Available online at www.elixirpublishers.com (Elixir International Journal)

Bio Diversity

Elixir Bio Diver. 52 (2012) 11587-11592

ISSN: 2229-712X

Phenotypic and agromorphometric characterisation of fourteen accessions of moringa (*Moringa oleifera* Lam.)

H.M. Amoatey[1,2*], D.K.Asare[1,2], M. Owusu-Ansah[1], A.Tweneboah Asare[2] and N. Amaglo[3]

[1]Nuclear Agriculture Centre, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, Accra-Ghana.

[2]Department of Nuclear Agriculture and Radiation Processing, School of Nuclear and Allied Sciences, University of Ghana, Legon-Accra, Ghana.

[3]Department of Horticulture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi-Ghana.

ARTICLE INFO

Article history:
Received: 17 July 2012;
Received in revised form:
19 November 2012;
Accepted: 19 November 2012;

Keywords
Moringa oleifera Lam,
Morphological traits,
Characterisation,
Dendrogram,
Principal component analysis,
Diversity.

ABSTRACT

Fourteen accessions of *Moringa oleifera* Lam. made up of thirteen accessions collected from four geographical regions of Ghana and one from India were propagated and characterised using descriptors of International Plant Germplasm Resource Institute, IPGRI, with slight modifications. Analysis of variance showed significant differences in eighteen agro-morphological traits while similarity was observed in three qualitative morphological traits. General linear modelling analysis grouped the accessions into two distinct clusters based on phenology, vegetative, and pod morphological characteristics. Phenological and pod yield data were found to be reliable markers in distinguishing among the moringa accessions. The results of the characterisation showed the existence of an intra-specific diversity of the fourteen accessions of moringa studied. Cluster analysis based on morphological data revealed one major and one minor cluster with a genetic diversity (dissimilarity) range of 0.483 to 0.997. From principal component (PC) analysis, PC1 and PC2 contributed 55.50% and 23.27% respectively, with total variation of 79.27. However, each accession showed specificity to its regions of collection, and therefore implies these moringa accessions are not mixed up but could be considered as pure breeds.

Introduction

Sub-Saharan Africa (SSA) is endowned with a high diversity of approximately 1000 leafy vegetables, constituting as much as 20.0% of edible plant species (Maundu 1999). Cassava leaves are important in Congo, spider plant is popular in East and Southern Africa and *Moringa oleifera* Lam. and *Hibiscus sabdariffa* leaves are particularly important in Senegal. Other popular SSA vegetables are amaranth, pumpkin, *Crotalaria spp.* and Africa nightshades (Dechasa *et al*. 2006).

High heterozygosity has resulted in increased genotypes of *Moringa oleifera* Lam. existing in varied geographical areas within SSA (Maundu 1999). These increased genotypes serve as useful resources for crop improvement programmes (Acquaah 2007; Nickson and Horak 2006). The numerous genotypes exhibit diversity in morphology. This diversity is as a result of the human movements within and out of the sub-region, dispersal of dehiscent fruit-bearing seeds and selection by farmers. Thus, in West Africa, the likelihood is high that existing moringa accessions are not pure breeds but novel ones altogether, as a result of mix-up at the hands of local collectors, users and farmers and the explosive seed dispersal mechanism typical of the crop (Enoh-Arthur and Van Damme 2008). Therefore, there is the need to assemble and characterise germplasm of *Moringa oleifera* Lam. available locally. This study focused on the characterisation of thirteen (13) accessions of moringa collected from four geographical regions of Ghana and one imported from India.

The main objective was to determine variability among 14 accessions of *Moringa oleifera* Lam. through morphological characterisation. The specific objective was to: assess phenotypic, vegetative and morphological similarity among 13 local accessions of *Moringa oleifera* Lam. collected from four different regions of Ghana in comparism with one accession obtained from India.

Materials and Methods

Study Site

The study was conducted at the research farm of the Biotechnology and Nuclear Agriculture Research Institute (BNARI) of the Ghana Atomic Energy Commission (GAEC), Kwabenya, in the Greater Accra Region of Ghana. The BNARI Research Farm is located at latitude 05° 40' N and longitude 0° 13' W, and elevated at 76 m above sea level within the Coastal Savannah agro-ecological zone. Kwabenya has an annual average temperature of 28°C and receives an annual rainfall less than 1000 mm (Ghana Meteorogical Authority, 2005). The soil at the site is the Nyigbenya-Haatso series, which is a typically well-drained savannah ochrosol (Ferric Acrisol) derived from quartzite schist. The experiment was conducted from September, 2008 to August 2009.

