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GENETIC DIVERGENCE OF NIGERIAN AND INDIAN PEARL MILLET ACCESSIONS BASED ON AGRONOMICAL AND MORPHOLOGICAL TRAITS

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Abstract: The study assessed the genetic diversity of pearl millet accessions grown in Nigeria and India based on morpho-agronomic traits in order to identify genotypes with superior characters which could be utilized in breeding programmes. Twenty-four pearl millet accessions were grown and evaluated for agronomic and morphological traits during the dry and wet seasons of 2015–2016. Data collected on the accessions using standard descriptors were analysed statistically. IP22281 had the highest mean plant height (108.90 cm) while NGB00531 recorded the lowest (61.02 cm). Significant intra-specific variation existed in number of leaves per plant, leaf length, leaf width, number of nodes and internode length, however, stem girth was similar for the accessions. Tillering was generally poor with the highest value (1.60 tillers per plant) found in NGB00531. A significant positive correlation occurred between plant height, number of leaves, leaf length and leaf width. Panicles emerged between 44 and 56 days and NGB00548 had the shortest maturity time. Also, panicle length and peduncle diameter varied significantly for the accessions. The highest grain yield and 1000-grain weight were recorded in NGB00616 and the lowest yield and weight were recorded in IP22269. The principal component analysis grouped the accessions into four clusters, comprising mixtures of Nigerian and Indian members. Similarly, the dendrogram grouped the accessions into two main groups which were sub-divided into smaller clusters with accessions from Nigeria and India in the same cluster. The study concludes that variations in morpho-agronomic and yield characters among the accessions studied could be harnessed for crop improvement. The clustering pattern of these accessions indicated their genetic relatedness, possibly from the same progenitor, but separation by geographical or ecological isolation mechanisms.

Key words: genetic diversity, grain yield and yield components, morphological variation, pearl millet.

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Introduction

Genetic variability is the prerequisite of plant evolution and crop improvement. Analysis of genetic variability in crop species is an important component of crop improvement programmes, as it provides information about characters that can be useful for various breeding purposes (Animasaun et al., 2015). In the wake of climatic change with its impending danger of food scarcity and insecurity, lives of nearly a billion poor people in dryland areas of Africa and Asia depend on cereals that can be grown in drought and water-stressed environments. The poor rural people whose main occupation is farming still await their salvaging crops whose genetics is well understood to develop hybrids of improved yield and stable crops for such conditions (CGIAR, 2012).

Pearl millet (*Pennisetum glaucum* L. R. Br), also known as *P. americanum* and sometimes called bulrush or cattail millet, is the most important cereal of the genus *Pennisetum.* This crop plays a significant role in tropical agriculture. Pearl millet can be grown in a vast range of environmental conditions including those characterized by drought and poor soil (FAO and ICRISAT, 1996). It is grown on approximately 40 million hectares in the arid and semi-arid regions of Asia and Africa where it serves as a staple food and plays a vital role in food security (Rai et al., 2009). Even, under abiotic stress conditions, pearl millet would comparatively produce higher grain yield than sorghum, which is another dryland crop (Hash et al., 2003; Khairwal et al., 2007). In the West African Sahel region and the Indian subcontinent, pearl millet is grown almost exclusively to feed millions of people who live in agroclimatic zones with severe stress limitations to crop production due to heat and inadequate rainfall. Furthermore, pearl millet has been suggested as a new feed grain crop for the south-eastern and mid-southern regions of the United States with acidic soil, low fertility and drought (Kennedy et al., 2002; Davis et al., 2003). In addition, it has a relatively short growing season (60–90 days) that allows double cropping after leguminous crops have been harvested (FAO and ICRISAT, 1996).

Pearl millet is an excellent forage crop with low hydrocyanic acid content and considerable amounts of protein, calcium, phosphorous and other minerals. The grain contains higher protein than wheat or rice (Poncet et al., 1998) and more essential amino acids than corn (Adeola et al., 1994; Amato and Forrester, 1995). In addition, pearl millet contains more oil than other cereals (Hill and Hanna, 1990; Sullivan et al., 1990). Feeding tests conducted on cattle, swine, and chicken have shown that pearl millet is at par with maize and superior to sorghum in feed formulations. Hence, pearl millet is used as a feed ingredient for broilers (Davis et al., 2003), laying hens (Kumar et al., 1991; Collins et al., 1997), ducks (Adeola et al., 1994), and cattle (Hill and Hanna, 1990). Also, it has been demonstrated that pearl millet is suitable for ethanol production and the plant of choice for biofuel in areas where other crop production is not economical for resource-limited farmers (Gulia et al., 2007; Dowling et al., 2013).

In Nigeria, in spite of the considerable economic importance of pearl millet, it has received relatively little research attention and is still regarded as an 'orphan' crop. Therefore, there is a need for a better understanding of the genetic diversity of this crop in relation to accessions available in other regions, in particular, India. The gene pool in cultivated pearl millet contains an enormous range of genetic variability with no incompatibility and few linkage problems (Wilson et al., 2004). The genetic relationship among genotypes of the pearl millet cultivated in Nigeria and India has not been well investigated. The understanding of the crop genetics and variability among the available germplasm could open a window of greater potentials for the sustainable utilization for fodder and grain production in the present erratic climatic changes. Intra-specific genetic diversity studies and morphological character correlation in pearl millet germplasm could offer possibilities for the improvement of the crop and its hybrids. Thus, the success of a breeding programme for pearl millet would require adequate information on variations in growth and reproductive traits of the available accessions which could be explored by the breeders. Therefore, the present work characterized pearl millet accessions from Nigeria and India based on morpho-agronomic traits with a view to assess the genetic diversity among the accessions and to provide information that would enhance crop improvement.

