123	0.214	0.662**										
conductance	G	0.368	0.165	0.277	0.841**										
(m mol $m^{-2}s^{-1}$)	E	0.042	0.116	0.037	0.609**										
Internal CO_2	P	-0.089	-0.087	-0.132	-0.082	-0.252									
conc. (ppm)	G	0.283	-2.004**	0.653**	-6.013**	-4.716**									
	E	-0.112	-0.013	-0.278	0.211	0.103									
Leaf	P	0.067	-0.083	-0.115	0.091	0.070	-0.149								
temperature (^0C)	G	0.048	-0.720**	-1.326**	0.512*	0.246	7.002**								
	E	0.073	-0.017	0.109	0.048	0.085	-0.231								
Plant height	P	0.098	0.166	0.061	0.180	0.117	0.183	0.075							
(cm)	G	0.175	0.035	0.194	0.249	0.116	0.437*	0.831**							
	E	0.058	0.316	0.190	0.118	0.135	0.359	0.071							
Productive	P	0.359	0.377	-0.028	0.217	0.207	-0.034	0.052	0.199						
Tillers	G	0.679**	0.604**	-0.091	0.406	0.250	0.489*	-0.044	0.251						
(No./plant)	E	0.182	0.193	0.106	0.010	0.060	-0.114	0.110	0.085						
Panicle diameter	P	0.044	0.147	-0.095	0.033	0.061	-0.032	-0.128	-0.135	0.006					
(cm)	G	0.084	0.177	-0.144	-0.046	0.055	-0.998**	-0.379	-0.213	-0.084					
	E	0.022	0.171	0.046	0.196	0.099	0.076	-0.181	0.115	0.343					
Panicle length	P	0.221	0.163	-0.024	0.129	0.249	0.064	0.124	0.487*	0.406	-0.140				
(cm)	G	0.321	-0.064	0.015	0.485	0.309	1.736**	1.774**	0.736**	0.441*	-0.271				
	E	0.196	0.448*	-0.107	-0.307	0.024	-0.064	-0.251	-0.078	0.319	0.355				
Test weight (g)	P	-0.021	0.457*	0.055	-0.112	0.189	-0.186	0.038	-0.156	0.256	0.403	-0.066			
	G	0.065	0.661**	0.052	0.030	0.247	-2.882**	0.204	-0.225	0.259	0.448*	-0.191			
	E	-0.122	0.324	0.064	-0.362	-0.093	-0.035	0.017	0.029	0.251	0.196	0.329			
Grain yield	P	-0.018	0.501*	-0.069	-0.338	-0.188	-0.162	-0.028	-0.214	0.149	0.203	-0.159	0.624**		
(kg/ plot)	G	-0.287	0.802**	-0.107	-0.586**	-0.285	-2.220**	-0.022	-0.249	0.107	0.200	-1.404**	0.721**		
	E	0.197	0.260	0.008	-0.080	0.161	-0.072	-0.045	-0.139	0.246	0.233	0.436*	0.352		
Dry Fodder yield	P	0.202	0.295	-0.256	-0.219	-0.111	-0.038	-0.080	0.313	-0.026	0.148	0.121	-0.197	0.146	
(kg/ plot)	G	0.650**	0.170	-0.470*	-0.419	-0.178	0.893**	-0.610**	0.404	-0.143	0.151	0.073	-0.324	-0.044	
	E	-0.093	0.448*	0.133	-0.019	0.102	-0.146	0.007	0.137	0.224	0.155	0.226	0.135	0.541**	
Harvest Index	P	-0.135	0.270	0.088	-0.184	-0.093	-0.107	0.010	-0.368	0.193	0.127	-0.225	0.655**	0.760**	-0.462*
	G	-0.607**	0.571**	0.159	-0.243	-0.110	-2.247**	0.310	-0.437*	0.268	0.147	-0.369	0.762**	0.833**	-0.530
	E	0.349	-0.081	-0.111	-0.143	0.000	0.069	-0.091	-0.180	-0.055	0.020	0.274	0.196	0.558**	-0.297

*Significance at 5 per cent level ** Significance at 1 per cent level

Table 4 : Direct and indirect effects of different character on grain yield of pearl millet at genotypic and phenotypic levels