Nursing and Field Planting

Ten accessions were collected in the form of seeds while four were collected as seedlings from four out of the ten regions of Ghana (Figure 1). Twenty seeds of each of these accessions collected as seeds were germinated without any form of

Tele: 0233 264 537 505, 0233 0269 547 856
E-mail addresses: punchmarty@yahoo.com,hmamoatey@yahoo.com

pre-treatment and nursed to seedling stage under greenhouse conditions. Eight weeks after seed germination, seedlings were exposed to full sunlight in the open space for a period of two week and subsequently transplanted to the field. Seedlings were planted on a plot of land measuring 35 m × 45 m. Ten (10) healthy and hardened seedlings of height 0.40 to 0.60 m for each of the moringa accessions were selected and transplanted onto the plot in single lines. Seedlings were planted at inter and intra row spacing of 3 m x 3 m.

The following agronomic practices were carried out after transplanting: (i) NPK 15:15:15 was applied as starter solution (at a rate of 2.0 g dissolved in 1.0 L water per plant) at the time of transplanting; (ii) daily watering was done during the first six weeks to facilitate seedling establishment and; (iii) the experimental plot was weeded six times, at approximately bi-monthly intervals to eliminate weed competition during the study period.

Figure 1. A map of Ghana showing collection sites of the accessions of moringa (Note: the accession, BNR14 was imported from India and it is not included in this map).

Data Collection and Statistical Analysis

Data Collection

Data collected on fifteen quantitative phenotypic and morphologic traits (Bioversity International, 2002), included: days to first flowering, number of days to 50% flowering, number of days to first fruiting, number of days to 50% fruiting, number of flowerings in a year, number of fruitings in a year, number of days to first maturity, mean stem girth at 12 months after transplanting, mean plant height at 12 months after transplanting, mean canopy radius at 50% flowering, mean number of pods per plant, mean pod length, mean number of seeds per pod, mean 100-seed weight and percent germination after harvesting. Also data were collected on the following six qualitative traits: pod appearance (straight or curled), colour of fresh pod (green or pale green), colour of dried pod (golden brown or brownish), colour of stem bark (grey or whitish), colour of flowers (white or creamy, with or without purple patches) and branching habit (horizontal branching or vertical branching).

Data collected from field evaluation were analyzed using ANOVA Multivariate statistical tools (SPSS, version 16.0.2, SPSS Inc., U.S.A; Nia and Hul (2008). Means which differed significantly were separated using the Tukey's pair-wise comparison. Passport data were presented using MS-Excel (2007 version).

Characterisation of Moringa Accessions

All the 14 moringa accessions were also scored based upon expression of phenotypic and morphological traits (using a scale of 1-5 where 1 = best and 5 = worst). The scores of the accessions were subjected to Genstat discovery analysis to generate a dendrogram and the percentage variation for the first two principal component analyses (PCA) and the result used to plot a bi-dimensional plot of the dispersal among accessions.

Results

General Status of Accessions Collected

A total of fourteen accessions of moringa were collected from the following locations: Ashanti Region (4), Eastern Region (1), Greater Accra Region (4), Upper East Region (4) and 1 sourced from India (Table 1).

Moringa collections from Ashanti, Greater Accra and Eastern Regions were introduced from other sources while collection from Upper East was indigenous to this region. Moringa accessions were collected as either seeds (71.0%) or seedlings (29.0%) (Table 1).

Vegetative Characteristics of 14 Accessions of Moringa

At 12 months after planting (MAP), mean plant height ranged between 4.7 m and 7.4 m while mean girth ranged between 5.2 cm and 9.7 cm (Table 2). For both parameters, the lowest values were recorded by BNR15 while BNR10 and BNR6 had the highest height and girth, respectively. Mean canopy radius ranged from 2.32 m to 3.96 m. There were significant differences ($P \leq 0.05$) among moringa accessions for mean plant height, girth and canopy radius (Table 2).

Reproductive Characteristics of 14 Accessions of Moringa

The overall mean number of days from transplanting to 50% flowering was 152.9 days, whilst overall mean number of days to 50% fruiting was 257.6. Variations in flowering and fruiting frequency among moringa accessions place them in three categories: (i) those that flowered and fruited twice within the year with two peaks, (ii) those that flowered twice within the year but with only one fruiting peak and (iii) those that flowered and fruited only once yearly.

There were significant differences among accessions for mean days to flowering and fruiting (Table 3).

