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Morphological characteristics of avocado (*Persea americana* Mill.) in Ghana

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Avocado (*Persea americana* Mill.) is an important economic tree crop grown in home gardens and farms all over Ghana. Although there are some studies on diverse aspects of the crop in several parts of the world, not much has been documented about its morphology in Ghana. This study was therefore conducted to describe the morphology of avocado in the Ashanti and Central Regions of Ghana. Using the avocado descriptor as a guide, morphological analyses of *P. americana* accessions in eight districts in the two regions were conducted. The study revealed that the avocado accessions had variable morphological characteristics but were more close to the Western Indian accession.

Key words: *Persea americana*, accessions, morphology, Ghana, economic tree crop, Western Indian.

INTRODUCTION

Persea americana commonly called avocado is a polymorphic tree crop that originated from a broad geographical area stretching from the eastern and central highlands of Mexico through Guatemala to the Pacific coast of Central America (Popenoe, 1920; Smith, 1966, 1969; Storey et al., 1986; Dreher and Davenport, 2013).

From its origin, the avocado plant spread very fast to many parts of the world due to its nutritional value and the desire for its fruit. The spread to different parts of the world resulted in different names given to it in different parts of the world e.g. “avocado” in English, “aguacate” in Spanish, “avocat” in French and “abacate” in Portuguese (Ochse et al., 1961; Morton, 1987). In West Africa, *P. americana* is also known as “custard apple” (Gustafson, 1976) and in Ghana, it is known locally as “pɛa” or “paya” in Twi, Fante, Ga and Adangme (Irvine, 1961).

The avocado plant is erect and grows up to ≥ 9 to 18 m high with bole diameter ranging from 30 to 60 cm. The leave could be of several shapes including lanceolate, elliptic, oval, ovate or obovate (Morton, 1987; Schaffer et al., 2013) and may be alternate, dark-green, glossy on the upper surface and whitish on the underside. Morton (1987) measured leaf lengths ranging from 7.5 - 40 cm long and found the fruit to be pear-shaped, often necked, oval or nearly round and 7.5-33 cm long in length and may reach 15 cm wide.

The fruit skin is known to be yellow-green, deep-green, reddish-purple or very dark purple to almost black. The

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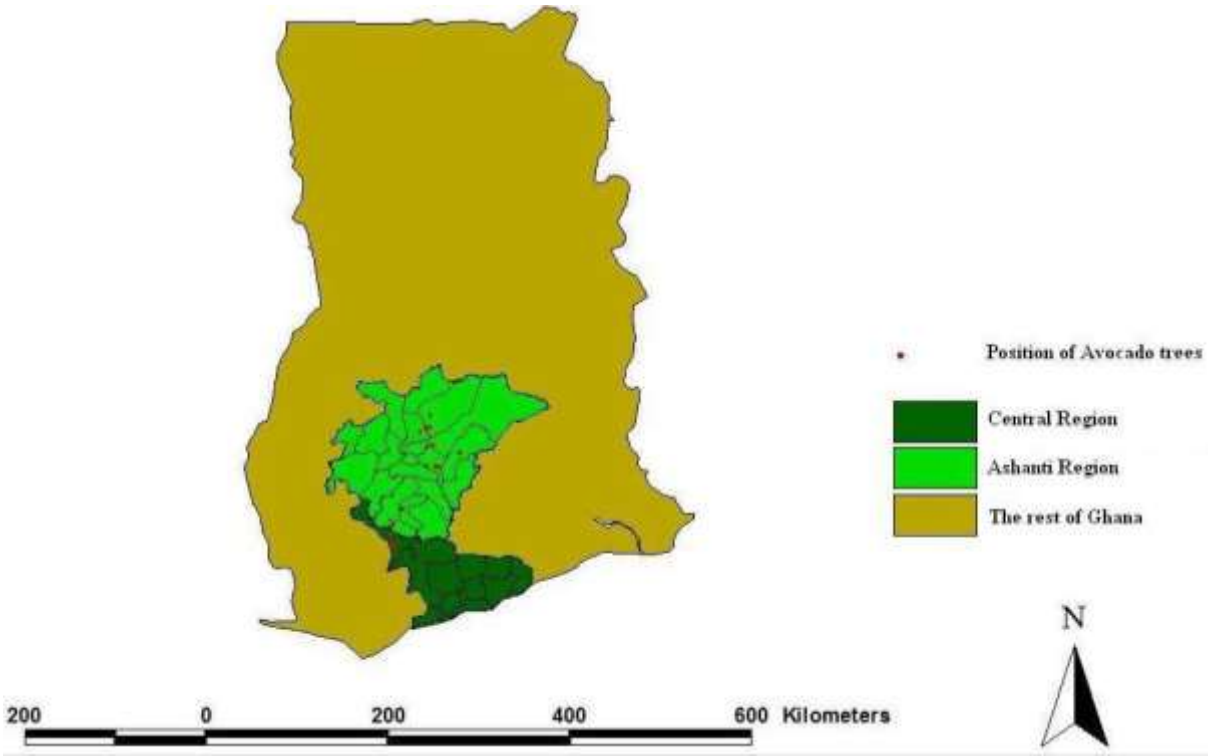

