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Survey, collection and characterization of Indian avocado (*Persea americana*) germplasm for morphological characters

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ABSTRACT

Avocado (*Persea americana* Mill.) is emerging as one of the high-valued fruit crops in India. Recently, demand for avocados is increasing due to the high nutritional value of the fruits. Currently, avocados are not grown on large commercial scale and there is a need of good high yielding varieties for commercial cultivation. Hence knowledge on genetic diversity of avocado is essential for selection of superior genotypes. Currently, the information on genetic diversity of Indian avocados is limited. Therefore, an intensive survey was carried out in major avocado growing areas of India to collect 83 diverse accessions. The collected accessions were characterized for 27 characters using IPGRI, avocado descriptors. Among the characters studied, 2 characters were dimorphic and remaining 25 were polymorphic. The maximum accessions showed the presence of rough trunk surface (48.19%), oval leaf shape (44.58%), acute leaf base (86.75%) and leaf apex (72.29%). The dominance of light green fruit colour (38.55%) with smooth peel surface (54.22%) was noticed. The wide variability for pulp and seed characters was also documented. The principal component analysis and cluster analysis showed the existence of wider variability among the collected accessions. The existence of huge diversity helps to conserve trait specific accessions and varietal improvement through selections and hybridizations.

Keywords: Breeding, Descriptors, Fruit, Genetic Diversity, IPGRI

The avocado (*Persea americana* Mill.) is an important exotic fruit crop belongs to the family of Lauraceae, and originated in Mexico and Central America (Dreher and Davenport 2013), possibly from more than one wild species. Avocado includes approximately 150 species among which Guatemalan, Mexican and West Indian (Bergh and Ellstrand 1986) races are very important from horticultural point of view. Presently the avocados are grown commercially in more than 80 counties comprising of 7.26 lakh ha area and 7.18 million tonnes of world production with 11.1% of contribution from Asian countries. Mexico is the largest producer and exporter of Avocado in the world followed by Dominican Republic, Peru, Colombia, Indonesia, Kenya, Brazil, Haiti, Chile, Isreal (FAOSTAT 2020).

Avocado was introduced to India during early decades of 19th century by American missionary residing in Bengaluru from Royal Botanical Gardens, Ceylon (Tripathi *et al.* 2016). Its cultivation in India has been distributed mainly to the hill stations or higher altitude regions (Ghosh 2000). A wide variability has been observed in avocado for different characters such as tree, leaf, fruit, seed and pulp quality traits in India due to cross pollination and sexual mode of propagation over the decades. As a result, large numbers of genotypes with wide morphological variations have evolved naturally in India. In recent years, interest in commercial cultivation of avocados has gained the momentum due to delicious nature of the fruit and its high value in the market. Hence, there is need for selection of varieties or accessions with better yield and quality for commercial cultivation to meet the growing demand for avocados. An understanding of the diversity existing in a crop species is prerequisite for its collection, conservation and utilization in crop improvement. The information on diversity existing in Indian avocado genotypes or accessions is lacking. In this study, we attempted collection and morphological characterization of avocado accessions grown in different parts of India with an objective of germplasm conservation and varietal development through selection.

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MATERIALS AND METHODS

The intensive survey was conducted during 2019–20 to 2021–22 in different avocado growing regions of India; mainly from Kodagu, Chikmagalur and Bengaluru districts in Karnataka; Salem and Dindigul districts of Tamil Nadu state and Wayanad and Idukki districts of Kerala. The altitudes of surveyed areas range between 680 and 1585 meters amsl. Trees older than 8 years of seedling origin were considered for germplasm collection from the homestead and coffee plantations. A total of 83 germplasm accessions were collected based on the variations existing in the morphological traits. Scion sticks, leaf, fruits and seeds of selected germplasm accessions were collected for the study. The morphological data of 25 characters related to tree growth, leaf, fruit, pulp and seeds were collected and described according to Bioversity International descriptors of avocado (IPGRI 1995). The descriptors details, score and status of recorded characters are given in Table 1 and 2. The 15 representative fruit samples of collected accessions were used for recording fruit traits. Pulp texture, sweetness of pulp, bitterness of pulp, nutty taste of pulp, fibre content in pulp and general taste of pulp was recorded by three semiskilled personal by visual and sensory evaluation as per descriptors in fully ripened fruit. All the collected germplasm were grafted and planted in the germplasm block at ICAR-Indian Institute