Yield and Germination Characteristics of 14 Accessions of Moringa Propagated *In Vivo*

Yield parameters measured at plant maturity were mean number of pods per plant, mean pod length, mean number of seeds per pod and mean 100-seed weight. Generally, the mean number of pods per plant ranged from 6.2 ±1.3 for BNR2 to 56.4 ±3.9 for BNR8 (Table 4). Length of the pod varied from 25.6±0.9cm to 56.5±1.9 cm. The minimum number of seeds per pod was 10.7±0.7 while the maximum number was 21.3±0.9 for BNR5 and BNR6, respectively. The moringa accession BNR9 had the highest mean 100-seed weight (41.6±1.5 g) while BNR3 recorded the least mean 100-seed weight (23.1±0.6 g). Generally, all the moringa accessions, except BNR9 had germination percentage of 70% and above (Table 4).

Assessing the Unique Traits and Genetic Similarity of Accessions of *M. oleifera* Lam.

Morphological as well as phenological characters varied among the accessions of moringa (Figure 2; Figure 3a). On the basis of days to maturity, eleven (11) out of fourteen accessions may be described as early maturing while the rest (BNR2, BNR3 and BNR7) are late maturing. Moringa accessions BNR3,

BNR5, BNR7, BNR8 and BNR15 bore short pods of approximately lower than 35.0 cm. On the other hand, BNR2, BNR9, BNR10, BNR11, BNR12 and BNR13 had medium-sized pods (35.00-44.00 cm) with BNR4, BNR6 and BNR14 exhibiting long pods which were greater than 45.0 cm but less than 70.0 cm. In addition, moringa accessions BNR4 and BNR6 had a combination of short but thick pods and long but slender pods. Figure 2 shows the diversity in pod architecture and length for the moringa accessions.

Figure 2. Diverse architecture and length of dried pods of accessions of *M. oleifera* Lam. (BNR2- 15 are found from Left-Right)

The cluster analysis from the standardized morphological data revealed one major and one minor cluster of the 14 accessions of moringa studied at a similarity level of 0.52. Genetic similarity ranged from 55% to 99.7% (Figure 3a).

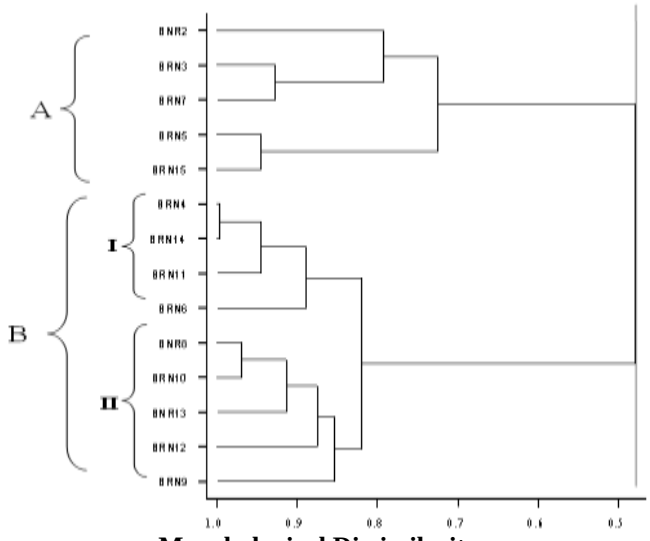

Figure 3a: Dendogram describing the Juccard Similarity matrix of standardized morphological traits of 14 moringa accessions

The minor cluster A comprised of five accessions (BNR2, BNR3, BNR5, BNR7 and BNR15) where as the major cluster B included nine accessions (BNR4, BNR6, BNR8, BNR9, BNR10, BNR11, BNR12, BNR13 and BNR14). Based on original source of collection, all the accessions from Volta Region (BNR3, BNR7 and BNR15) with the exception of BNR9 grouped together with BNR2 and BNR5 from USA and Wa respectively in cluster A while in cluster B all accessions from Bolgatanga (BNR10, BNR11, BNR12 and BNR13) and BNR8 from Wa paired up with BNR4 and BNR6, BNR9 and BNR14 from USA, South Volta and India respectively (Figure 3a).

However, on the basis of their collection site at the commencement of this study, cluster A consists of accessions BNR3, BNR5 and BNR7 from the Greater Accra Region, BNR2 (Ashanti Region) and BNR15 (Eastern Region) grouped together. In cluster B, BNR9 from Greater Accra Region, the remaining three accessions from Ashanti Region (BNR4, BNR6 and BNR8), all those from the Upper East Region (BNR10, BNR11, BNR13 and BNR14) clustered with BNR14 from India (Figure 3a).

