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Genetic divergence studies in drumstick (*Moringa oleifera* Lam.)

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Abstract

Twenty-five drumstick accessions were evaluated for morphological, qualitative and quantitative characters. Considerable variation was observed among the accessions. Two peaks of flowering *viz.,* January-March and September-November, were observed in accessions VKMo 2, VKMo 7, VKMo 12, VKMo 15, VKMo 16 and VKMo 17. Three accessions *viz*., VKMo 32, VKMo 35 and VKMo 38 were categorized as leafy types. Tree shape varied from upright to spreading. Accession VKMo 3 recorded greatest tree height (7.68 m) and trunk girth (65.8 cm). Accession VKMo 10 recorded highest fruit length (89.50 cm), fruit girth (6.72 cm) and number of ridges/fruit (10.50). Highest fruit weight was recorded in VKMo 9 (160.00 g). Accession VKMo 6 recorded highest number of seeds per fruit (21.20). Highest number of fruits/tree was recorded in VKMo 2 (22.21) and total fruit yield/tree in VKMo 3 (1775.54 g/tree). Principal component analysis for the quantitative characters revealed that first three principal components accounted for 88.1 per cent of the total variation which was contributed by number of seeds per fruit, fruit girth, trunk girth and tree height. Clustering of the accessions resulted in formation of five clusters in which VKMo 3 collected from Vellanikkara recorded highest mean values for almost all quantitative characters.

Key words: Drumstick, Genetic divergence, Principal component analysis, Quantitative characters.

Introduction

Drumstick (*Moringa oleifera* Lam.), belonging to the mongeneric family Moringaceae, is a multipurpose tree vegetable cultivated widely for edible as well as medicinal purposes. Drumstick, commonly known as 'horseradish tree', 'miracle tree' or 'tree of life', is native to the sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan (Paliwal et al., 2011). Drumstick tree is economically useful as a vegetable, natural medicine, animal fodder, natural coagulant for water purification, fertilizer, living fence, and as a bio-fuel (Fahey, 2005). Leaves, pods and seeds are suggested as a viable supplement of digestible proteins, vitamin C, vitamin A, minerals like calcium, iron, magnesium, potassium, manganese, phosphorus, zinc and antioxidant compounds such as flavonoids, phenols, carotenoids, and vitamin E (Sultana et al., 2009).

Drumstick seed oil contains around 76 per cent of Poly Unsaturated Fatty Acids (PUFA) such as linoleic acid, linolenic acid and oleic acid that has the ability to control cholesterol. In fact, drumstick is said to provide nine times more protein than yoghurt, seven times more vitamin C than oranges, 10 times more vitamin A than carrots, 17 times more calcium than milk, 25 times more iron than spinach and 15 times more potassium than bananas (Rockwood et al., 2013).

Multiple biological properties of drumstick were attributed to the presence of functional bioactive compounds such as phenols, flavonoids, alkaloids, phyto-sterols, natural sugars, vitamins, minerals, and organic acids. Different plant parts have been used to treat inflammations, cardiovascular problems, carcinogenic problems, gastrointestinal illnesses, nervous disorders, infectious diseases etc. They also contain active components like

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glucomoringin which is responsible for inducing apoptosis and anti-cancerous activities (Maldini et al., 2014).

Even though drumstick is cultivated in countries like Philippines, Nigeria and Kenya, the crop cultivated in India is superior in quality and quantity. India contributes to about 80 per cent of world drumstick production. The total area is estimated as 43,600 ha with a production of 22,000 tons per annum (APEDA, 2018). The crop is commercially cultivated in Tamil Nadu, Andhra Pradesh, Karnataka, and Odisha and in Kerala, drumstick cultivation is limited to home gardens to meet the family requirement. Fruits, leaves and dried products are mainly exported to China, USA, Canada and South Korea.