Materials and Methods

Plant material

A total of twenty-four accessions of pearl millet were used for the investigation. The seeds of 10 accessions were collected from the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Oyo State, Nigeria and another 10 from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. In addition, 4 unclassified accessions were obtained from the farmer's field at Bardoli, Surat District, Gujarat State of India. The names of the accessions and source of collection are presented in Table 1.

Agro-ecological description of the experimental location

The morpho-agronomic characterization of twenty-four accessions of pearl millet was conducted in the screenhouse facility at C. G. Bhakta Institute of Biotechnology (CGBIBT), Uka Tarsadia University (UTU), Bardoli, Gujarat State, India in the period 2013–2015. UTU is located at latitude 21.04°N, longitude

073.03°E and at an elevation of 39 feet above mean sea level. The climate of Gujarat varies from tropical monsoon in the south to temperate in the north with annual average maximum temperatures of 33°C and minimum of 22°C. The annual average rainfall is about 1117.6 mm with the mean precipitation of 66 days. The annual maximum and minimum average relative humidity values are 77% and 54% respectively. The estimated length of daylight is 12.5 h and the wind speed is 4 mph (Indian Metrological Society, 2015).

Table 1. Accession name and source of pearl millet used for the study.

SN	Accession	†Collection source
1	IP3616	ICRISAT
2	IP3495	ICRISAT
3	NGB00463	NACGRAB
4	BALKUVE	GUJARAT*
5	BAJARA	GUJARAT*
6	NGB00616	NACGRAB
7	IP4133	ICRISAT
8	NGB01263	NACGRAB
9	IP22281	ICRISAT
10	IP12556	ICRISAT
11	NGB00458	NACGRAB
12	NGB00531	NACGRAB
13	IP22271	ICRISAT
14	NGB00476	NACGRAB
15	IP22268	ICRISAT
16	TAYABI	GUJARAT*
17	JALGONE	GUJARAT*
18	NGB00551	NACGRAB
19	IP17862	ICRISAT
20	IP3122	ICRISAT
21	NGB00528	NACGRAB
22	IP22269	ICRISAT
23	NGB00528	NACGRAB
24	NGB00537	NACGRAB

†NACGRAB: National Centre for Genetic Resources and Biotechnology, Ibadan, Nigeria.
†ICRISAT: International Crops Research Institute for the Semi-Arid Tropics, India.
*Accession obtained from the farmer's field within the state of Gujarat, India.

Morpho-agronomic traits

Dry seeds of each pearl millet accessions were grown in pots filled with soil (clay, sand and topsoil in the ratio of 3:1:1) for morphological characters and genetic diversity assessment. The experiment was carried out in the randomized complete block design (RCBD) with five replicates. Watering was done every four days with automated overhead fogging irrigation facility, and humidity was regulated by an auto-humidifier system, while weeding was carried out by hand-picking throughout the period of evaluation. After seedling emergence, plants were thinned and a plant was chosen and tagged from a pot for observation and data collection. Data were collected on morpho-agronomic characters such as plant height, number of leaves per plant, leaf length, leaf width, number of nodes, internode length, stem girth, number of tillers per plant, and number of leaves per tiller. Other characters considered were: days to panicle emergence, panicle length and 1000-grain weight based on the crop descriptor index (IBPGR and ICRISAT, 1993). The growth and grain yield related characters were considered at maturity for each accession.

Statistical analysis

Data collected on quantitative growth and reproductive traits (days to panicle emergence, panicle size, and grain weight) of the accessions were subjected to analysis of variance (ANOVA), and agronomic trait correlations were determined using the Statistical Package for the Social Sciences (SPSS) version 17. The mean values of the analysed traits were separated by Duncan's multiple range test (DMRT). The intervariety divergence was calculated using the unweighted pair-group method of arithmetic averages (UPGMA) to evaluate the degree of genetic diversity in the accessions.

Results and Discussion

The mean values and standard errors of a mean between qualitative and quantitative variations were observed in vegetative and reproductive parameters. A comparison of the mean for the morpho-agronomic traits evaluated at maturity in two years (pooled data) showed significant differences (Table 2). Plant height varied significantly across the accessions. IP22281 was the tallest accession (108.90 cm), closely followed by IP22269 (104.10 cm) while NGB00531 had the lowest plant height (67.46 cm) (Table 2). The results obtained here were similar to those documented by Al-Suhaibani (2011). The difference in plant height among the accessions could be due to a combination of genetic variability and environmental effects. The mean number of leaves per plant also varied significantly and ranged from 7.00 to 10.90 (Table 2), and the highest number of leaves per plant (10.90) occurred in accession IP3616. Expectedly, NGB00531 which was the shortest accession also had the lowest number of leaves per plant. Leaf length differed statistically for the accessions – the shortest leaf (21.1 cm) was found in a Nigerian accession (NGB00463), and the longest (57.4 cm) in IP3616, followed by IP3132 (51. 4 cm), which are both ICRISAT accessions (Table 2).

Table 2. The mean values of morpho-agronomic traits and vegetative characters of twenty-four accessions of pearl millet at maturity.