Table 1 Grouping of avocado accessions for trunk, leaf and fruit characters

Character	Score	Status	No. of accessions/ Frequency of occurrence (%)
Trunk surface	3	Smooth	14 (16.87)
	7	Rough	40 (48.19)
	9	Very rough	29 (34.94)
Leaf shape	1	Ovate	0 (0.00)
	2	Narrowly obovate	1 (1.20)
	3	Obovate	3 (3.61)
	4	Oval	37 (44.58)
	5	Roundish	5 (6.02)
	6	Cordiform	0 (0.00)
	7	Lanceolate	15 (18.07)
	8	Oblong	0 (0.00)
	9	Oblong lanceolate	22 (26.51)
	10	Others	0 (0.00)
Leaf base shape	1	Acute	72 (86.75)
	2	Obtuse	11 (13.25)
	3	Truncate	0 (0.00)
Leaf apex shape	1	Very acute	14 (16.87)
	3	Acute	60 (72.29)
	5	Intermediate	7 (8.43)
	7	Obtuse	2 (2.41)
	9	Very obtuse	0 (0.0)
Fruit shape	1	Oblate	0 (0.00)
	2	Spheroid	7 (8.43)
	3	High spheroid	5 (6.02)
	4	Ellipsoid	9 (10.84)
	5	Narrowly obovate	20 (24.10)
	6	Obovate	18 (21.69)
	7	Pyriform	6 (7.23)
	8	Clavate	9 (10.84)
	9	Rhomboidal	9 (10.84)
	10	Others	0 (0.00)
Fruit base shape	1	Depressed	38 (45.78)
	2	Flattened	9 (10.84)
	3	Inflated	35 (42.17)
	4	Pointed	1 (1.20)
Fruit apex shape	1	Deeply depressed	4 (4.82)
	2	Slightly depressed	43 (51.81)
	3	Flattened	4 (4.82)
	4	Rounded	32 (38.55)
	5	Pointed	0 (0.00)
Fruit apex position	1	Central	32 (38.55)
	2	Asymmetric	51 (61.45)
Pedicel position of fruit	1	Central	46 (55.42)
	2	Asymmetrical	36 (43.37)
	3	Very asymmetrical	1 (1.20)
	4	Extremely asymmetrical	0 (0.00)
Pedicel shape	1	Cylindrical	29 (34.94)
	2	Conical	46 (55.42)
	3	Rounded	8 (9.64)
	4	Others	0 (0.00)
Adherence of peel to pulp	3	Slight	69 (83.13)
	5	Intermediate	13 (15.66)
	7	Strong	1 (1.20)
Fruit peel surface	3	Smooth	45 (54.22)
	5	Intermediate	36 (43.37)
	7	Rough	2 (2.41)
Fruit peel colour	1	Light green	32 (38.55)
	2	Green	18 (21.69)
	3	Dark green	3 (3.61)
	4	Yellow	2 (2.41)
	5	Red	5 (6.02)
	6	Purple	16 (19.28)
	7	Black	4 (4.82)
	8	Speckled	0 (0.00)
	9	Other (light yellow)	3 (3.61)
Fruit peel thickness	3	Thin (0–1mm)	60 (72.29)
	5	Medium (1–2 mm)	20 (24.10)
	7	Thick (2–3 mm)	3 (3.61)

Contd.

Table 1 (*Concluded*)