Since drumstick is a cross-pollinated tree and also naturalized in many areas, high heterogeneity with respect to form and yield is reported. Large variability exists in drumstick with respect to flowering time (from annual type to perennial type), tree nature (from deciduous to evergreen), tree shape (from semi spreading to upright), resistance to hairy caterpillar, flowering time (i.e., some trees flower throughout the year while others flower in two distinct seasons) (Ramachandran et al., 1980). Mgendi et al. (2011) used morphological markers to assess variations between and within cultivated and non-cultivated species of drumstick and variations were observed with respect to bark colour such as white, grey or pale buff, along with textural differences like corky, rugose or smooth texture. Selvakumari (2013) carried out an investigation on 34 genotypes of drumstick to study the extent of genetic variability and relationship among different morphological parameters and reported variability in plant height (3.16 to 8.09 m) and trunk girth (74.08 to 250.40 cm). Kumar et al. (2014) reported variation with respect to leaflet shape viz., oblong and elliptical shapes. Sindhu (2002) studied floral biology, anthesis and fruit development in drumstick under Kerala conditions using sixty bearing plants and reported that flowering occurs throughout the year except in the months of November and December with two flowering peaks viz., July - August and February - March. Raja et al. (2013) recorded fruit length of drumstick in the range of 32.5 cm to 123.1 cm. Popoola et al. (2016) reported variability in fresh pod color (pale green and green), mature pod colour (brown and golden brown) and fruit shape (straight and curved). Number of pods per peduncle/panicle ranged from 2-6, and number of pods per plant ranged from 10 to 62. Pod characters like pod length (25.45 cm to 43.87 cm) and pod weight (59.37 g to 91.34 g) also exhibited wide range of variation. Resmi et al. (2006) evaluated 28 drumstick accessions from central and southern Kerala and recorded variability in number of fruits per plant (174 to 612) and total fruit yield (8.94 to 70.46 kg per tree).

Collection, evaluation and characterization of drumstick germplasm are the pre-requisites for identifying the existing variability. The genetic variability pattern has to be studied for successful breeding and improvement of crop. Thus, the present study aimed to characterize and evaluate 25 drumstick accessions collected from Kerala and Tamil Nadu with respect to yield, and identify the superior accessions.

Material and methods

Twenty-five drumstick accessions collected from farmers' fields and planted in AICVIP experimental field of Department of Vegetable Science, College of Agriculture, Vellanikkara, which were in 5th year of planting were used as the experimental material for the study (Table 1). The stem cuttings of 25 accessions were planted in Randomized Block Design (RBD) with three replications. Monthly observations were taken for a period of one year from January to December (2018). Drumstick accessions were catalogued at appropriate growth stages as per drumstick minimal descriptors (Santhoshkumar et al., 2013).

Both qualitative and quantitative characters of

Table 1. Source of drumstick accessions

Sl. No.	Accession No.	Place of collection	Tree type
1	VKMo 2	Vellanikkara	Perennial
2	VKMo 3	Vellanikkara	Perennial
3	VKMo 5	Vellanikkara	Perennial
4	VKMo 6	Vellanikkara	Perennial
5	VKMo 7	Vellanikkara	Perennial
6	VKMo 8	Nenmara	Perennial
7	VKMo 9	Vellanikkara	Perennial
8	VKMo 10	Vellanikkara	Perennial
9	VKMo 11	Elanad	Perennial
10	VKMo 12	Elanad	Perennial
11	VKMo 13	Thrissur	Perennial
12	VKMo 15	Vellanikkara	Perennial
13	VKMo 16	Elanad	Perennial
14	VKMo 17	Elanad	Perennial
15	VKMo 19	Elanad	Perennial
16	VKMo 20	Vellanikkara	Perennial
17	VKMo 21	Elanad	Perennial
18	VKMo 22	Elanad	Perennial
19	VKMo 29	Periyakulam	Annual
20	VKMo 30	Periyakulam	Annual
21	VKMo 32	Vellanikkara	Perennial
22	VKMo 35	Vellanikkara	Perennial
23	VKMo 36	Vellanikkara	Perennial
24	VKMo 37	Vellanikkara	Perennial
25	VKMo 38	Vellanikkara	Perennial

accessions were recorded. Qualitative characters recorded included tree shape, bark colour, young shoot colour, foliage density, leaflet shape, leaflet apex, nature of flowering branchlets, shape of calyx, nature of calyx, colour of calyx, shape of corolla, nature of corolla, colour of corolla, pulp colour and taste of pulp. Quantitative characters recorded included tree height, trunk girth, fruit length, fruit girth, fruit weight, number of ridges per fruit, number of seeds per fruit, number of fruits per tree and fruit yield per tree.