Accession	PH (cm)	NL	LL (cm)	LW (cm)	SG (cm)
IP3616	103.06±22.66[abc]	10.90±43.85 [a]	57.4±5.33 [bc]	2.08±0.11[cdefghi]	0.75±0.5[cde]
IP3495	77.92±12.46[cdef]	7.60±0.89 [c]	38.2±2.5 [bcde]	1.66±0.11[hijk]	0.58±0.02[de]
NBG00463	80.54±17.57[bcdef]	9.40±1.67 [ab]	21.1±7.37 [e]	1.80±0.11[fghijk]	0.72±0.05[cde]
BALKUVE	71.90±4.25[def]	7.80±1.10 [c]	33.4±5.91 [cdef]	2.10±0.15[bcdefghi]	0.56±0.05[de]
BAJARA 2	92.22±9.76[bcde]	9.20±1.92 [ab]	37.9±17.4 [bcde]	2.52±0.18[abcde]	0.88±0.12[c]
NGB00616	72.42±23.26[def]	8.20±0.84 [bc]	44.4±11.9 [abcd]	1.97±0.21[efghij]	0.64±0.05[cde]
IP4133	80.64±35.68[bcdef]	8.40±1.14 [b]	38.0±15.3 [bcde]	2.26±0.18[cdefgh]	0.67±0.07[cde]
NGB01263	73.68±17.10[def]	10.80±1.10 [a]	41.4±12.6 [bcde]	1.93±0.23[efghijk]	0.74±0.07[cde]
IP22281	108.90±17.52[a]	10.00±1.22 [a]	41.1±12.8 [bcde]	1.74±0.22[ghijk]	0.65±0.08[cde]
IP12556	83.16±12.80[bcdef]	7.60±1.14 [c]	33.1±5.63 [cdef]	1.67±0.14[hijkl]	0.49±0.05[e]
NGB00458	72.40±21.91[def]	7.20±1.30 [d]	33.1±5.62 [cdef]	1.42±0.14[kl]	0.50±0.47[e]
NGB00531	67.46±9.75[e]	7.00±1.00 [d]	30.5±5.36 [abc]	1.10±0.16[l]	0.51±0.04[e]
IP22271	89.62±12.78[b]	8.00±1.58 [bc]	28.1±3.79 [de]	1.66±0.14[hijkl]	0.54±0.03[e]
NGB00476	94.46±26.11[bcde]	10.20±1.48 [a]	37.0±5.34 [bcde]	1.56±0.19[ijkl]	0.58±0.06[de]
IP222868	103.04±12.60[b]	8.40±1.52 [b]	42.3±3.67 [bcde]	1.91±0.16[fghijk]	0.81±0.11[cd]
TAYABI	84.64±13.91[bcdef]	7.80±1.1 0 [c]	36.6±7.79 [cde]	1.94±0.24[efghijk]	0.62±0.05[cde]
JALGONE	91.12.±32.02[bcde]	8.20±1.30 [bc]	33.7±4.52 [cdef]	2.14±0.35[bcdefghi]	0.66±0.05[cde]
NGB00551	108.40±12.67[bc]	8.40±1.34 [bc]	33.4±4.84 [cdef]	1.46±0.20[jkl]	0.56±0.03[de]
IP17862	82.82±14.87[bcdef]	10.00±1.58 [a]	41.3±4.67 [bcde]	2.00±0.19[efghijk]	0.60±0.02[de]
IP3132	99.88±19.75[abcd]	9.20±2.17 [ab]	51.4±15.1 [c]	1.83±0.15[fghijk]	0.64±0.02[de]
NGB00528	95.42±19.34[ab]	7.80±1.30 [c]	37.0±9.77 [bcde]	1.92±0.18[efghijk]	0.51±0.03[e]
IP22269	104.10±19.19[ab]	8.20±1.48 [bc]	42.4±16.6 [bcde]	2.34±0.16[bcdefg]	0.63±0.03[cde]
NGB00523	85.82±14.87[bcdef]	10.40±0.55 [a]	33.5±4.81 [cdef]	2.96±0.22[a]	0.70±0.04[cde]
NGB00537	103.46±24.69[a]	9.60±2.30 [ab]	46.5±5.78 [abc]	2.05±0.19[defghij]	0.53±0.06[e]

Means followed by different letters along a column are significantly different at the 0.05 probability level; PH = Plant height, NL = Number of leaves per plant, LL = Leaf length, LW = Leaf width, SG = Stem girth, NON = Number of nodes, INL = Internode length, NTP = Number of tillers per plant, NLT = Number of leaves per tiller.

In terms of leaf width, accession NGB00523 had the broadest leaves (2.96 cm), IP3616, BALKUVE, BAJARA 2, IP4133, JALGONE, IP17862, IP22296, NGB00523 and NGB00537 had leaf width greater than 2.00 cm while NGB00531 had significantly narrower leaves (Table 2). All the accessions had stem girth less than 1.0 cm, but nevertheless the highest stem girth (0.88 cm) was recorded in BAJARA 2, an unclassified accession from the farmer’s field (Table 2). The number of nodes per plant was highest in accessions NGB00463 and BALKUVE which had 5.20 and 5.10 nodes per plant respectively, while other accessions had between 2 and 4 nodes per plant (Table 2). The highest internode length (24.08 cm) occurred in Nigerian accession NGB00537 (Table 2). To corroborate the present results, according to Hash et al. (2003) and Burson et al. (2015), gene actions and environmental influences have great effects on vegetative and yield performance of cereals. Furthermore, it has been demonstrated that particular genotypes perform best in particular environments because of favoured interactions (Mano and Takeda, 1995**).** However, at maturity, due to senescence, gene interactions and a switching mechanism from vegetative to reproductive stages drastically reduced growth rate.

Table 2. Continuation.