Figure 1. Map of Ghana showing the geographical points of the avocado plants used for the study. Map was produced from the GPS coordinates of each single tree sampled.

fruit may be speckled with tiny yellow dots, may be smooth or pebbled, glossy or dull, thin or leathery and up to 6 mm skin thickness, pliable or granular and brittle (Morton, 1987). Generally, the flesh of avocado is entirely pale to rich-yellow in colour but in some fruits, there is a thin layer of soft, bright-green flesh immediately beneath the skin. The avocado fruit has a single seed enclosed in two brown, thin, papery seed coats often adhering to the flesh cavity and may be oblate, round, conical or ovoid in shape, hard and heavy, ivory in colour and 5-6.4 cm long (Morton, 1987).

The avocado tree crop is one of the most important in Ghana. Local people use the fruit and other parts of the tree for diverse purposes including food and medicine. In the Ashanti region, the avocado fruit is a major component of meals when in season (Abraham, personal observation). The intense utilization of all parts of avocado makes it a crop of great commercial potential in the agricultural sector. The potential for commercialisation has not been utilized in Ghana due to marginalisation of the crop and inadequate documented information on it in Ghana. Moreover, there is the need to conserve all the avocado accessions in Ghana to avoid extinction of any of them. To do this, it is important to determine the accessions of avocado in Ghana. Therefore, this study was conducted to characterize the *P. americana* accessions in the Ashanti and Central regions of Ghana based on their morphology.

MATERIALS AND METHODS

Study area

The study was conducted in eight districts randomly distributed in the Ashanti and Central regions of Ghana between March and October 2008. A minimum of two and a maximum of twelve avocado plants were randomly sampled for study in each study district bringing the grand total of avocado plants studied in all districts to 53 (Adansi South: n = 2; Afigya Sekyere: n = 3; Asante Akyem North: n = 6; Ejisu-Juaben: n = 11; Sekyere East: n = 5; Sekyere West: n = 12; Obuasi: n = 6; Upper Denkyira: n = 8). The GPS coordinates of each plant assessed was recorded and used to produce a map (Figure 1).

Morphological characters studied

Based on a field guide for morphological studies, data on tree, leaf, fruit and seed characteristics were taken for each avocado plant selected for study (IPGRI, 1995).

Tree characteristics

The tree characteristics studied were canopy spread, tree height, trunk surface, branching pattern, distribution of branches and a

measure of the truck circumference at 30 cm above ground level.

To determine the canopy spread, the distance from the centre of the crown to the tip of the outermost leaves on two opposite sides of the tree was measured using a 100 m fibreglass measuring tape [Rollins & Sons (London) Ltd, Harlow, Essex, UK]. Tree height was measured with a suunto clinometer (PM-5 Suunto, Valimotie, Finland). The tree heights were classified into 1-4, > 4-8, >8-12, >12-16 and >16 m. The appearance of the trunk surface of the avocado trees was scored according to the criteria described by the IPGRI (1995) such that a score of 3 represented a smooth surface, 7 represented a rough surface and 9 represented very rough. Other tree characteristics such as branching pattern, distribution of branches and the measure of the truck circumference at 30 cm above ground level were described following the avocado descriptor (IPGRI, 1995).