The data pertaining to the quantitative characters were analyzed using statistical tools such as path coefficient analysis to understand the correlation between yield and yield contributing characters in drumstick. Data from drumstick accessions were analyzed using principal component analysis with the software Minitab 17.1, to elucidate the diversity among the genotypes. Based on first two principal components, association among various quantitative characters were done. Clustering based on quantitative characters was carried out and accessions with similar performance were grouped and studied.

Results and discussion

Observations recorded on morphological qualitative characters are enumerated in Table 2. Tree shape varied from upright to spreading among the twenty-five accessions and majority of accessions had spreading tree shape. Grey coloured barks were observed in majority of accessions except for VKMo 3, VKMo 4 and VKMo 8, which had white bark. Leaflet shape varied from ovate to elliptical and majority of accessions had ovate leaflet shape. Leaflet apex varied from obtuse to acute and majority of accessions had obtuse leaflet apex. Leafy tree types generally showed ovate leaflet and acute leaflet apex. Both secondary and tertiary flowering branchlets were observed among flowering accessions and majority of accessions had secondary flowering branchlets. Foliage density in flowering period varied from sparse to medium to dense and majority of accessions had medium foliage density. There was no variability with respect to flower characters. All the accessions produced flowers with triangular shape, were polysepalous, and with pale green coloured calyx; corolla had triangular shape, were polypetalous and cream in colour. Variability in flower morphology determines the mating system in plant population and also attracts the pollinating agents such as bees and ants.

The fruit colour was pale green in all the 22 accessions that flowered. All the accessions produced pale green coloured young shoots with purple tinge. Fresh fruit pulp colour was white in all the accessions. Fresh fruit pulp taste was palatable in all the accessions except in VKMo 3, VKMo 6, VKMo 11, VKMo13 and VKMo 29, which had bitter taste.

Flowering behavior of all drumstick accessions was studied for one calendar year from January 2018 to December 2018 (Table 3). Flowering in drumstick

Table 2. Morphological characters of drumstick accessions

Accession	Tree shape	Bark colour	Young shoot colour	Foliage density	Leaflet shape	Leaf apex	Leafy/ Flowering type	Nature of flowering branchlets
VKMo 2	Upright	Grey	Pale green	Sparse	Ovate	Obtuse	Flowering	Tertiary
VKMo 3	Spreading	White	Pale green	Medium	Ovate	Obtuse	Flowering	Tertiary
VKMo 5	Spreading	White	Pale green	Dense	Ovate	Obtuse	Flowering	Secondary
VKMo 6	Upright	Grey	Pale green	Medium	Ovate	Obtuse	Flowering	Secondary
VKMo 7	Spreading	Grey	Pale green	Medium	Ovate	Acute	Flowering	Tertiary
VKMo 8	Spreading	White	Pale green	Medium	Ovate	Obtuse	Flowering	Tertiary
VKMo 9	Spreading	Grey	Pale green	Dense	Elliptical	Acute	Flowering	Secondary
VKMo 10	Spreading	Grey	Pale green	Medium	Ovate	Obtuse	Flowering	Secondary
VKMo 11	Spreading	Grey	Pale green	Dense	Ovate	Obtuse	Flowering	Secondary
VKMo 12	Spreading	Grey	Pale green	Dense	Elliptical	Obtuse	Flowering	Secondary
VKMo 13	Upright	Grey	Pale green	Sparse	Ovate	Obtuse	Flowering	Tertiary
VKMo 15	Spreading	Grey	Pale green	Dense	Ovate	Obtuse	Flowering	Tertiary
VKMo 16	Upright	Grey	Pale green	Medium	Ovate	Obtuse	Flowering	Tertiary
VKMo 17	Spreading	Grey	Pale green	Dense	Elliptical	Obtuse	Flowering	Secondary
VKMo 19	Spreading	Grey	Pale green	Medium	Ovate	Obtuse	Flowering	Secondary
VKMo 20	Spreading	Grey	Pale green	Dense	Ovate	Obtuse	Flowering	Tertiary
VKMo 21	Spreading	Grey	Pale green	Dense	Oblong	Obtuse	Flowering	Secondary
VKMo 22	Upright	Grey	Pale green	Medium	Ovate	Obtuse	Flowering	Secondary
VKMo 29	Spreading	Grey	Pale green	Medium	Oblong	Obtuse	Flowering	Tertiary
VKMo 30	Spreading	Grey	Pale green	Sparse	Ovate	Obtuse	Flowering	Secondary
VKMo 32*	Upright	Grey	Pale green	Medium	Oblong	Obtuse	Leafy	-
VKMo 35*	Spreading	Grey	Pale green	Medium	Ovate	Acute	Leafy	-
VKMo 36	Spreading	Grey	Pale green	Medium	Elliptical	Obtuse	Flowering	Secondary
VKMo 37	Spreading	Grey	Pale green	Medium	Ovate	Obtuse	Flowering	Tertiary
VKMo 38*	Upright	Grey	Pale green	Sparse	Ovate	Acute	Leafy	-