The first and second principal components of the 14 moringa accessions under study yielded 55.50% and 23.77% of the total variation (79.27%) respectively. The PCA was similar to the cluster analysis (Figure 3b). In addition, the results was comparable to cluster analysis in Figure 3a

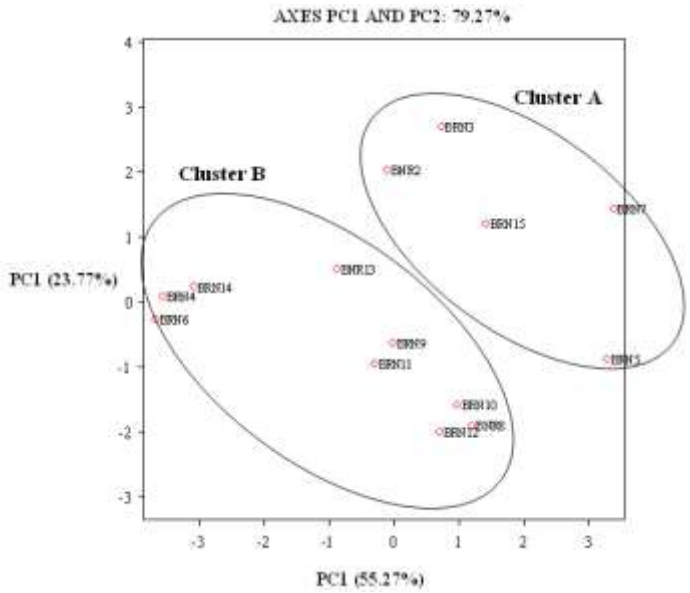

Figure 3b: A two dimensional plot of Principal Components Analysis of the 14 moringa accessions based on variance-covariance matrix using genstat discovery 4th edition.

Discussion

Phenotypic, Phylogenic and Morphological Diversity among Accessions of *M. oleifera* Lam.

The 14 accessions of *M. oleifera* Lam. exhibited variation with respect to 18 agro-morphological characteristics such as: days to first flowering, days to first fruiting, days to 50% flowering, days to 50% fruiting, frequency of flowering in 12 MAP, frequency of fruiting in 12 MAP, height (at 12 MAP), girth (at 12 MAP), canopy radius at 50% flowering, number of days to pod maturity, nature of pods, number of pods per plant, pod length, number of seeds per pod, 100–seed weight, colour of flowers, branching habit and percentage germinability. These agro-morphological characteristics could be employed as markers in germplasm characterisation and management (Acquaah 2007) as well as provide basic information on genetic relatedness of the accessions. Such information is helpful in the choice of desirable accessions for breeding work and in avoiding duplications during conservation (Gitonga *et al.* 2008).

Variability in morphological characteristics such as number of days to maturity and frequency of flowering in a year, constitute useful information to the breeder in scheduling planting towards synchronised flowering to facilitate hybridization among accessions. Generally, considerable variability in flowering characteristics among accessions of *Moringa spp.* had been observed **(**Resmi *et al*. 2005; Matthew and Rajamony 2004).

Diversity in plant architecture, growth and branching habits as well as yield and yield characteristics observed in this study are desirable. That is, diversity provides the breeder with genetic material for selection and improvement of the plant (Brothers and Kelly 1993; Acquaah *et al.* 1992). For instance, selection for high yield among these accessions could focus on either BNR8 or BNR6 towards progressive increase in yield over time. Indeed, it is known that this selection tool is already common among moringa farmers in the Sarando village in Niger (Sauveur and Hartout, 2001).

The characteristics influencing superior ecotypes are wide and dark leaves, long and tender pods, bushy growth habits, and rapid regeneration after trimming (Amaglo 2006) as well as short juvenile (pre-fruiting phase) in the view of Rajangam *et. al.* (2001). Based on agro-morphological traits, BNR6, BNR4 and BNR14 stand out as superior genotypes among the 14 accessions of moringa evaluated.