Table 2 Grouping of avocado accessions for pulp and seed characters

Character	Score	Status	No. of accessions/ Frequency of occurrence (%)
Pulp texture	1	Watery	1 (1.20)
	2	Buttery	71 (85.54)
	3	Pastose	11 (13.25)
	4	Granular	0 (0.00)
	5	Other	0 (0.00)
Sweetness of pulp	3	Low	45 (54.22)
	5	Intermediate	35 (42.17)
	7	High	3 (3.61)
Bitterness of pulp	3	Low	58 (69.88)
	5	Intermediate	24 (28.92)
	7	High	1 (1.20)
Nut taste of pulp	3	Low	2 (2.41)
	5	Intermediate	49 (59.04)
	7	High	32 (38.55)
Fibre in pulp	3	Low	34 (40.96)
	5	Intermediate	37 (44.58)
	7	High	12 (14.46)
General taste of pulp	1	Very poor	0 (0.00)
	3	Poor	2 (2.41)
	5	Fair	18 (21.69)
	7	Good	47 (56.63)
	9	Excellent	16 (19.28)
Seed shape	1	Oblate	0 (0.00)
	2	Spheriod	4 (4.82)
	3	Ellipsoid	1 (1.20)
	4	Ovate	8 (9.64)
	5	Broadly ovate	17 (20.48)
	6	Cordiform	1 (1.20)
	7	Base flattened, apex rounded	29 (34.94)
	8	Base flattened, apex conical	23 (27.71)
	9	Other	0 (0.00)
Seed position in fruit	1	Basal	1 (1.20)
	2	Central	37 (44.58)
	3	To one end	0 (0.00)
	4	Apical	45 (54.22)
Free space of the seed cavity	1	Space on seed apex	35 (42.17)
	2	Space on seed base	3 (3.61)
	3	Space on seed apex and base	6 (7.23)
	4	other	39 (46.99)
Cotyledon surface	3	Smooth	8 (9.64)
	5	Intermediate	65 (78.31)
	7	Rough	10 (12.05)
Seed coat	1	Seed not free, coat not attached to the flesh	52 (63.86)
	2	Seed not free, coat attached to the flesh	0 (0.00)
	3	Seed free, coat not attached to the flesh	21 (25.30)
	4	Seed free, coat attached to the flesh	9 (10.84)

of Horticultural Research, Experimental Station, Chettalli, Karnataka for further characterization and evaluations. Frequency distribution for various morphological characters of avocado was worked out by histogram and expressed in percentage. Cluster analysis of accessions was performed by using 25 characters based on similarity index, and dendrogram was constructed by unweighted pair-group method (UPGMA) in PAST statistics software (Hammer *et al.* 2001). Relationships among the collected accessions were determined by Principal component analysis (PCA) using GRAPES R statistics software.

RESULTS AND DISCUSSION

Collection and characterization of germplasm accessions is very important in crop improvement especially for the unexploited crops like avocado. In present study 83 accessions were collected from the major avocado growing regions of India. Forty-three accessions were collected from Karnataka, 29 accessions from Tamil Nadu and 11 accessions from Kerala. Majority of the accessions were from the regions having the altitude between 800 to 1200 MSL (55.42%) followed by regions between 1200 and 1600 MSL (32.53%) and remaining from below 800 MSL (12.05%). Generally, the three races of avocados were observed to grow well at certain range of elevations i.e. the Mexican races were observed to grow well at altitudes ranging from 500 to 3,000 MSL, the Guatemalan race grows well at altitudes from 1,000 to 2,000 MSL and the West Indian races grows well from 0 to 1,000 MSL (Ruiz *et al.* 1999). The results of survey and collection of accessions in this study indicate that avocados exist mainly in the medium to high altitude regions i.e. 600 to 1600 MSL in India. Besides, the presence of avocado accessions in the wide range of altitudes suggests existence of the three races of Avocados.

Tree trunk surface analysis showed existence of three variants in collected accessions (Table 1). The occurrence of rough trunk surface (48.19%) was dominant over very rough (34.94 %) and smooth surface (16.87%). Abraham

et al. (2018) documented 64.2% of rough trunk surface in the avocado accessions of Ghana and Juma *et al.* (2020) reported 38.9% very rough trunk surface and 36.9% rough surface in Tanzanian avocados. Bergh (1992) has pointed out that the tree barks of the West Indian races are very rough while Mexican and Guatemala races have less rough. The high existence of rough and very rough trunk surface in the avocado accessions collected in this study indicates dominance of West Indian races in the Indian germplasm. The variations of leaf characters are mainly dependent on genetic makeup of that plant (Ranjitha *et al.* 2021). The leaf characters, viz. leaf shape and leaf apex shape showed polymorphism while leaf base shape showed dimorphic nature. Majority of the collected accessions had oval leaf shape with 44.58% of frequency occurrence followed by oblong lanceolate (26.51%) and lanceolate (18.07%). The dominance of oblong lanceolate, oval and roundish leaf shapes were also reported in the avocado populations of Ghana and Indonesia (Yunus *et al.* 2019; Abraham *et al.* 2018). Frequency of occurrence for acute leaf apex shape (60%) and acute leaf base shape (72%) was higher compared to other types. The supremacy of acute leaf base shape and acute apex shape in avocado germplasm has also been reported in avocado accessions grown in other parts of the world (Nkansah *et al.* 2013, Abraham *et al.* 2018, Ranjitha *et al.* 2021).