Table 2. (Cont.)

Accession	Calyx shape	Nature of calyx	Calyx colour	Corolla shape	Nature of corolla	Corolla colour	Pulp colour	Pulp taste
VKMo 2	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 3	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Bitter
VKMo 5	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 6	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Bitter
VKMo 7	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 8	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 9	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 10	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 11	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Bitter
VKMo 12	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 13	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Bitter
VKMo 15	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 16	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 17	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 19	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 20	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 21	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 22	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 29	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Bitter
VKMo 30	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 32*	-	-	-	-	-	-	-	-
VKMo 35*	-	-	-	-	-	-	-	-
VKMo 36	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 37	Triangular	Polysepalous	Pale green	Triangular	Polypetalous	Cream	White	Palatable
VKMo 38*	-	-	-	-	-	-	-	-

* Leafy Types

Table 3. Flowering pattern of drumstick accessions for one calendar year

Accession	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
VKMo 2	+	+	+	+	-	-	-	-	+	+	-	-
VKMo 3	+	+	+	-	-	-	-	-	-	-	-	-
VKMo 5	+	+	-	-	-	-	-	-	-	-	-	-
VKMo 6	+	+	+	-	-	-	-	-	-	-	-	-
VKMo 7	+	+	+	-	-	-	-	-	+	+	-	-
VKMo 8	+	-	-	-	-	-	-	-	-	-	-	-
VKMo 9	+	-	-	-	-	-	-	-	-	-	-	-
VKMo 10	+	-	-	-	-	-	-	-	-	-	-	-
VKMo 11	+	-	-	-	-	-	-	-	-	-	-	-
VKMo 12	+	-	-	-	-	-	-	-	-	+	+	-
VKMo 13	+	+	+	+	-	-	-	-	-	-	-	-
VKMo 15	+	+	+	+	-	-	-	-	-	+	+	-
VKMo 16	+	-	-	-	-	-	-	-	-	+	+	-
VKMo 17	+	-	-	-	-	-	-	-	-	+	+	-
VKMo 19	-	-	+	+	-	-	-	-	-	-	-	-
VKMo 20	+	+	-	-	-	-	-	-	-	-	-	-
VKMo 21	-	-	+	+	-	-	-	-	-	-	-	-
VKMo 22	+	+	-	-	-	-	-	-	-	-	-	-
VKMo 29	+	+	-	-	-	-	-	-	-	-	-	-
VKMo 30	+	+	-	-	-	-	-	-	-	-	-	-
VKMo 36	+	+	+	-	-	-	-	-	-	-	-	-
VKMo 37	+	+	+	-	-	-	-	-	-	-	-	-