Leaf characteristics

Leaf shape was described according to the criteria suggested by the avocado descriptor (IPGRI, 1995). Data on leaf shape, number of primary veins, leaf apex shape and leaf blade length (cm) were taken.

Fruit characteristics

Fruit shape, ridges on fruit, pedicel position on fruit, pedicel length and nailhead pedicel apex shape, colour of flesh next to skin, colour of flesh next to seed, fruit skin colour and gloss on fruit skin were observed and recorded following IPGRI (1995). Moreover, the fruit length (cm) as the longest part of the fruit, fruit diameter (cm) (the mid-section of each fruit), fruit weight (g), peduncle length (cm) and peduncle diameter (mm) were measured. Fruit skin surface was observed and classified as smooth, intermediate or rough. Using an electronic digital calliper (Powerfix®, Milomex Ltd, Bedfordshire, UK), the average fruit skin thickness of five fruits were determined. Adherence of skin to flesh was graded as slightly, intermediate or strong.

Seed characteristics

For every avocado fruit studied, the shape of the seed and attachment of cotyledons to seed were noted. Moreover, the seed weight (g) was measured with an electronic weighing balance (Sartorius AG, Göttingen, Germany), and the length of seed cavity (cm), diameter of seed cavity (cm), length of seed (cm), diameter of seed (cm) and free space of the seed cavity were measured with an electronic digital calliper (Powerfix®). The length of seed was taken as the measure of the longest part of the seed and the diameter measurement was taken from the mid section of the seed with the base and tip of the seed as reference points.

Data analysis

The frequency of occurrence of the various morphological characters of the avocados was determined. Since a cluster analysis defines a natural population of the same species into distinctively related phylogenetic main groups and subgroups, the morphological characters were studied. The protocol utilized characteristics of the tree, leaves, fruit and seed. In the analysis, the hierarchical single linkage and Euclidean distance method was used to produce a dendrogram of morphological similarities (Statistica, version 7; StatSoft Inc., Tulsa, OK, USA).

RESULTS

Tree characteristics

The tree characteristics varied among the avocado trees studied (Figure 2). Other tree characteristics were:

Canopy spread

The tree spread (canopy spread) of the avocado trees studies ranged from 4.9 - 13.17 m with an average of 8.43 ± 0 .25 m. Most (92.4%) of the trees had canopy spreads between 6 and 12 m.

Trunk circumference

The trunk circumference ranged between 46.30 and 283.10 cm. The modal circumference was 111.0 cm. The mean tree circumference was 133.04 cm. Majority (77.4%) of the plants had circumferences between 70 and 160 cm.

Leaf characteristics

The avocado trees studied had several leaf shapes (Figure 3A) with different leaf apex shapes (Figure 3B).

Number of primary veins

A large percentage (71.7%) of the plants under study had between 14 and 16 primary veins. Only 3.8% had 18 primary veins. The least number of venation being 12 was represented by 11.3% of the trees.

Leaf blade length

The least average leaf blade length recorded was 12.92 cm while the highest average leaf blade length recorded was 28.64 cm. The mean average leaf blade length of the samples used for the study was 19.03 cm.

Fruit characteristics

Fruit shape

The shapes of fruit studied included pyriform (Figure 4A), narrowly obovate (Figure 4B and C), ellipsoid (Figure 4D), clavate (Figure 4E), rhomboid (Figure 4F), oblate (Figure 4G) and spheroid (Figure 4H). Other fruit shapes included high spheroid and obovate. The trees studied had various fruit characteristics (Figure 5).