The 8 different fruit shapes were noticed in the collected accessions (Table 1). Most of the accessions had narrowly obovate fruit shape (24.10%) followed by obovate (21.69%) and ellipsoid, clavate, rhomboidal (10.84%). Seven types of fruit shapes have been reported in Ghana accessions (Nkansah *et al.* 2013), 5 types of fruit shapes in Indonesian accessions (Yunus *et al.* 2019) and 21 types of fruit shapes in Tanzanian accessions (Juma *et al.* 2020) have been reported. The frequent occurrence of obovate, rhomboid, pyriform and ellipsoid fruit shapes indicates the presence of West Indian race accessions (Abraham *et al.* 2018).

The collected accessions expressed frequent occurrence of depressed (45.78%) and inflated (42.17%) fruit base shapes compared to the flattened (10.84%) and pointed (1.2%) (Table 1). Fruits of about 61% of accessions expressed asymmetric apex position. The pedicel position of fruit and pedicel shape were polymorphic in the collected accessions. The central pedicel position (55.42%) was observed to be dominant over other types (Table 1). The accessions of Ghana also expressed similar results for pedicel position (Abraham *et al.* 2018). The differences were also noticed for pedicel shape; conical pedicel shapes (55.42%) were found to be at a higher frequency compared to cylindrical (34.94%) and rounded (9.64%). The dominance of conical shape of pedicel was also noticed in Indonesian, Ghana and Tanzanian accessions (Abraham *et al.* 2018, Yunus *et al.* 2019, Juma *et al.* 2020).

The collected accessions exhibited wide variations for different peel characters and found polymorphic in nature (Table 1). The 72.29% of the accessions showed thin peel while 24% had medium thick peel and the remaining had thick peel. The accessions PA-084, PA-043 and PA-011 exhibited more than 2 mm of peel thickness. More than 90% Tanzanian and Ghana avocados accessions were categorized under less than 1 mm peel thickness types (Abraham *et al.* 2018, Juma *et al.* 2020). Popenoe (1974) reported the presence of thin peel in Mexican and West Indian types and thick to very thick peel in Guatemalan races except Taylor variety. In this study, majority of the accessions showed strong (51.81%) to medium (43.31%) glossiness of the fruit peel. The rough peels of fruit surface are the prominent character of Guatemalan races of avocado (Bergh and Ellstrand 1986). In our study more than 90% of fruits had medium to strong gloss peel which indicates the dominance of West India races.

The diverse peel colours were also noticed for the ripened fruits of avocado accessions. Light green colour (38.55%) fruit peels were more frequent in the collected accessions compared to the green (21.69%) and purple colour peels (19.28%). Besides, few other variants like yellow (2.41%), light yellow (3.61%), black (4.82%) and red types (6.02%) were also observed. Avocado accessions in Ghana exhibited more of red (30.19%) and green types (26.42%) while in Tanzania, black fruit peel accessions (19.3%) were more prominent compared to other colours. The studied accessions also showed high values for buttery pulp (85.54%), low sweetness (54.22%), low bitterness (69.88 %), intermediate nut taste (59.04%), intermediate fiber (44.58%) with good general taste (56.63%) (Table 2). The presence of high nut taste (38.55%), low bitterness (69.88%), low fibre (40.96%) and excellent general taste of pulp (19.28%) in different accessions showed the scope for selection of accessions suitable for commercial orcharding.

The watery (1.2%), buttery (71%) and pastose (11%) pulp textures were exhibited in collected accessions. it could be due to the preference of consumers for buttery taste. The four variants in pulp texture were reported in Tanzanian avocados with frequent occurrence of buttery pulp (58.3%) through sensory evaluation. Generally, Mexican and some Guatemalan avocados showed buttery flesh texture (Popenoe 1974). The accessions with good pulp quality identified in this study could be used for selection of varieties for commercial cultivation as well as in hybridization programmes.