Table 4. Mean performance of quantitative characters in drumstick accessions

Accession	Tree height (m)	Trunk girth (cm)	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Number of ridges /fruit	Number of seeds /fruit	Number of fruits /tree	Yield /tree (g/tree)
VKMo 2	4.40	35.80	43.25	6.05	75.90	8.50	15.70	**22.21**	1685.74
VKMo 3	**7.68**	**65.80**	58.33	6.30	117.12	8.80	20.40	15.16	**1775.54**
VKMo 5	6.90	64.50	53.74	6.27	86.31	9.40	15.30	12.32	1063.34
VKMo 6	7.13	47.70	61.50	6.65	106.66	9.50	**21.20**	6.17	658.09
VKMo 7	5.28	53.40	62.25	6.47	97.20	9.20	20.20	10.25	996.30
VKMo 8	3.97	51.20	69.88	5.34	65.00	9.60	16.20	5.14	334.10
VKMo 9	6.37	57.10	72.27	6.57	**160.00**	8.30	18.30	5.32	851.20
VKMo 10	5.10	54.50	**89.50**	**6.72**	100.50	**10.50**	20.20	3.41	342.71
VKMo 11	7.15	59.40	68.27	6.52	109.37	9.80	18.10	6.67	729.50
VKMo 12	5.30	50.00	41.88	5.57	65.27	9.40	17.70	6.55	427.52
VKMo 13	2.82	55.00	50.40	5.15	65.40	7.20	17.60	12.21	798.53
VKMo 15	6.67	61.70	41.75	4.90	95.20	9.00	13.50	10.57	1006.26
VKMo 16	3.90	**30.50**	49.50	5.66	98.80	8.50	18.20	9.23	911.92
VKMo 17	5.74	59.70	46.84	6.12	54.47	9.60	20.10	12.17	662.90
VKMo 19	4.83	55.50	61.32	5.89	74.48	8.70	17.50	17.58	1309.36
VKMo 20	5.40	47.00	51.32	5.87	48.35	8.80	17.10	11.74	567.63
VKMo 21	5.68	48.70	72.14	6.21	58.21	7.90	16.40	6.89	401.07
VKMo 22	6.20	50.40	85.30	6.14	74.61	8.00	18.10	11.2	835.63
VKMo 29	4.80	34.50	51.57	4.57	75.00	9.30	17.20	5.27	395.25
VKMo 30	5.80	49.50	48.07	6.26	92.10	9.60	18.30	8.31	765.35
VKMo 32*	5.52	34.80	-	-	-	-	-	-	-
VKMo 35*	6.21	57.62	-	-	-	-	-	-	-
VKMo 36	6.43	50.70	65.21	6.50	75.29	8.20	18.37	11.87	893.69
VKMo 37	5.20	50.50	66.37	6.00	86.31	9.50	19.14	9.27	800.09
VKMo 38*	**2.75**	39.30	-	-	-	-	-	-	-
Mean	5.49	50.59	63.51	6.15	82.53	8.89	18.45	10.09	728.47

is dependent on genetic factors as well as climatic factors. In the present investigation, two peaks of flowering were observed in drumstick (January-April and September-November). Accession VKMo 2 and VKMo 15 flowered for six months in total in two seasons. This is an important factor while determining the total yield of the tree. Accessions that flowered in September-November viz., VKMo 2, VKMo 7, VKMo 12, VKMo 15, VKMo 16 and VKMo 17, might have been the early types. Variability in flowering time was reported by several workers in many locations (Ramachandran et al., 1980; Pushpangathan et al., 1996). Three accessions viz., VKMo 32, VKMo 35 and VKMo 38 could be categorized as leafy types that rarely flowered and could be cultivated exclusively for leaves. Similar results were reported by Ochse and van den Brink (1977).

Quantitative characters such as tree height, trunk girth, fruit length, fruit girth, fruit weight, number of ridges per fruit, number of seeds per fruit, number of fruits per tree and fruit yield per tree were recorded in 25 drumstick accessions (Table 4).

Plant height is considered as one of the important traits for better growth and vigour of the plants. Optimum plant height is a desirable character in drumstick. Tree height was the greatest in VKMo 3 (7.68 m), followed by VKMo 11 (7.15 m), VKMo 6 (7.13 m) and VKMo 5 (6.90 m). The accessions VKMo 38 (2.75 m) and VKMo 13 (2.82 m) were observed to be dwarf which is a desirable character for high density planting. Shorter trees are preferred over taller ones, as they are less expensive to prune, thin, and harvest. Present study revealed that the taller trees were more productive compared to shorter ones. Similar findings were reported by Tak and Maurya (2015). With respect to trunk girth, VKMo 3 (65.8 cm) had high trunk girth, followed by VKMo 5 (64.50 cm), VKMo 15 (61.70 cm) and VKMo 17 (59.70 cm), all of which was greater than the mean trunk girth (50.59 cm). Tall trees recorded more trunk girth compared to short trees. Similar results were reported by Karunakar et al. (2018).