Characters		Relative water content (%)	Total chlorophyll (mg/g)	Photosynthesis (µ mol m^{-2}s^{-1})	Transpiration(m mol m^{-2}s^{-1})	Stomatal conductance (m mol m^{-2}s^{-1})	Internal CO_2 conc. (ppm)	Leaf temperature (°C)	Plant height (cm)	Productive Tillers (No./ plant)	Panicle diameter (cm)	Panicle length (cm)	Test weight (g)	Dry Fodder yield (kg plot)	Harvest index	Correlations with grain yield
Relative water	P	0.022	0.008		0.019	-0.027	0.001	0.000	-0.008	-0.038	-0.004	0.014	-0.004	0.129	-0.125	-0.018
content (%)	G	0.130	-0.564	-0.003	0.476	-0.378	-0.004	0.001	-0.044	-0.571	-0.005	0.091	0.003	0.338	-0.661	-0.287
				-0.074												
Total chlorophyll	P	0.002	0.078		-0.018	-0.019	0.001	0.000	-0.013	-0.014	-0.015	0.011	0.096	0.189	0.249	0.501*
(mg/g)	G	0.057	-1.297	-0.001	-0.152	-0.170	0.026	-0.016	-0.009	-0.508	-0.011	-0.018	0.026	0.088	0.621	0.802**
Photosynthesis	P	-0.003	-0.003	-0.015	0.016	-0.033	0.002	0.000	-0.005	0.003	0.010	-0.002	0.011	-0.164	0.081	-0.069
(µ mol m^{-2}s^{-1})	G	-0.063	0.130	0.022	0.279	-0.284	-0.009	-0.030	-0.048	0.077	0.009	0.004	0.002	-0.244	0.173	-0.107
Transpiration	P	0.003	-0.011	0.152	0.133	-0.101	0.001	0.000	-0.015	-0.023	-0.003	0.008	-0.023	-0.140	-0.170	-0.338
(m mol m^{-2}s^{-1})	G	0.072	0.229	0.003	0.860	-0.864	0.079	0.012	-0.062	-0.341	0.003	0.137	0.001	-0.218	-0.265	-0.586**
Stomatal	P	0.004	0.010	0.049	0.088	-0.152	0.004	0.000	-0.010	-0.022	-0.006	0.013	0.040	-0.071	-0.085	-0.188
conductance	G	0.048	-0.214	0.005	0.723	-1.027	0.062	0.006	-0.029	-0.210	-0.003	0.087	0.010	-0.092	-0.119	-0.285
(m mol m^{-2}s^{-1})				0.042												
Internal CO_2	P	-0.002	-0.007		-0.011	0.038	-0.015	0.000	-0.015	0.004	0.003	0.004	-0.039	-0.024	-0.098	-0.162
conc. (ppm)	G	0.037	2.599	-0.003	-5.171	4.845	-0.013	0.159	0.109	-0.411	0.063	0.490	-0.115	0.464	-2.445	-2.220**
Leaf temperature	P	0.001	-0.007	0.099	0.012	-0.011	0.002	0.002	-0.006	-0.005	0.013	0.008	0.008	-0.051	0.010	-0.028
(°C)	G	0.006	0.934	-0.003	0.440	-0.253	-0.092	0.023	-0.207	0.037	0.024	0.500	0.008	-0.317	0.338	-0.022
Plant height	P	0.002	0.013	-0.202	0.024	-0.018	-0.003	0.000	-0.081	-0.021	0.014	0.032	-0.033	0.201	-0.339	-0.214
(cm)	G	0.023	-0.046	0.001	0.214	-0.119	0.006	0.019	-0.249	-0.211	0.013	0.208	-0.009	0.210	-0.475	-0.249
Productive Tillers	P	0.008	0.029	0.030	0.029	-0.032	0.001	0.000	-0.016	-0.105	-0.001	0.027	0.054	-0.017	0.178	0.149
(No./plant)	G	0.089	-0.783	-0.001	0.349	-0.256	-0.006	-0.001	-0.063	-0.840	0.005	0.124	0.010	-0.074	0.292	0.107
Panicle diameter	P	0.001	0.012	-0.014	0.004	-0.009	0.000	0.000	0.011	-0.001	-0.101	-0.009	0.084	0.095	0.117	0.203
(cm)	G	0.011	-0.229	-0.002	-0.040	-0.056	0.013	-0.009	0.053	0.071	-0.063	-0.076	0.018	0.079	0.160	0.200
Panicle length	P	0.005	0.013	-0.022	0.017	-0.038	-0.001	0.000	-0.040	-0.043	0.014	0.065	-0.014	0.077	-0.208	-0.159
(cm)	G	0.042	0.083	-0.001	0.417	-0.318	-0.023	0.040	-0.183	-0.370	0.017	0.282	-0.008	0.038	-0.402	-1.404**
Test weight	P	0.000	0.036	0.002	-0.015	-0.029	0.003	0.000	0.013	-0.027	-0.041	-0.004	0.209	-0.126	0.604	0.624**
(g)	G	0.008	-0.857	0.001	0.026	-0.254	0.038	0.005	0.056	-0.218	-0.028	-0.054	0.040	-0.168	0.829	0.721**
				0.008												
Dry Fodder yield	P	0.004	0.023		-0.029	0.017	0.001	0.000	-0.026	0.003	-0.015	0.008	-0.041	0.640	-0.426	0.146
(kg/ plot)	G	0.085	-0.220	-0.006	-0.360	0.183	-0.012	-0.014	-0.101	0.120	-0.010	0.021	-0.013	0.520	-0.576	-0.044
Harvest index	P	-0.003	0.021	-0.071	-0.024	0.014	0.002	0.000	0.030	-0.020	-0.013	-0.015	0.137	-0.296	0.922	0.760**
	G	-0.079	-0.740	0.002	-0.209	0.113	0.030	0.007	0.109	-0.225	-0.009	-0.104	0.030	-0.275	1.088	0.833**
				0.024												