Accession	NON	INL	NTP	NLT	NON
IP3616	4.00±.29^{abcdefg}	15.84±4.46^{bc}	0.20±0.45^{c}	1.50±0.63^{bc}	4.00±.29^{abcdefg}
IP3495	4.00±0.36^{abcdefg}	18.64±2.92^{b}	0.40±0.55^{c}	1.60 ±0.60^{bc}	4.00±0.36^{abcdefg}
NBG00463	5.20±0.35^{a}	17.44±3.60^{b}	0.40±0.55^{bc}	1.40±0.49^{bc}	5.20±0.35^{a}
BALKUVE	5.10±0.40^{ab}	16.64±2.18^{b}	0.63±0.15^{bc}	1.90±0.69^{bc}	5.10±0.40^{ab}
BAJARA 2	3.60±0.56^{cdefg}	10.60±9.61^{c}	0.60±0.55^{abc}	1.10±0.48^{bc}	3.60±0.56^{cdefg}
NGB00616	3.20±0.41^{fgh}	12.94±5.53^{c}	0.80±0.84^{abc}	2.20±0.69^{b}	3.20±0.41^{fgh}
IP4133	4.20±0.55^{abcdef}	14.12±6.81^{b}	1.00±0.71^{b}	2.10±0.52^{bc}	4.20±0.55^{abcdef}
NGB01263	2.50±0.50^{hi}	11.44±5.54^{c}	1.00±0.71^{abc}	2.30±0.66^{b}	2.50±0.50^{hi}
IP22281	4.00±0.25^{abcdefg}	10.56±3.17^{c}	0.80±0.84^{abc}	2.40±0.71^{b}	4.00±0.25^{abcdefg}
IP12556	4.70±0.26^{abcd}	15.46±2.52	1.60±0.45^{b}	1.40±0.61^{bc}	4.70±0.26^{abcd}
NGB00458	4.70±0.21^{abcd}	12.96±1.96^{c}	0.20±0.45^{bc}	1.20±0.46^{bc}	4.70±0.21^{abcd}
NGB00531	4.70±0.26^{abcd}	10.62±3.46^{c}	1.60±0.89^{b}	2.20±0.41^{b}	4.70±0.26^{abcd}
IP22271	4.20±0.41^{abcdef}	12.08±2.56^{c}	0.00±0.00^{c}	0.00±0.00^{c}	4.20±0.41^{abcdef}
NGB00476	4.50±0.40^{abcdef}	13.92±1.89^{b}	0.60±0.89^{abc}	1.60±0.54^{bc}	4.50±0.40^{abcdef}
IP222868	4.60±0.40^{abcde}	15.24±3.81^{b}	0.40±0.89^{bc}	0.60±0.42^{bc}	4.60±0.40^{abcde}
TAYABI	4.10±0.31^{abcdefg}	19.46±3.95^{b}	0.40±0.89^{bc}	1.80±0.74^{bc}	4.10±0.31^{abcdefg}
JALGONE	3.50±0.34^{defgh}	17.90±3.14^{b}	0.20±0.45^{c}	1.20±0.62^{bc}	3.50±0.34^{defgh}
NGB00551	4.00±0.21^{abcdefg}	16.38±3.87^{b}	0.40±0.55^{bc}	1.10±0.45^{bc}	4.00±0.21^{abcdefg}
IP17862	4.30±0.30^{abcdef}	11.02±1.42^{c}	0.00±0.00^{c}	0.50±0.50^{bc}	4.30±0.30^{abcdef}
IP3132	3.30±0.26^{efgh}	13.28±2.24^{c}	0.60±0.89^{abc}	1.20±0.51^{bc}	3.30±0.26^{efgh}
NGB00528	3.90±0.27^{abcdefg}	13.44±3.70^{c}	0.00±0.00^{c}	0.00±0.47^{bc}	3.90±0.27^{abcdefg}
IP22269	3.70±0.44^{cdefgh}	10.02±1.31^{c}	0.40±089^{bc}	1.10±0.58^{bc}	3.70±0.44^{cdefgh}
NGB00523	3.80±0.53^{bcdefgh}	13.84±2.52^{c}	0.20±0.45^{c}	1.50±0.63^{bc}	3.80±0.53^{bcdefgh}
NGB00537	3.60±0.45^{cdefgh}	24.08±52.57^{a}	1.60±1.52^{b}	1.60±0.47^{bc}	3.60±0.45^{cdefgh}

Means followed by different letters along a column are significantly different at the 0.05 probability level; PH = Plant height, NL = Number of leaves per plant, LL = Leaf length, LW = Leaf width, SG = Stem girth, NON = Number of nodes, INL = Internode length, NTP = Number of tillers per plant, NLT = Number of leaves per tiller.

Tillering was generally poor among the accessions evaluated, and the highest number of tillers per plant (1.60) was found in IP12556 and NGB00537 (Table 2). The maximum number of leaves per tiller (2.30) was recorded in NGB01263, and lower number was observed in other accessions, but neither the number of tillers per plant nor the number of leaves per tiller was found in accessions NGB00528 and IP22271 (Table 2).

Stem base was basically green in most of the accessions, however, purple stem base was observed in the seedlings of NGB00616, JALGONE, NGB000551, IP22269 and NGB00523, which gradually changed to light purple at maturity (Figure 1). Leaf blades were razor-sharp, typically green, with white midribs and thin ligule margins in all the accessions. The occurrence of the stem base pigmentation at the juvenile stage, which gradually disappeared at maturity, may likely be due to the presence of mutant chlorophyll, which eventually normalized in the course of growth. A similar scenario was documented by Ukwunguwu et al. (2003), who noticed a gradual disappearance of the base colouration in juvenile rice, as it reached maturity.

The correlation coefficients of the vegetative traits of the investigated accessions showed that plant height correlated significantly and positively with the number of leaves and leaf width (Table 3). The correlation was also found between plant height, leaf length and stem girth (Table 3). The number of leaves significantly and positively correlated with leaf length, leaf width, stem girth, number of tillers per plant and number of leaves per tiller (Table 3). Furthermore, a significant and positive correlation was found between leaf length and leaf width, stem girth, number of tillers per plant and number of leaves per tiller (Table 3).