Cluster analysis from the standardized morphological data revealed one major and one minor group. A high genetic similarity range of 0.483 to 0.997 was observed among all the 14 accessions studied. This indicates that the accessions used in the study are genetically diverse and these accessions could have diverse ancestry (Fikiru, 2010). Also, the high genetic distance could imply either little or no gene flow across the various collection sources and explain why the accessions clustered specific to their source of collection. Generally, most accessions clustered according to the regions (site) of collection. However, one would have expected BNR14 which was obtained from India to be an entity, yet it was included in the major cluster B. This might be explained to be as a result of BNR14 sharing a distantly related parent with the 13 other accessions from Ghana. Also, BNR14 and BNR4 were highly similar at GS of 0.997 suggests that both accessions are duplicates. Similarly, BNR8 and BNR10 which exhibited a similarity index of 0.970 may also be considered as duplicates (Chiorato et al., 2006). Although there were these occurrences, the remaining moringa accessions grouped to their sources of collection and therefore, could imply no mix up of these moringa accessions at all.

Principal components analysis (PCA) confirmed the results of the cluster analysis showing a high genetic relationship among the accessions. High genetic diversity implies that some of the accessions with superior characteristics may be chosen as parents in future breeding programmes (Gitonga *et al.* 2008; Varalakshmi, 2007).

Use of molecular method which combines data from DNA sequences and agro-morphological traits for evaluation would conclusively determine the extent of diversity and similarity among the accessions of moringa studied (Gul *et al.* 2002; Olson 2002).

Table 1. Summary of Passport data of the fourteen accessions of *M. oleifera* Lam

Acc. Code	Form of Acc.	Age of Donor Plant (Yrs)	Original Source	Accession Owner
BNR 2	Seeds	8	USA	Department of Horticulture, KNUST, AR
BNR 3	Seedlings	10	South Volta (VR), Ghana	Agric. Science Research Farm, UG, GAR
BNR 4	Seedlings	6	USA	Department of Horticulture, KNUST, AR
BNR 5	Seeds	6	Wa (UER), Ghana	Mr Arhin, ADRA-Ghana, GAR
BNR 6	Seeds	6	USA	Department of Horticulture, KNUST, AR
BNR 7	Seedlings	4	South Volta (VR), Ghana	Arday, GAR
BNR 8	Seeds	8	Wa (UWR), Ghana	Karikari, Abuakwa, AR
BNR 9	Seeds	20	South Volta (VR),Ghana	Gbecko-Kove, Nungua, GAR
BNR10	Seeds	10	Bolgatanga (UER), Ghana	Tsema Kumasi, UER
BNR 11	Seeds	10	Bolgatanga (UER), Ghana	Tsema Kumasi, UER
BNR 12	Seeds	7	Bolgatanga (UER), Ghana	Tsema Kumasi, UER
BNR 13	Seeds	10	Bolgatanga UER), Ghana	Anson, UER
BNR 14	Seeds	9	India	Pascal / Amaglo, India
BNR 15	Seedlings	4	North Volta (VR), Ghana	CSRPM, Mampong-Ahuapem, ER

Note: AR = Ashanti Region; ER = Eastern Region; GAR =Greater Accra Region; UER = Upper East Region; UEW = Upper West Region; VR =Volta Region; CSRPM = Centre for Scientific Research into Plant Medicine; KNUST = Kwame Nkrumah University of Science and Technology; UG = University of Ghana; USA= United States of America and; Acc. = Accession

Table 2. Mean and standard error of the vegetative morphological traits of the 14 accessions of *M. oleifera* Lam

Mean Vegetative Features at 1 2 MAP			
Accession Code	Height±SE (m)	Girth±SE (cm)	Canopy radius at 50% flowering±SE (m)
BNR2	7.20 ± 0.11^{cde}	7.07 ± 0.003^{bc}	2.64 ± 0.18^{ab}
BNR3	6.32 ± 0.11^{b}	6.49 ± 0.010^{b}	2.34 ± 0.09^{a}
BNR4	6.58 ± 0.07^{bcd}	9.67 ± 0.01^{c}	3.78 ± 0.29^{cd}
BNR5	6.38 ± 0.07^{b}	6.56±0.00ab	2.83 ± 0.24^{ab}
BNR6	6.74 ± 0.19^{bcde}	$\underline{9.68\pm0.00}^{c}$	$\underline{3.96\pm0.08}^{d}$
BNR7	6.52 ± 0.18^{bc}	9.29 ± 0.01^{bc}	2.32 ± 0.08^{a}
BNR8	7.00 ± 0.10^{bcde}	9.55 ± 0.01^{c}	3.30 ± 0.17^{bcd}
BNR9	7.27 ± 0.16^{de}	9.55 ± 0.00^{c}	3.00 ± 0.11^{abc}
BNR10	$\underline{7.37\pm0.33}^{e}$	8.44 ± 0.01^{bc}	3.13 ± 0.29^{abcd}
BNR11	6.88 ± 0.11^{bcde}	8.21 ± 0.01^{bc}	3.72 ± 0.22^{cd}
BNR12	674 ± 0.09^{bcde}	7.83 ± 0.00^{abc}	3.85 ± 0.13^{cd}
BNR13	6.54 ± 0.12^{bc}	7.45 ± 0.01^{abc}	3.34 ± 0.14^{bcd}
BNR14	6.82 ± 0.17^{bcde}	9.16 ± 0.01^{bc}	3.92 ± 0.16^{d}
BNR15	4.74 ± 0.14^{a}	5.22 ± 0.00^{a}	2.65 ± 0.17^{ab}