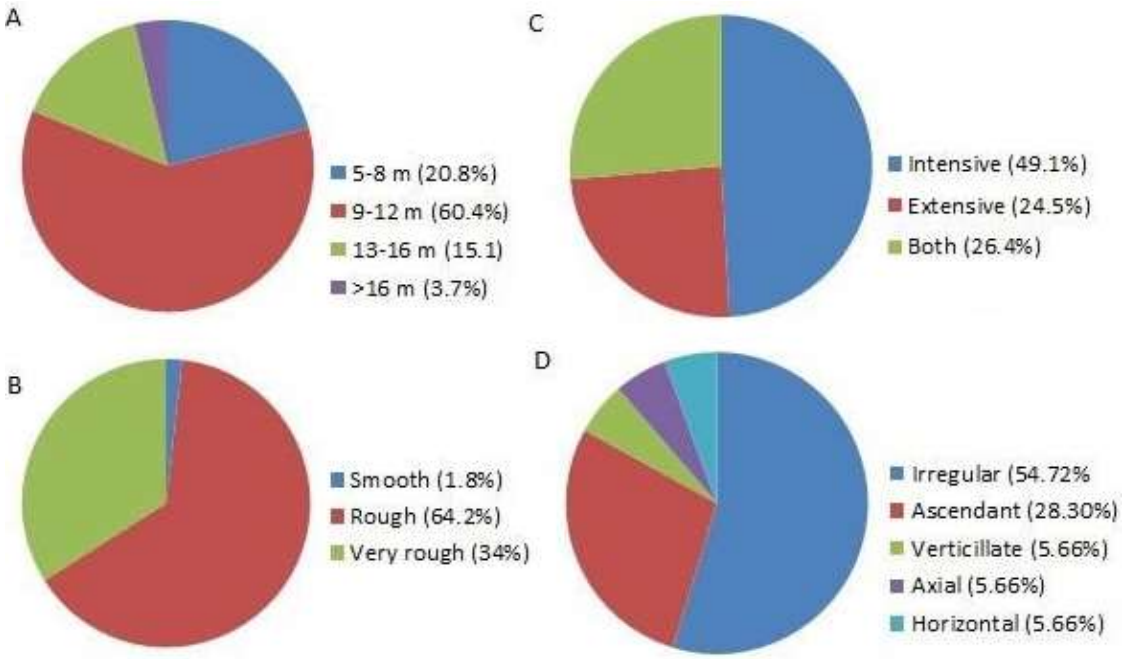

Figure 2. Percentage of the avocado trees studied with (A) tree heights ranging from 5 m to more than 16 m, (B) trunk surface being smooth, rough or very rough (C) branching pattern with intensive, extensive or both branching patterns and (D) distribution of branching being irregular, ascendant, verticillate, axial and horizontal.

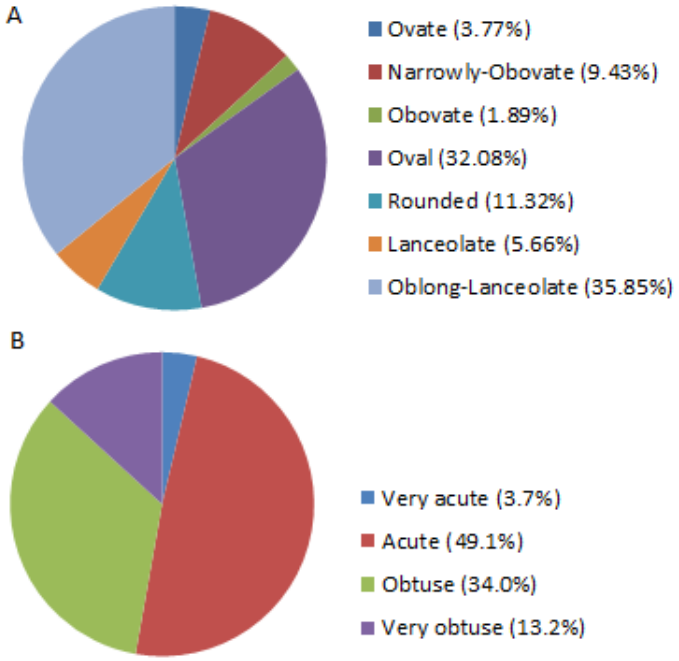

Figure 3. Leaf shapes (A) and leaf apex shapes (B) of avocado trees studied.