Table 3. Correlation coefficients of quantitative vegetative traits of twenty-four accessions of pearl millet evaluated at maturity.

	PH	NL	LL	LB	SG	NON	INL	NTP	NLT
PH	1.000								
NL	0.468*	1.000							
LL	0.393*	0.870**	1.000						
LB	0.494*	0.702*	0.654*	1.000					
SG	0.397*	0.949*	0.879**	0.687*	1.000				
NI	0.020	-0.419*	-0.390	-0.434*	-0.393*	1.000			
NLL	0.105	-0.151	-0.133	-0.106	-0.227	0.164*	1.000		
NTP	0.261	0.821**	0.781*	0.497*	0.862*	-0.370	-0.223*	1.000	
NLT	0.297**	0.915**	0.843**	0.569*	0.942**	-0.376*	-0.204	0.939**	1.000

** – significant at the 0.01 level; * – significant at the 0.05 level; PH – Plant height, NL – Number of leaves, LL – Leaf length, LW – Leaf width, SG - Stem girth, NON – Number of nodes, INL – Internode length, NTP – Number of tillers per plant and NLT – Number of leaves per tiller.

The high (> 0.900) significant and positive correlations obtained for number of leaves and stem girth, number of leaves and number of leaves per tiller, stem girth and number of leaves per tiller, number of tillers per plant and number of leaves per tiller showed that the traits were genetically linked and/or under the influence of pleiotropy. The high and positive correlations between agronomic traits can be useful in breeding programmes, allowing simultaneous improvement of both characters through correlated responses to selection. This finding is congruent with those of Azeez (2010) and Al-Suhaibani (2011), who obtained positive significant correlations among growth and seed yield characters studied in sesame and pearl millet, respectively.

The mean values and standard errors of a mean between quantitative seed characters and seed related characters of the accessions are shown in Table 4. The accessions varied significantly for the following characters: days to panicle emergence, peduncle length, panicle diameter and 1000-grain weight. Panicles emerged from 44 to 56 days, and the accession NGB00458 was the first to flower at 44 days after sowing, followed by IP2281 and IP22269 at 47 days, while NGB00463 was the last to flower at 56 days after sowing (Table 4). Differences in flowering time could be due to photoperiodic sensitivity. It has been noted that flowering in wild relatives of cultivated plants is influenced by photoperiodism as observed in *Digitaria exilis* (Aliero and Morakinyo, 2002). Peduncle lengths of 11.54 and 11.50 cm were the highest, obtained for IP12556 and NGB00476, respectively, and the shortest peduncle length was observed in IP3616 (Table 4). Panicle length was between 6.54 and 13.63 cm, but it was statistically similar in NGB00463 (12.53 cm), BALKUVE (12.56 cm) and NGB00616 (12.10 cm) (Table 4). The highest peduncle diameter of 2.11 cm was found in IP3132 (Table 4). TAYABI (2.09 cm), IP22271 (2.06 cm) and IP17862 (2.05 cm) differed statistically from other accessions with a peduncle diameter below 2.0 cm.

Meanwhile, accessions NGB00616, NGB00551, NGB00532 and NGB00537, which are all Nigerian accessions, were superior in terms of early maturity and panicle size. Panicle and yield related traits may be influenced by environment as pointed out by Al-Suhaibani (2011). Variations observed in flowering and panicle characters were remarkable, correlating with earlier work (Barbosa et al., 2003), and could be of significant consideration in a breeding programme. Considering grain weight, NGB00616 produced the heaviest grains (10.13 g/1000 grain) (Table 4). The 1000-grain weight was similar for other accessions, except for IP22269, which had the smallest weight (8.08 g/1000 grain). With respect to 1000-grain weight, the results in this study were similar to those reported by other authors (Zerbini and Thomas 2003; Al-Suhaibani, 2011).

Table 4. The mean values of seed related characters of twenty-four Indian and Nigerian accessions of pearl millet.