Residual (P) = 0.0818; Residual (G) = -0.0447; Diagonal figures are the direct effect and non- diagonal are indirect effect; *Significance at 5 per cent level; ** Significance at 1 per cent level

Table 5 : Composition of Clusters in diverse pearl millet genotypes

Cluster	Number of genotypes	Genotypes
I	14	HHB-223, GHB-538, GHB-744, Pusa-23, CZP-9802, GHB-732, RHB-121, RHB-173, RAJ-171, GHB-558, ICMH-8203, ICMH-356, PB-106 and ICMH-221
II	3	JBV-2, PUSA-266 and PUSA-383
III	1	HHB-367 IMPROVED
IV	1	NANDI-61
V	1	HHB-197

Cluster	Relative water content (%)	Total chlorophyll (mg/g)	Photosynthesis (μ mol m^{-2}s^{-1})	Transpiration (m mol m^{-2}s^{-1})	Stomatal conductance (m mol m^{-2}s^{-1})	Internal CO_2 conc. (ppm)	Leaf temperature (^{0}C)	Plant height (cm)	Productive tillers (No/ plant)	Panicle diameter (cm)	Panicle length (cm)	Test weight (g)	Dry fodder yield/ plant (g)	Seed yield/ Plant (g)	Harvest index (%)
I	77.13	2.49	10.32	5.04	206.33	247.86	38.22	157.57	2.62	2.00	19.53	8.63	4.37	1.21	27.92
II	79.61	2.44	10.34	5.48	260.52	263.41	38.55	174.67	3.33	1.81	26.09	7.67	4.42	0.70	16.01
III	79.98	3.02	9.22	5.63	231.89	255.33	38.44	166.33	3.27	2.97	20.73	9.70	5.10	1.18	23.33
IV	84.08	2.21	5.78	5.64	236.22	287.00	37.78	162.33	2.87	2.43	19.40	6.67	6.61	0.73	11.10
V	75.21	3.21	9.74	5.44	272.44	247.11	38.11	152.33	5.07	2.17	21.60	10.60	3.09	1.51	49.11

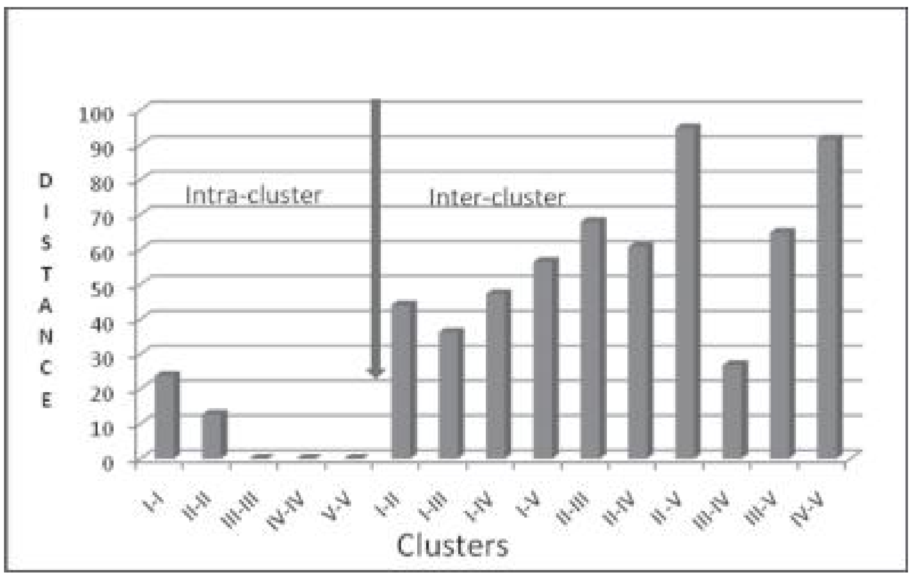

Fig. 1: Estimates of intra-cluster (left of the arrow) and inter-cluster distance (right of the arrow) based on corresponding D^2 values

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