Note: Means with different letters in a column are significantly different ($P \leq 0.05$) according to the Tukey's test. MAP = months after planting and SE = standard error of the mean. Highest values are bolded and underlined.

Table 3. Mean and standard error of the reproductive phenologic traits of the 14 accessions of *M. oleifera* Lam.

Accession Code	Days to first flowering ±SE	Days to 50% flowering	Days to first fruiting±SE	Days to 50% fruiting	Flowering / Fruiting Frequency	
					Flowering	Fruiting
BNR2	187.2±2.3^{c}	192	359.0±1.4^{b}	360	2 x / year	1 x / year
BNR3	349.2±3.7^{d}	355	448.0±5.4^{bd}	447	1 x / year	1 x / year
BNR4	84.8±1.4^{ab}	89	203.0±2.2a	208	2 x / year	2 x / year
BNR5	159.0±1.9^{c}	163	239.0±3.7^{a}	235	2 x / year	2 x / year
BNR6	87.4±1.4^{ab}	92	212.0±3.4^{a}	222	2 x / year	2 x / year
BNR7	343.2±3.5^{d}	351	499.0±6.0^{cd}	511	1 x / year	1 x / year
BNR8	79.0±0.9^{a}	81	201.0±3.1^{a}	204	2 x / year	2 x / year
BNR9	84.8±34.7^{ab}	147	157.0±64.0^{a}	251	2 x / year	2 x / year
BNR10	77.8±10.6^{a}	104	183.0±45.9^{a}	236	2 x / year	2 x / year
BNR11	96.2±2.1^{ab}	101	172.0±4.5^{a}	178	2 x / year	2 x / year
BNR12	103.2±2.3^{ab}	109	182.0±5.1^{a}	193	2 x / year	2 x / year
BNR13	94.2±2.1^{ab}	100	172.0±4.7^{a}	184	2 x / year	2 x / year
BNR14	138.2±3.6^{bc}	148	205.0± 6.4^{a}	201	2 x / year	2 x / year
BNR15	94.4±1.9^{ab}	100	166.0±4.5^{a}	176	2 x / year	2 x / year
Mean	141.3±11.1	152.3	242.7±10.7	257.6	–	–

Note: Means with different letters are significantly different ($P \leq 0.05$) according to the Tukey's test.

Table 4. Mean and standard error of pod morphological traits and percent germinability of the 14 accessions of *M. oleifera* Lam.

	Yield Characteristics				
Acc. Code	No. of Pods Plant^{-1}±SE	Pod Length±SE(cm)	No. of Seeds Pod^{-1}±SE	100-Seed Weight±SE (g)	Germinability (%)
BNR 2	6.2 ±1.3^{a}	38.7±1.6^{c}	15.2±1.5^{abcd}	28.1±0.1^{bc}	70.0
BNR 3	23.2 ±10.3^{ab}	30.3±0.3^{ab}	15.5±0.4^{bcd}	23.1±0.5^{a}	70.0
BNR 4	13.0 ±0.7^{a}	52.9±1.2^{de}	18.2±2.1^{cde}	32.8±0.2^{efg}	70.0
BNR 5	14.8 ±3.9^{a}	32.7±0.8^{bc}	10.7±0.7^{a}	32.9±0.3^{fg}	80.0
BNR 6	43.2 ±13.3^{bc}	56.5±1.9^{e}	21.3±0.9^{e}	32.4±0.2^{def}	100.0
BNR 7	12.4 ±3.4^{a}	25.6±0.9^{a}	12.2±0.8^{ab}	24.4±0.4^{a}	100.0
BNR 8	56.4 ±3.9^{c}	30.3±0.8^{ab}	11.0±0.9^{ab}	31.8±0.4^{def}	70.0
BNR 9	9.00 ±3.7^{a}	38.1±0.8^{c}	14.4±0.8^{abc}	41.6±1.5^{h}	40.0
BNR 10	25.40 ±6.5^{ab}	37.5±1.0^{c}	12.0±0.3^{ab}	33.4±0.4^{fg}	80.0
BNR 11	12.80 ±3.8^{a}	37.3±1.4^{c}	13.7±0.8^{abc}	35.1±0.6^{g}	60.0
BNR 12	20.00 ±3.9^{ab}	36.5±0.2^{bc}	11.0±0.2^{ab}	30.8±0.2^{cdef}	80.0
BNR 13	18.40 ±3.5^{ab}	37.4±1.0^{c}	17.2±1.1^{cde}	27.4±0.5^{b}	70.0
BNR 14	7.00 ±1.5^{ab}	48.5±3.1^{d}	19.2±1.1^{de}	30.1±0.2^{bcd}	70.0
BNR 15	10.400 ±3.2^{a}	33.3±1.3^{bc}	13.7±0.8^{abc}	30.2±0.3^{cde}	70.0