Ridges on fruit

More than half (54.7%) of fruits had partial ridges on them and 17% were entirely covered with ridges (Figure 6A). There were no ridges on fruits of 28.3% of the plants (Figure 6C).

Figure 4. Avocado fruits showing various morphological characters. (A) Pyriform shape, broadly ovate seed, cotyledon not attached to seed; (B and C) Narrowly obovate shape; (D) Ellipsoid shape, free space on seed base; (E) Clavate shape; (F) Rhomboidal shape, small seed, cotyledon not attached to seed; (G) Oblate shape, base flattened apex rounded seed; (H) Spheroid shape. Photos: Janice D. Abraham

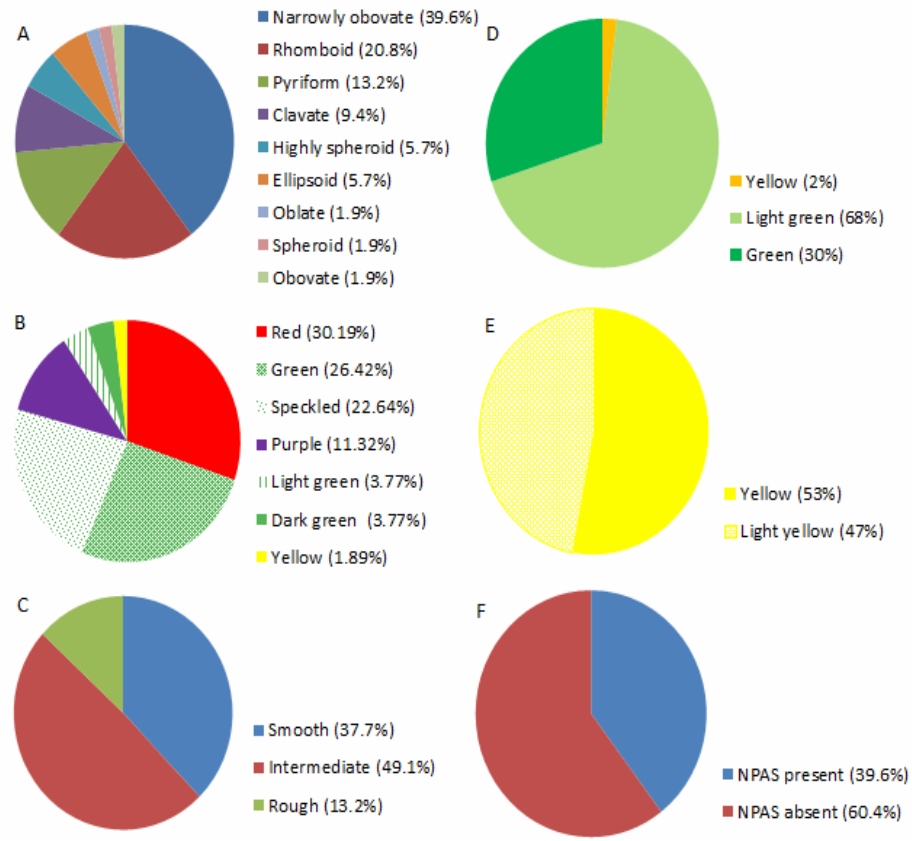

Figure 5. Percentage fruit shape (A), fruit skin colour (B), fruit skin surface texture (C), colour of flesh next to skin (D), colour of flesh next to seed (E) and Nailhead pedicel apex shape avocado fruits studied (F). NPAS = Nailhead pedicel apex shape.