Wide range of variability was observed in the length of the fruit. Highest fruit length was reported in accession VKMo 10 (89.50 cm), followed by VKMo 22 (85.30 cm), VKMo 9 (72.27 cm) and VKMo 21 (72.14 cm). Fruit girth is an important trait that contributes to the yield. The drumstick accessions showed less variability with respect to this character. The fruit girth was highest in accession VKMo 10 (6.72 cm), followed by VKMo 6 (6.65 cm) and VKMo 9 (6.57 cm). Highest length and girth of fruit were recorded in same accession VKMo 10, showing a positive relation between fruit length and girth. Similar results were reported by Resmi et al. (2006). Fruit weight is one of the key characters for selecting high yielding types. Highest fruit weight was recorded in accession VKMo 9 (160.00 g) followed by VKMo 3 (117.12 g), and the mean value was 82.53 g. Accession VKMo 9 recorded high fruit weight and a high fruit length of 72.27 cm. This showed a positive association between fruit length and fruit weight. Similar findings were reported by Selvakumari (2013).

Number of ridges per fruit varied from 7.20 (VKMo 13) to 10.50 (VKMo 10) with mean value of 8.89. Accession VKMo 10 recorded greatest fruit length, girth and highest number of ridges per fruit. This showed a positive association between these characters which ultimately resulted in high fruit yield per tree. Number of seeds per fruit ranged from 13.50 (VKMo 15) to 21.20 (VKMo 6), with a mean value of 18.45. The accessions VKMo 17 (20.10), VKMo 7 (20.20), VKMo 10 (20.20), VKMo 3 (20.40) and VKMo 6 (21.20) recorded more number of seeds per fruit. From the present study it was found that large sized fruits had more number of seeds, since accession VKMo 10 recorded highest fruit length (89.50 cm) and more number of seeds per fruit (20.20). The number of fruits per plant is the most important trait in moringa in deciding the yield potentiality. The best performing accessions with regard to number of fruits per plant were VKMo 17 (12.17), VKMo 13 (12.21), VKMo 5 (12.32), VKMo 3 (15.16), VKMo 19 (17.58) and VKMo 2 (22.21) and the mean for this character was 10.9.

Table 5. Path coefficient analysis of various characters on fruit yield of drumstick (unreplicated data)

Character	Tree height	Trunk girth	Fruit length	Fruit girth	Fruit weight	Number of ridges/fruit	Number of seeds/fruit	Number of fruits/tree
Tree height	**0.0748**	0.01486	0.00720	-0.15251	0.25830	-0.03342	0.04537	0.07321
Trunk girth	0.0417	**0.02665**	0.00915	-0.16063	0.21715	-0.06014	0.05286	0.17925
Fruit length	0.0181	0.00819	**0.02976**	-0.43728	0.47463	-0.15572	0.16883	0.35099
Fruit girth	0.0231	0.00869	0.02642	**-0.49260**	0.52002	-0.18836	0.18919	0.58417
Fruit weight	0.0302	0.00905	0.02209	-0.40063	**0.63940**	-0.14961	0.15483	-0.35148
Number of ridges/fruit	0.0121	0.00779	0.02252	-0.45098	0.46495	**-0.20575**	0.18208	0.59111
Number of seeds/fruit	0.0173	0.00721	0.02571	-0.47684	0.50656	-0.19168	**0.19544**	0.53776
Number of fruits/tree	0.0056	0.00489	0.01069	-0.29442	-0.22993	-0.12443	0.10753	**0.97738**

Residual effect, h = 0.0284

Yield/tree is the ultimate character that decides the superiority of the accession from others. Prabhakar and Hebbar (2008) reported that higher number of pods is the desirable factor for high yield per tree instead of fruit size. Accessions with more yield/ tree (g/tree) such as VKMo 2, VKMo 3, VKMo 5 and VKMo 19 also recorded more number of fruits per tree. Accessions VKMo 15 (1006.26 g/tree), VKMo 5 (1063.34 g/tree), VKMo 19 (1309.36 g/ tree), VKMo 2 (1685.74 g/tree) and VKMo 3 (1775.54 g/tree) recorded high yield. The mean value for this character was 728.47 g/tree. Thus, these accessions were ranked as superior ones for higher number of pods per plant and could be further utilized in the breeding programmes.