Note: Means with different letters in a column are significantly different ($P \leq 0.05$) according to Tukey's test.

Table 5. Scoring for dendrogram analysis (Supplementary Material)

Parameter	*Moringa oleifera* Accessions Scoring													
	BNR2	BNR3	BNR4	BNR5	BNR6	BNR7	BNR8	BNR9	BNR10	BNR11	BNR12	BNR13	BNR14	BNR15
Vegetative Traits														
Height	1	2	1	2	1	2	1	1	1	1	1	2	1	3
Girth	2	2	1	2	1	1	1	1	1	1	1	2	1	3
Canopy radius	3	3	1	3	1	3	2	2	2	1	1	2	1	3
Branching habit	3	3	1	2	1	3	1	2	2	2	2	2	1	2
Bark colour	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Phylogenic Traits														
50% Flowering age	2	3	1	2	1	3	1	1	1	1	1	1	1	2
50% Fruiting age	2	2	1	1	1	3	1	1	1	1	1	1	1	1
Germination Success	1	1	1	1	1	1	1	2	1	1	1	1	1	1
Flowering pattern	1	2	1	1	1	2	1	1	1	1	1	1	1	1
Fruiting pattern	2	2	1	1	1	2	1	1	1	1	1	1	1	1
Flowers colour	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Pod Morphologic Traits														
Number of pods plant^{-1}	3	2	3	3	1	3	1	3	2	3	2	2	3	3
Pod length	3	4	1	4	1	5	4	3	3	3	3	3	2	4
Number of seeds pod^{-1}	2	2	1	5	1	4	4	3	4	3	4	2	1	3
100-seed weight	2	2	1	5	1	4	4	3	4	3	4	2	1	3
Fresh pod colour	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dried pod colour	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Pod architecture	1	1	1	1	1	1	1	1	1	1	2	1	1	1

Conclusions

Characterisation as a decision making tool in plant germplasm usage and management seeks to provide some basic information to users. Agro-morphological traits predominantly were the factors considered in this study for future breeding programme. All the 14 accessions of *Moringa oleifera* Lam. studied showed similarity in three qualitative morphological traits (colour of stem bark, colour of fresh and dried pods); while they exhibited variability with respect to 18 agro-morphological traits. The morphological characterisation has provided preliminary information for future research, which would employ biochemical and molecular tools in order to verify the above results.

Acknowledgement

The Biotechnology and Nuclear Agriculture Research Institute, of the Ghana Atomic Energy Commission is gratefully acknowledged for granting access to research facilities used for this study. Provision of accessions by owners for the study is also highly appreciated.

References

Acquaah, G. (2007). Principles of plant genetics and breeding. 1st Ed. Blackwell, Malden, USA, pp. 199

Acquaah, G., Adams, M. W. and Kelly, J. D. (1992). A factor analysis of plant variables associated with architecture and seed size in dry bean. Euphytica. 60: 171-177

Amaglo, N. (2006). How to produce moringa leaves efficiently? Moringa et autres végétaux à fort potentiel nutritionnel: Stratégies, normes et marchés pour un meilleur impact sur la nutrition en Afrique. Accra, Ghana, 16-18 novembre 2006. In: http://www.moringanews.org/doc/GB/Groups/Group_2_Newton-text-GB.pdf. Accessed 2nd Sep., 2008

Brothers, M. E. and Kelly, J. D. (1993). Interrelationship of plant architecture and yield components in the pinto bean ideotype. *Crop Science* 33: 1234-1238