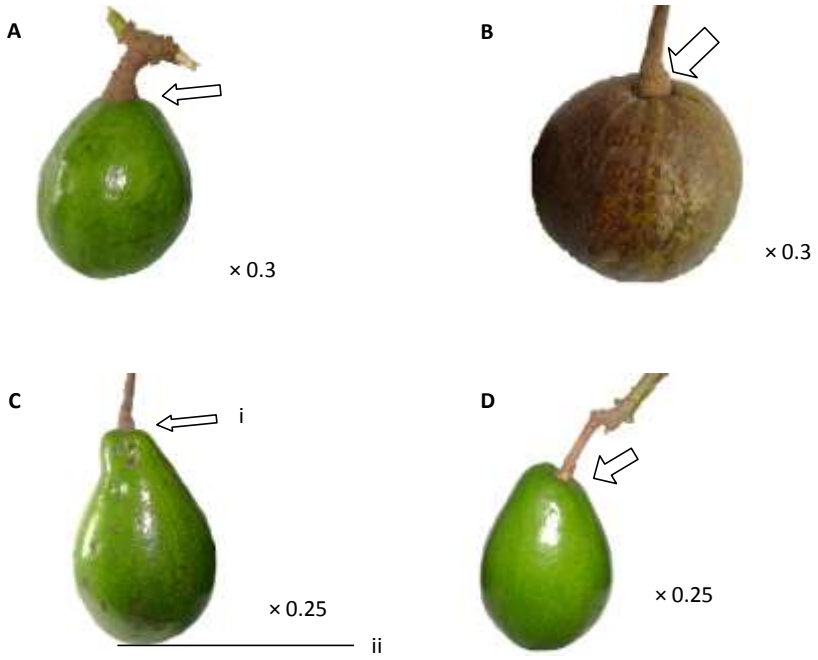

Figure 6. Avocado fruits showing different morphological characters. (A) a fruit with a conical pedicel shape (arrowed), (B) a rounded pedicel shape fruit (arrowed) with a weak glossy skin,(C) a fruit with (i) a central pedicel position on fruit and (ii) a central fruit apex position, (D) fruit with a very asymmetrical pedicel position (arrowed) and a strong glossy skin. Photos: Janice D. Abraham.

Pedicel position on fruit

The pedicels were either centrally (50.9%) or asymmetrically (49.1%) positioned on fruits (Figure 6C and D).

Pedicel length

Pedicel lengths ranged from 0.68 to 1.5 cm. The pedicel length of 96.2% of the fruits was > 1.5 cm.

Gloss on fruit skin

Fruits had a strong glossy skin (35.8%) (Figure 6D), medium glossy skins (35.8%) or weak glossy skin (28.3%).

Fruit length

The lengths of the fruits ranged between 7 and 19 cm with an average of 11.10 ± 1.52. About half (49.1%) of the fruits were between 10 and 13 cm long, 34% were up to 10 cm long and 17% were more than 13 cm long.

Fruit diameter

Most (81.1%) of the fruits were in the same diameter range of 7 to 9 cm. Only 1.9% was in the range of 9 to 11 cm, while a relatively small percentage (17%) was between 5 and 7 cm.

Fruit weight

Fruit weight of avocado studied was variable; however, more than half (58.6%) of them weighed between 220 and 370 g. Only 18.9% weighed more than 420 g, while 11.3% weighed between 170 and 220 g. Another 11.3% weighed between 370 and 420 g.

Peduncle length

There was a wide range of peduncle length of fruits studied. Most (83%) of the fruits had peduncle lengths between 2 and 6 cm. About 47% of the fruits had peduncle lengths of 4 to 6 cm. Very few (7.6%) had their peduncle lengths over 8 cm long.

Peduncle diameter

A much larger percentage (92.5%) of fruits had their peduncle diameters between 4 and 8 mm. Only 7.6% of the fruits had peduncle diameters between 8 and 12 mm.