The differences were observed in accessions of avocado for seed shape, seed position, free space of seed cavity, cotyledon surface and seed coat characters (Table 2). A total of 7 different seed shapes were observed. The frequency of occurrence was maximum for base flattened and apex rounded seed shape (34.94%) followed by base flattened and apex conical (27.71%). Five types of seed shapes were reported in Ghana accessions while 17 seed shapes in Tanzania accessions (Abraham *et al.* 2018, Juma *et al.* 2020). The presence of large seeds is the characteristic feature of West Indian and Mexican races whereas existences of small seeds are the indication of Guatemalan races (Bergh and Lahav 1996). In the studied accessions, seed characters such as seed at the apical portion of the fruit (54.22%),

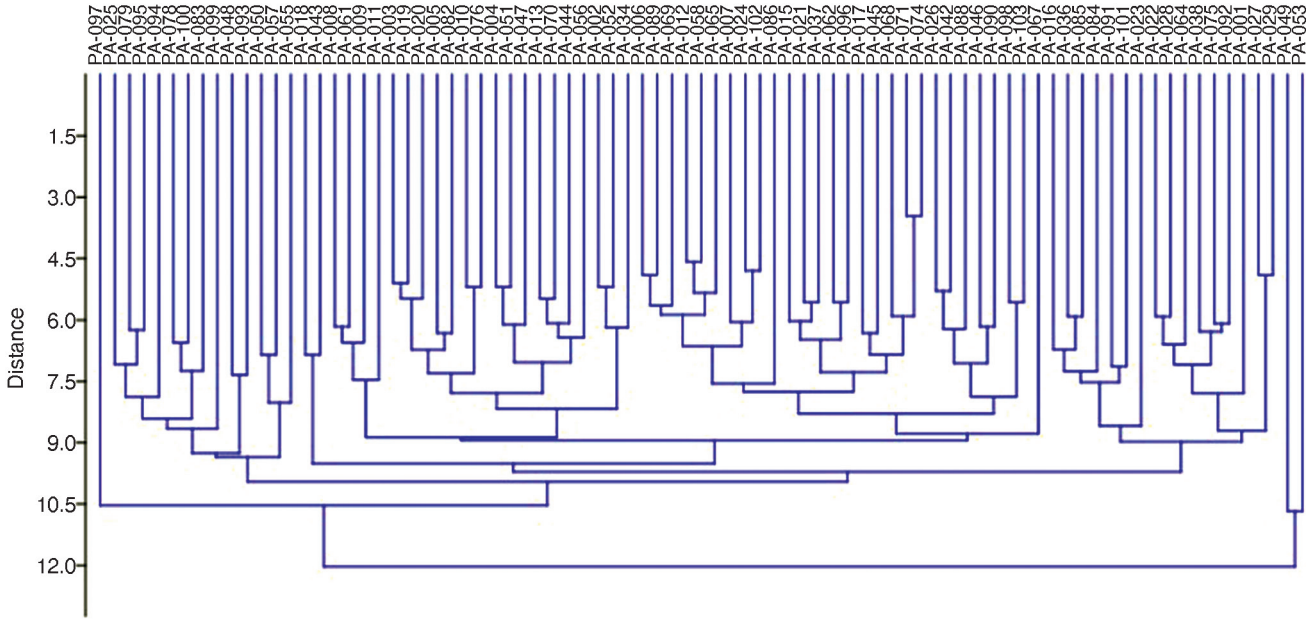


Fig 1 UPGMA dendrogram of cluster analysis for the collected accessions of avocado based on the morphological characters.

intermediate cotyledon surface (78.31%) and seed not free and coat not attached to pulp (63.86%) were dominant. The 46.99% of the accessions did not show any space or cavity between seed and pulp followed by accessions with space on seed apex (42.17%). Rough cotyledon surface are most common in West Indian types and smooth cotyledon surfaces are more common in Guatemalan and Mexican types (Bergh 1992).

Clustering and principal component analysis of collected accessions: Clustering analysis of collected accessions was done using 25 morphological characters based on similarity index of algorithm UPGMA dendrogram. The dendrogram was divided into two main clusters based on their similarity and distinctiveness of their characters (Fig 1). Cluster I consisted of 82 accessions which was again divided into the 2 sub clusters while Cluster II had only 2 genotypes (PA049 and PA053). The accessions PA-053, PA-049 exhibited poor quality pulp and strong adherence