Present study revealed the association among yield and yield contributing characters (Table 5). Knowledge on the association of component characters with the yield may greatly help in making more precise and accurate selection. High direct positive effect on yield was exhibited by number of fruits per tree (0.977), fruit weight (0.639) number of seeds (0.195) and tree height (0.0748). Thus, increase in number of fruits/ tree, tree height and fruit weight may result in high fruit yield/tree. This finding was in confirmation with the results of Tak and Maurya (2015). Yield per tree showed highest direct negative relation with fruit girth (0.492) and number of ridges (0.205). From the above genetic analysis, it was concluded that characters such as number of fruits/ tree, tree height and fruit weight played a significant role in increasing the yield in moringa and fruit yield could be enhanced by selection based on these characters.

Table 6. Principal components of quantitative characters

Variables	Components		
	PC1	PC2	PC3
Tree height	0.164	**0.686**	-0.129
Trunk girth	0.186	**0.613**	-0.175
Fruit length	0.361	-0.011	0.389
Fruit girth	**0.414**	-0.065	0.162
Fruit weight	0.367	0.101	0.172
Number of ridges	0.389	-0.160	0.131
Number of seeds	**0.403**	-0.119	0.222
Number of fruits/tree	0.291	-0.294	**-0.592**
Yield/tree	0.322	-0.115	**-0.573**
Eigenvalue	5.4660	1.3686	1.0937
Proportion	0.607	0.152	0.122
Cumulative	0.607	0.759	0.881

To identify the contribution of each variable to the total variation, principal component analysis was performed for the morphological quantitative characters. This resulted in the grouping of nine quantitative characters into different principal components (Table 6). The first three main principal components (PCs) with eigenvalue > 1 (Fig. 1) accounted for 88.1 per cent of the total variation. The first factor (PC1) accounted for 60.7 per cent

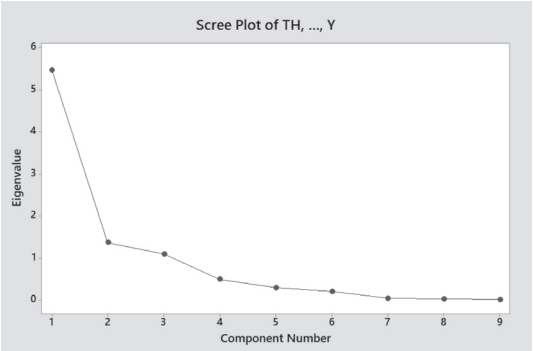
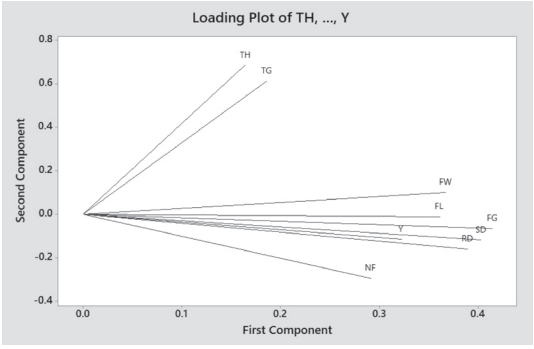


Figure 1. Scree plot showing eigenvalues of various quantitative characters

of the total variance which was comprised of fruit girth (0.414) and number of seeds (0.403). The second factor (PC2) contributed 15.2 per cent of total variance which was comprised of trunk girth (0.613) and tree height (0.686). The third factor contributed 12.2 per cent of total variance and was comprised of yield per tree (0.573) and number of fruits per tree (0.592). Thus, variation observed in the drumstick accessions for quantitative characters was mostly due to the influence of fruit girth and number of seeds. Variation with respect to tree height, trunk girth, number of fruits/tree and yield/ tree was also observed in less proportion. The loading plot (Fig. 2) explained the correlation between any two variables by estimating the angle between their vectors. It showed that first three PCs exhibited a strong association between tree height



TH- Tree height **TG-** Trunk girth **FW-** Fruit weight **FL-** Fruit length **FG-** Fruit girth **SD-** Number of seeds **RD-** Number of ridges **Y-** yield/tree **NF-** Number of fruits/tree

Figure. 2. Loading plot of first two PCs relation with various quantitative characters

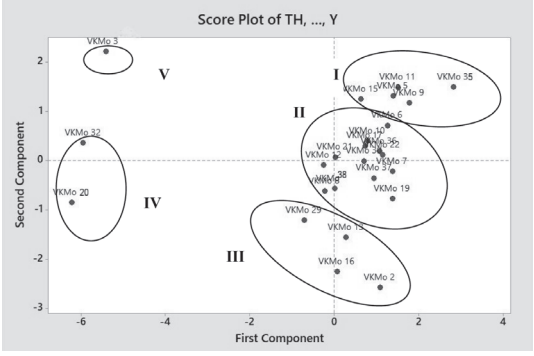


Figure 3. Clustering based on quantitative characters by principal component analysis