Accession	DPE	PL (cm)	PNL (cm)	PND (cm)	1000GW (g)
IP3616	47.51±4.21^{c-f}	5.37±0.96^{f}	10.01±1.04^{e-i}	1.53±0.01^{d-i}	9.24±1.02^{b}
IP3495	51.42±4.18^{a-f}	8.93±0.54^{bcd}	7.13±0.89^{jk}	1.62±0.05^{c-i}	9.66v1.06^{b}
NBG00463	56.91±10.12^{a}	6.33±0.98^{ef}	12.53±0.97^{a-e}	1.80±0.09^{a-g}	9.69±0.98^{b}
BALKUVE	49.06±6.01^{b-f}	6.67±0.31^{ef}	12.56±1.02^{a-e}	1.94±0.07^{a-d}	9.86±1.04^{b}
BAJARA 2	52.53±6.87^{a-e}	8.32±1.01^{de}	12.62±0.86^{a-d}	1.78±0.04^{a-h}	9.33±0.92^{b}
NGB00616	49.41±5.16^{b-f}	10.56±0.64^{abc}	12.10±0.58^{a-e}	1.76±0.18^{a-h}	10.13±1.02^{a}
IP4133	50.20±7.11^{a-f}	7.70±0.43^{de}	8.97±0.66^{g-k}	1.37±0.04^{ghi}	9.94±0.97^{b}
NGB01263	55.84±1113^{ab}	10.85±1.07^{ab}	11.65±1.06^{b-g}	1.45±0.07^{f-i}	9.57±1.01^{b}
IP22281	47.21±6.81^{def}	10.54±0.87^{abc}	6.54±0.65^{k}	1.68±0.06^{a-i}	9.73±0.89^{b}
IP12556	54.56±12,01^{a-d}	11.54±1.01^{a}	9.16±0.45^{f-j}	1.27±0.04^{i}	9.43±0.69^{b}
NGB00458	44.72±9.21^{f}	10.54±0.84^{abc}	13.10±1.05^{abc}	1.58±0.08^{d-i}	9.09±0.88^{b}
NGB00531	49.71±4.05^{a-f}	9.72±0.56^{bcd}	12.34±0.99^{a-e}	1.48±0.08^{e-i}	9.55±0.73^{b}
IP22271	50.53±6.14^{a-f}	10.85±1.02^{ab}	13.39±1.12^{ab}	2.06±0.10^{abc}	9.89±0.91^{b}
NGB00476	52.44±4.89^{a-e}	11.50±0.91^{a}	7.83±0.57^{ijk}	1.63±0.07^{b-i}	9.40±1.01^{b}
IP222868	47.91±5.90^{c-f}	8.13±0.59^{de}	9.52±0.96^{f-j}	1.84±0.05^{a-f}	9.47±0.96^{b}
TAYABI	52.86±5.31^{a-e}	8.14±0.97^{de}	13.59±1.04^{ab}	2.09±0.09^{ab}	9.73±0.79^{b}
JALGONE	49.11±6.34^{b-f}	7.54±0.66^{de}	11.43±0.78^{b-g}	1.77±0.09^{a-h}	9.80±0.94^{b}
NGB00551	50.14±7.71^{a-f}	8.15±0.81^{de}	14.33±1.11^{a}	1.68±0.07^{a-i}	9.60±1.02^{b}
IP17862	49.21±5.15^{b-f}	7.98±0.71^{de}	10.42±0.96^{d-h}	2.05±0.05^{abc}	9.52±0.99^{b}
IP3132	46.34±6.71^{ef}	6.48±0.67^{ef}	9.55±0.87^{f-j}	2.11±0.11^{a}	9.87±1.00^{b}
NGB00528	54.86±4.73^{abc}	7.80±0.38^{de}	8.94±0.81^{g-k}	1.88±0.08^{a-f}	9.25±0.78^{b}
IP22269	47.21±6.61^{def}	8.43±0.72^{cde}	8.82±0.74^{h-k}	1.34±0.05^{hi}	8.08±0.99^{c}
NGB00523	50.57±4.76^{a-e}	8.69±0.77^{bcd}	12.67±1.08^{c-h}	1.96±0.06^{a-e}	9.21±0.73^{b}
NGB00537	52.50±7.31^{a-e}	9.22±1.01^{bcd}	13.63±1.02^{a}	1.97±0.07^{a-d}	9.26±1.05^{b}

Means followed by different letters along a column are significantly different at the 0.05 probability level according to Duncan's multiple range test; DPE – Days to panicle emergence, PL – Peduncle length, PNL – Panicle length, PND – Panicle diameter, 1000GW – 1000-grain weight.

The first three principal component axes accounted for 98.89% of the total variation, out of which PCA 1 accounted for 74.41%. PCA analysis separated the accessions into four groups (Figure 1). The first quadrant (I) had eight mixtures of Nigerian and Indian pearl millet accessions 1. Cluster 2 consisted of eight mixtures of ICRISAT and NACGRAB accessions in quadrant II with accessions IP22271 and NGB00528 farther apart. In quadrant III, combination of IP3132 and IP3616 accessions formed cluster 3. IP22269, IP222868, NGB00523 and NGB0537 accessions were located in the fourth quadrant to form cluster 4. Interestingly, both Indian and Nigerian accessions clustered together. Though accessions in cluster 1 were more closely related, those of clusters 2–4 were more diffused, which implies they are distant relatives, possibly separated by geographical isolation. Meanwhile, Azeez (2010) is of the opinion that accessions in the same cluster are genetically similar or related. Cultivation of pearl millet in the arid and semi-arid regions, during breeding for new cultivars and lines, could increase the genetic differentiation under artificial selection conditions, and consequently increase the genetic distance as opined by Xie et al. (2009).