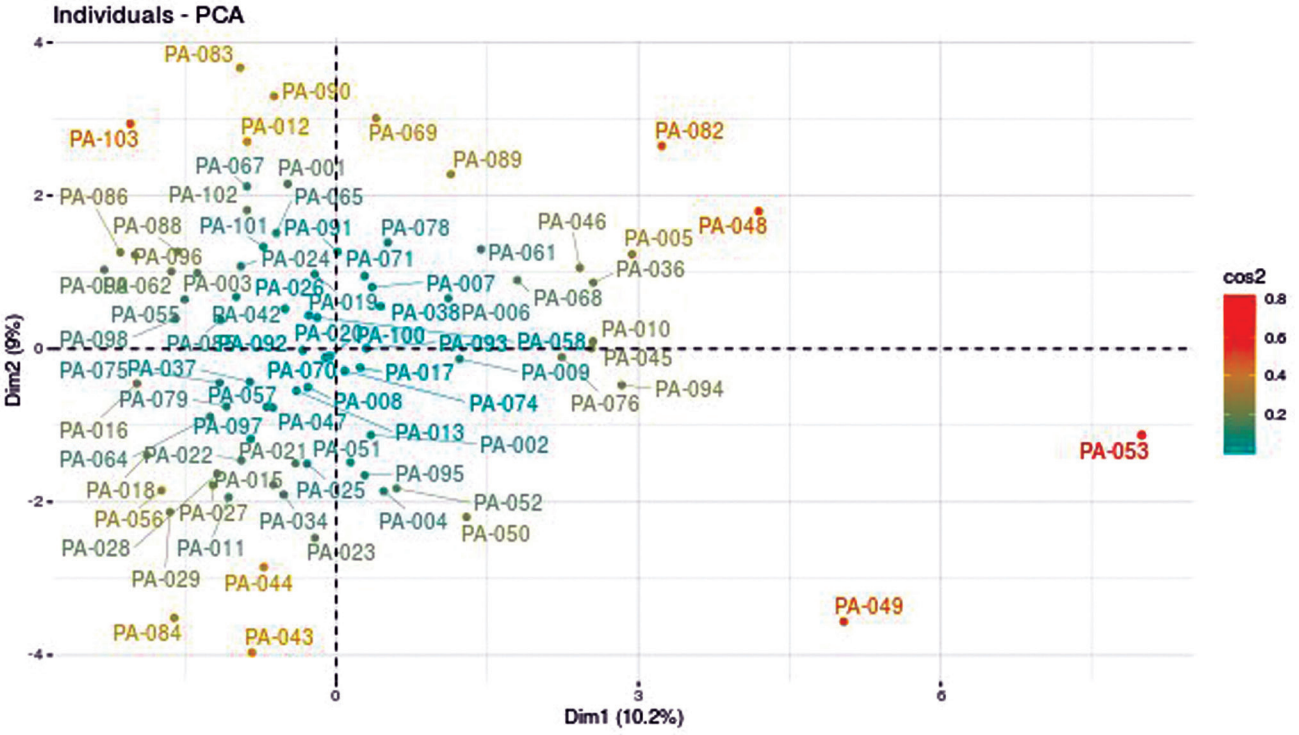


Fig 2 PCA showing the distribution of 83 avocado accessions based on the dissimilarities of morphological characters.

of pulp and peel after ripening. Further, no relationship was observed between the grouping of genotypes and the geographic location of collection.

The PCA based on morphological descriptors also indicated high variations among the collected accessions. The accessions were distributed in all the 4 sides of the plot (Fig 2). The accession PA-049 and PA-053 were found to be highly distinctive among the accessions as demonstrated by the cluster analysis. The first 3 components explained 26.89% of the total variance. The first component showed (PC1) 10.17% of total variance, the contribution of peel adherence to pulp (23.85%), pulp texture (23.85%) and seed coat (7.98%) were dominating compared to other variables. The second component represented about 9.02% of total variance; general taste of pulp (11.97%) and fruit peel surface (11.34%) were most prominent. The third component (PC3) represented 7.70% of total variance; fruit apex shape (15.66%), fruit apex position (13.10%) and general taste of pulp (10.09%) were dominant. The fourth principal component showed 7.15% of total variance and it was dominated by fruit shape (17.56%), fruit base shape (15.31%), pedicel position of the fruit (12.15%) and seed position in fruit (11.21%). The earlier workers in avocado (Juma *et al*. 2020) and pomegranate (Khadivi *et al*. 2018) also observed that fruit characters were significant factors in differentiating and analyzing breeding material. In conclusion, the collected accessions exhibited the mix characters of all 3 horticultural races existing in studied area but the West Indian races are more dominant for many traits compare to others. The great amount of variations in morphological characters in collected accessions allow selection of elite genotypes for commercial cultivation as well as to conserve the germplasm with distinct genes for future breeding programmes.

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