Table 7. Cluster wise distribution based on quantitative characters

Cluster	Cluster size	Accessions
I	5	VKMo 35, VKMo 5, VKMo 9, VKMo 11, VKMo 15
II	13	VKMo 6, VKMo 7, VKMo 8, VKMo 10, VKMo 12, VKMo 17, VKMo 19, VKMo 21, VKMo 22, VKMo 30, VKMo 36, VKMo 37, VKMo 38
III	4	VKMo 2, VKMo 13, VKMo 16, VKMo 29
IV	2	VKMo 32, VKMo 20
V	1	VKMo 3

and trunk girth. Same results were obtained in the correlation studies. Positive correlation between fruit weight, fruit length, fruit girth, number of ridges, number of seeds, number of fruits/tree and yield/tree were also revealed.

Clustering of the accessions was done based on the principal component analysis (Fig. 3). From 25 accessions of drumstick, five clusters were made (Table 7). Mean performance of each cluster was calculated (Table 8). Cluster I consisted of five accessions viz., VKMo 35, VKMo 5, VKMo 9, VKMo 11 and VKMo 15, which recorded highest mean value for number of ridges per fruit (9.12). These included four accessions from Vellanikkara (VKMo 5, VKMo 9, VKMo 15 and VKMo 35) and one from Elanad (VKMo 11). Cluster II consisted of maximum number of accessions viz., VKMo 6, VKMo 7, VKMo 8, VKMo 10, VKMo 12, VKMo 17, VKMo 19, VKMo 21, VKMo 22, VKMo 30, VKMo 36, VKMo 37 and VKMo 38. Cluster III consisted of four accessions viz., VKMo 2 and VKMo 16 collected from Vellanikkara, VKMo 13 from Thrissur and VKMo 29 from Periyakulam recorded highest mean value for fruit length (64.18cm). Cluster IV consisted of two accessions viz., VKMo 32 and VKMo 20. Cluster V consisted of single accession, VKMo, 3 which recorded high mean values for almost all characters like tree height (7.68 m), trunk girth (65.8 cm), fruit girth (6.30 cm), fruit weight (117.12 g), number of seeds per fruit (20.4), number of fruits per tree (15.16) and yield per tree (1775.53 g/tree). This revealed that the

Table 8. Mean performance of clusters based on quantitative characters

Cluster	Tree height (m)	Trunk girth (cm)	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Number of ridges per fruits	Number of Seeds per fruits	Number of fruits per tree	Yield (g/tree)
I	6.66	60.06	59.00	6.06	112.72	**9.12**	16.3	8.72	912.57
II	5.33	50.85	**64.18**	6.15	79.17	8.86	18.61	9.06	702.23
III	3.98	38.95	48.68	5.35	78.77	9.2	17.17	12.23	947.86
IV	5.46	40.9	51.32	5.87	48.35	8.8	17.10	11.74	567.62
V	**7.68**	**65.8**	58.33	**6.30**	**117.12**	8.8	**20.4**	**15.16**	**1775.53**

accession from Vellanikkara excelled in quantitative characters compared to other accessions from other locations. The leafy types VKMo 35, VKMo 38 and VKMo 32 were grouped in cluster I, II and IV respectively.

Variability in morphological characters was observed among accessions. Flowering in drumstick were observed in two peaks in January-April and September-November in accessions VKMo 2, VKMo 7, VKMo 12, VKMo 15, VKMo 16 and VKMo 17. There were leafy types (VKMo 32, VKMo 35 and VKMo 38) that rarely flowered and could be cultivated exclusively for foliage. Findings based on path analysis helped to identify the yield contributing characters and these could be considered for selection of desirable parents for hybridization as well as recombination breeding for better yield. Clustering based on principal component analysis revealed the excellence of accession VKMo 3 with highest mean values for tree height, trunk girth, fruit girth, fruit weight, number of seeds, number of fruits/tree and yield. The variability existing among the drumstick accessions could be utilized further for genetic improvement.

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