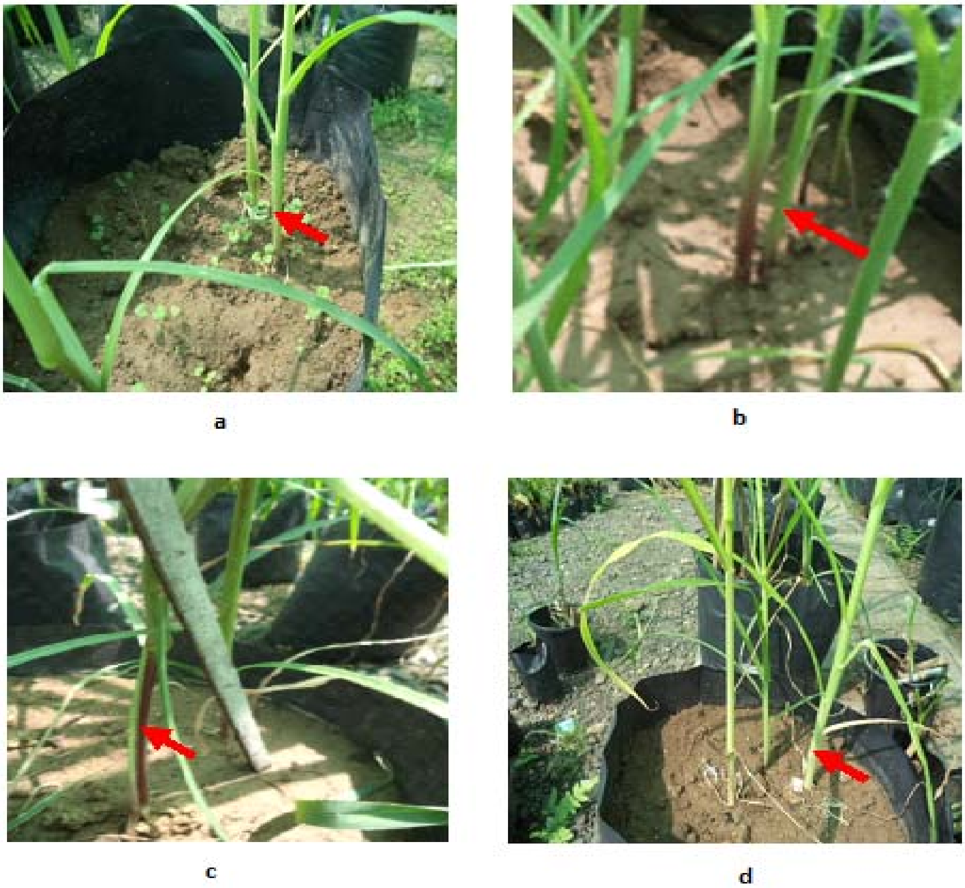

Figure 1. (a) green stem base colour of most pearl millet accessions at 4WAP; (b) purple stem colouration of NGB00616, JALGONE, NGB000551, IP22269 and NGB00523; (c) purple stem base colouration at maturity; (d) green stem base colouration of all other pearl millet accessions at maturity.

The genetic dissimilarity coefficients between the accessions varied and ranged from 0.05 to 0.95. The accessions were separated into two major groups I and II (Figure 2). The group I was sub-divided into two sub-groups (Ia and Ib), with subgroup Ia splitting into two clusters (Ia1 and Ia2). The cluster Ia1 consisted of eight pearl millet accessions. The three of the accessions: TAYABI, JALGONE and BALKUVE, which were unimproved and sourced from the farmers' field, clustered together, and were similar to IP12556, IP17862, NBG00551, NGB00476 and NGB00463. It has been demonstrated by the present study that morphologically similar accessions may be genetically different, and it is clear that most morpho-agronomic traits could be influenced by environmental factors. The spatial locations of the accessions in a cluster signified their genetic distance and closeness. JALGONE and BALKUVE were the most related with the closest genetic distance and the similarity index above 90% among the accessions. The other cluster Ia2 comprised of BAJARA 2, NGB00523, NGB00537, IP22269, IP22281 and IP222868 genotypes, similar at a genetic distance less than 5.0. These results are in agreement with the findings of Burson et al. (2015), who observed that accessions of pearl millet did not necessarily congregate into the same cluster based on their geographical origins. Contrarily, Swain and Dikshit (1997) observed that clustering pattern of accessions was such that genetic diversity might not be necessarily compatible with geographic diversity, as reflected in this study.

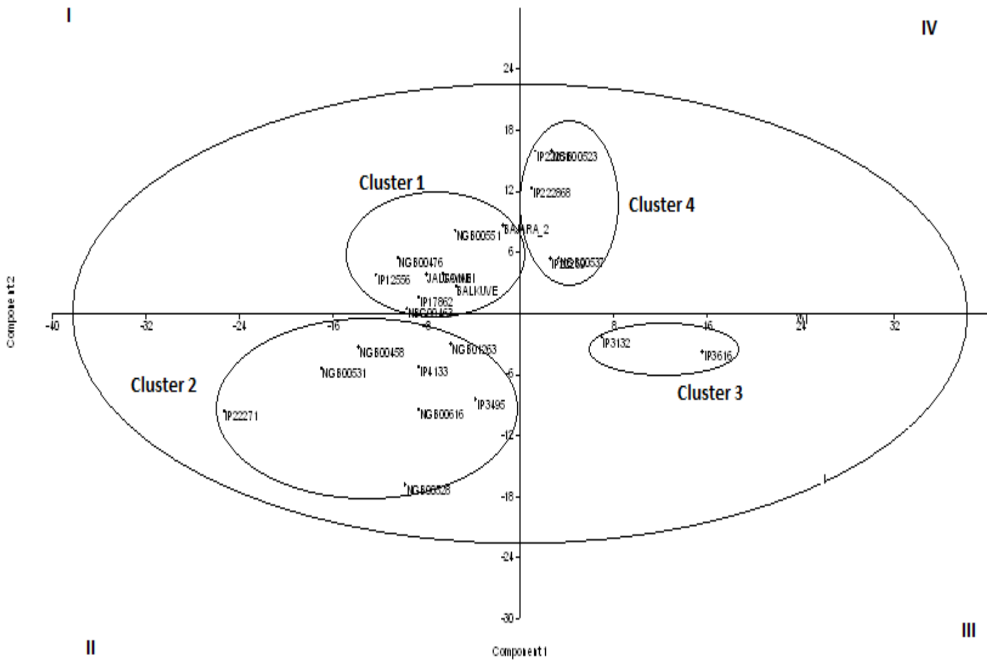

Figure 2. The ordination of twenty-four accessions of pearl millet on principal component axes PCA 1 versus PCA 2, based on cluster analysis of vegetative and reproductive traits.

The subgroup (Ib) separated into two distinct clusters Ib1 and Ib2 (Figure 2). Three closely related accessions (NGB00458, NGB00531 and IP22271) constituted the cluster Ib1, while cluster Ib2 was made up of five accessions of two closely related ICRISAT genotypes (IP3495 and IP4133) and the remaining three members were NACGRAB accessions (NGB00528, NGB01263 and NGB00616). The other major group (group II) included only two accessions: IP3132 and IP3616. Clustering of pearl millet accessions together regardless of their source supports the possibility of a common progenitor elucidated by Jauhar (1981). In contrast, the origin of collections has been identified to also influence the clustering pattern (Fasakin, 2002). Accessions may cluster based on geographical origin or genetic difference and further small clusters could be based on similar characteristics, pedigree relation or close area of cultivation within the main group (Ercan et al., 2002). Co-existence of farmers' field accessions with those from NACGRAB and ICRISAT was expected because these accessions could interbreed, thus limiting potential recombination between them, consequently reducing genetic diversity.