Dechasa, J., Sonder, K., Alemayehu, L., Mekonen, Y. And Agena, N. (2006.) Leaf yield and nutritive value of *Moringa stenopetala* and *Moringa oleifera* accessions: Its potential role in food security in constrained dry farming agroforestry system. Moringa and other highly nutritious plant resources: strategies, standards and markets for a better impact on nutrition in Africa. Accra, Ghana. Workshop paper presentation. http://www.moringanews.org/doc/GB/Papers/Dechasa_Jiru_Text_GB.pdf. Accessed 27th March 2009

Enoh-Arthur, S., Van Damme, P. (2008). Household analysis on local knowledge, domestication and use of *Moringa oleifera* in the Volta region of Ghana. In: http://www.underutilized-species.org/documents/EVENTS/5_int_Symposium_new_crops_anduses_%20sept_07/proceedings Accessed 20th November, 2008

Ghana Metrological Authority Database. (2005). Ghana Metrological Authority, Accra-Ghana.

Gitonga, L., Kahangi, E., Muigai, A., Ngamau, K., Gichuki, S., Cheluget, W. and Wepukhulu, S. (2008). Assessment of phenotypic diversity of macadamia (*Macadamia* spp) germplasm in Kenya using leaf and fruit morphology. African Journal of Plant Science 2 (9): 86–93

Gul, S. S. K., Haq, M. A., Ashraf, M., Khan, A. J. and Zamir, R. (2002). Genetic architecture of secondary yield components in mungbean (*Vigna radiata* L. Wilczek). Breed. Sci 52: 235-241

Jahn, S. A. A. (1996). On the introduction of a tropical multipurpose tree to China traditional and potential utilisation of *Moringa oleifera* Lamarck. Senckenbergiana Biologica 75 (1 - 2): 243-254

Mathew, S. K. and Rajamony, L. (2004). Flowering biology and palynology in drumstick (*Moringa oleifera* Lam.). The Planter 80: 357-368

Maundu, P., (1999). Promoting underutilised food plants in sub-Saharan Africa; Experiences with African leafy vegetables. Research findings sponsored by Directorate General for International Cooperation of the Netherlands and IDRC, Pp. 1-34

Muluvi, G. M., Sprent, J. I., Soranzo, N., Provan, J., Odee, D., Folkard, G., McNicol, J. W. and Powell, W. (1999). Amplified fragment length polymorphism (AFLP) analysis of genetic variation in *Moringa oleifera* Lam. Molecular Ecology 8: 463-470

Nia, N. H. and Hull, H. (2008). Statistics package for Social Scientists, SPSS, version 16.0.2. SPSS Inc. (IBM Co.), Chicago Illinois, USA

Nickson, T. E. and Horak, M. J. (2006). Assessing familiarity: the role of plant characterisation. Paper presented at the ninth international symposium on biotechnologically-modified organisms.http://www.gmo.safety.eu/pdf/biosafenet/Nickson.pdf Accessed 12th July, 2008

Olson, M. E. (2002). Combining data from DNA sequences and morphology for a phylogeny of Moringaceae (Brassicales). Systematic Bot. 27: 55-73

Palada, M. C., Chang, L. C., Yang, R. Y. and Engle, L. M. (2002). Introduction and varietal screening of drumstick tree (*Moringa spp*.) for horticultural traits and adaptation in Taiwan. ACTA Horticulturae (752): 249-253

Rajamony, L. G., Anitha, K. C. N. and Radhakrishnan, T. C. (1994). Assessment of banana (*Musa paradisiaca*) clones of AAB group based on stability and adaptation. Indian J. agric. Sci., 64: 521-526

Rajangam, J., Azahakia, M. R. S., Thangaraj, T., Vijayakumar, A. and Muthukrishan, N. (2001). Status of production and utilisation of moringa in Southern India. Workshop on development potential for moringa products. Held at Dar es Salaam, Tanzania, 29th October-2nd Nov. 2001

Resmi, D. S., Celine, V. A. and Rajamony, L. (2005). Variability among drumstick (*Moringa oleifera* Lam.) accessions from central and southern Kerala. Journal of Tropical Agriculture 43 (1-2): 83-85

Sauveur, A. S. and Hartout, G. (2001). Moringa Culture and Economy in Niger. In: "The Miracle Tree - The Multiple Attributes of Moringa." LJ, Fuglie (Ed.), CTA pub. Wagenimgen. The Netherlands. Pp 37

Varalakshmi, B. D. (2007). Genetic diversity in drumstick (*Moringa oleifera* Lam.) germplasm. ACTA Horticulturae 752: 411-412.