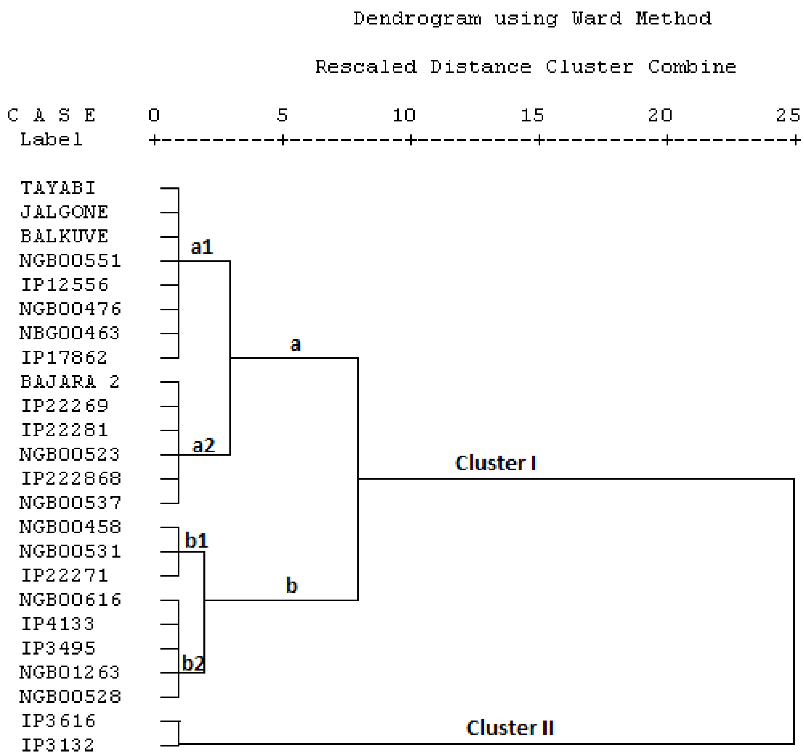

Figure 2. Dendrogram generated using minimum dissimilarity distance based on the UPGMA clustering method, showing genetic distance for vegetative and seed related traits among twenty-four accessions of pearl millet.

Conclusion

An accurate assessment of genetic diversity is important in crop breeding and improvement. Adequate genetic information would identify potential parental combinations to create segregating progenies with maximum genetic variability for further selection. The present study showed the existence of the large morphological diversity in the Nigerian and Indian accessions of pearl millet. Clustering of pearl millet accessions from Nigeria with the accessions from India has confirmed that they are genetically related, and possibly from the same progenitor, but could have been separated by geographical or ecological isolation mechanisms. To further understand a genetic relationship among the accessions, a combination of morphological and molecular characterizations is recommended. This would give more valid genetic variability information for a robust crop improvement programme.

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GENETIČKA DIVERGENTNOST GENOTIPOVA NIGERIJSKOG I INDIJSKOG BISERNOG PROSA ZASNOVANA NA AGRONOMSKIM I MORFOLOŠKIM OSOBINAMA

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R e z i m e

Ovim istraživanjem ocenjivana je genetička divergentnost genotipova bisernog prosa uzgajanih u Nigeriji i Indiji na osnovu morfo-agronomskih osobina kako bi se identifikovali genotipovi sa superiornim svojstvima koji bi se mogli iskoristiti u programima za oplemenjivanje. Dvadeset četiri genotipa bisernog prosa uzgajano je i evaluirano u pogledu agronomskih i morfoloških osobina tokom suve i vlažne sezone 2015–2016. godine. Podaci prikupljeni o genotipovima korišćenjem standardnih deskriptora statistički su analizirani. IP22281 je imao najvišu srednju visinu biljke (108,90 cm), dok je kod NGB00531 zabeležena najniža (61,02 cm). Značajna varijacija u okviru vrste postojala je kod broja listova po biljci, dužini lista, širini lista, broju nodija i dužini internodija, međutim, obim stabljike je bio sličan za ove genotipove. Bokorenje je generalno bilo slabo sa najvišom vrednošću (1,60 bokora po biljci) uočenom kod NGB00531. Značajna pozitivna korelacija javila se između visine biljke, broja listova, dužine lista i širine lista. Metlice su se pojavljivale između 44. i 56. dana i NGB00548 je imao najkraće vreme sazrevanja. Dužina metlice i prečnik cvetne drške varirali su značajno među genotipovima. Najveći prinos zrna i masa 1000 zrna zabeleženi su kod NGB00616, dok su najniži prinos i masa zabeleženi kod IP22269. Analizom glavnih komponenti genotipovi su grupisani u četiri klastera, obuhvatajući nigerijske i indijske genotipove. Pored toga, dendrogramom su genotipovi grupisani u dve glavne grupe, koje su dalje podeljene u manje klastere sa genotipovima iz Nigerije i Indije u istom klasteru. Istraživanjem se zaključuje da bi varijacije u morfo-agronomskim osobinama i osobinama prinosa među proučavanim genotipovima mogle biti iskorišćene za poboljšanje useva. Obrazac grupisanja ovih genotipova u klastere ukazao je na njihovu genetičku povezanost, moguće od istog pretka, ali i na odvojenost mehanizmima geografske ili ekološke izolacije.

Ključne reči: genetička divergentnost, prinos zrna i komponente prinosa, morfološka varijacija, biserno proso.

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