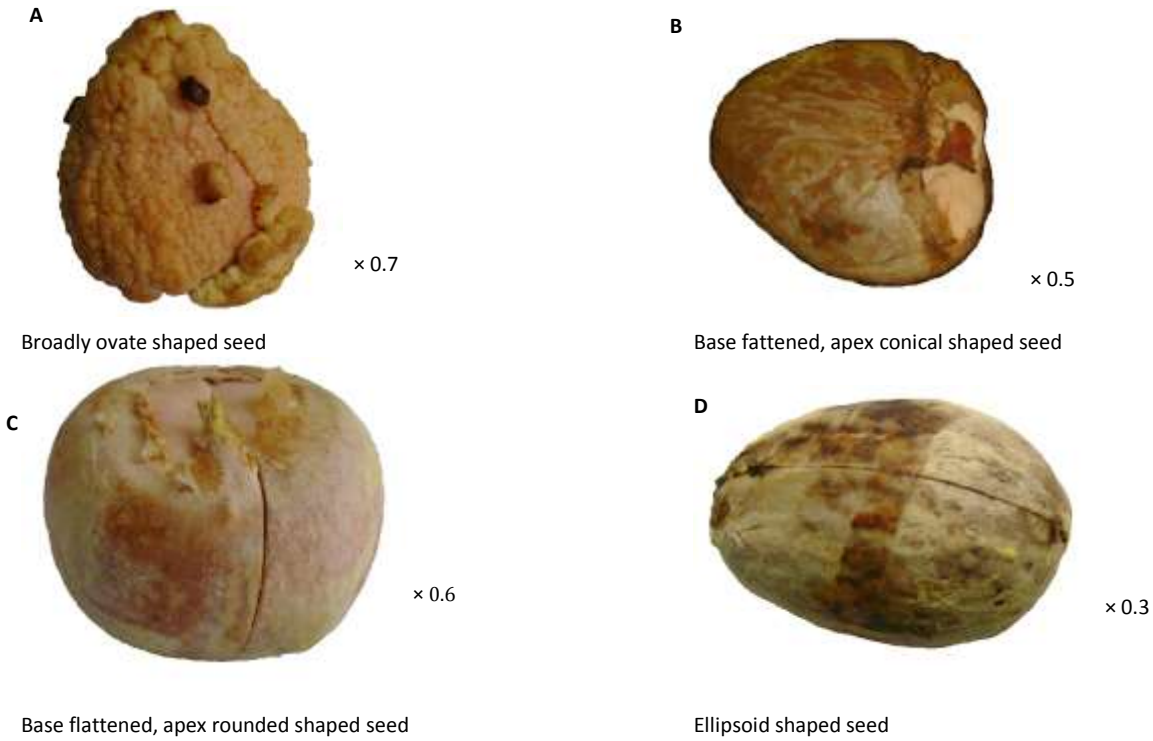

Figure 7. Various seed shapes of avocado. Photos: Janice D. Abraham.

Fruit skin thickness

The skin of the fruit had thickness ranging between 2 and 8 mm. The skin thickness of 96.2% of the fruit was between 2 and 6 mm. Only 3.8% had skin thickness of 7 mm.

Adherence of skin to flesh

There was a strong attachment of flesh to skin in 13.2% of the fruits; 67.9% had a slight attachment, while 18.9% had an intermediate strength of attachment.

Seed characteristics

Shape of the seed

Among the avocado fruits studied, five different seed shapes were identified: broadly ovate (Figure 7A; 37.7%), base flattened and conical apexes (Figure 7B; 35.8%), base flattened and rounded apexes (Figure 7C; 18.9%), cordiform (5.7%) and ellipsoid (Figure 7D; 1.9%).

Some of the seeds had their cotyledons attached to the seeds while others did not (Figure 8A). The weights of avocado seeds studied were between 25 and 125 g (Figure 8B). The diameter of seed cavity and diameter of seeds were different (Figure 8C and D, respectively).

Length of seed cavity

The seed cavities of 92.4% of fruits studied were between 4 and 8 cm, and 7.5% had seed cavities of 8 to 10 cm.

Length of seed

The seeds were between 2 and 8 cm in length: 2-4 (1.9%), 4-6 (84.9%), 6-8 cm (13.2%).

Free space of the seed cavity

Seed cavity space was as follows: space on the seed base only (66%), spaces on both seed apex and seed base (32.1%) and space on the seed apex only (1.9%).

A dendrogram of the relationships between all avocado plants based on 35 morphological characters identified three major distinct groups (Figure 9). The first distinct group (A) was defined with samples one and eight at either ends, with four subgroups. The four subgroups had samples 1-30, 42-50, 40-33; however, sample eight stood alone. The second distinct group (B) had samples three and six at either ends. This also had four subgroups made up of samples 3-17, 15-21, 37-19 and 23-6. The third distinct group (C) was between samples 11 and 39. This group had three subgroups made up of samples 35-

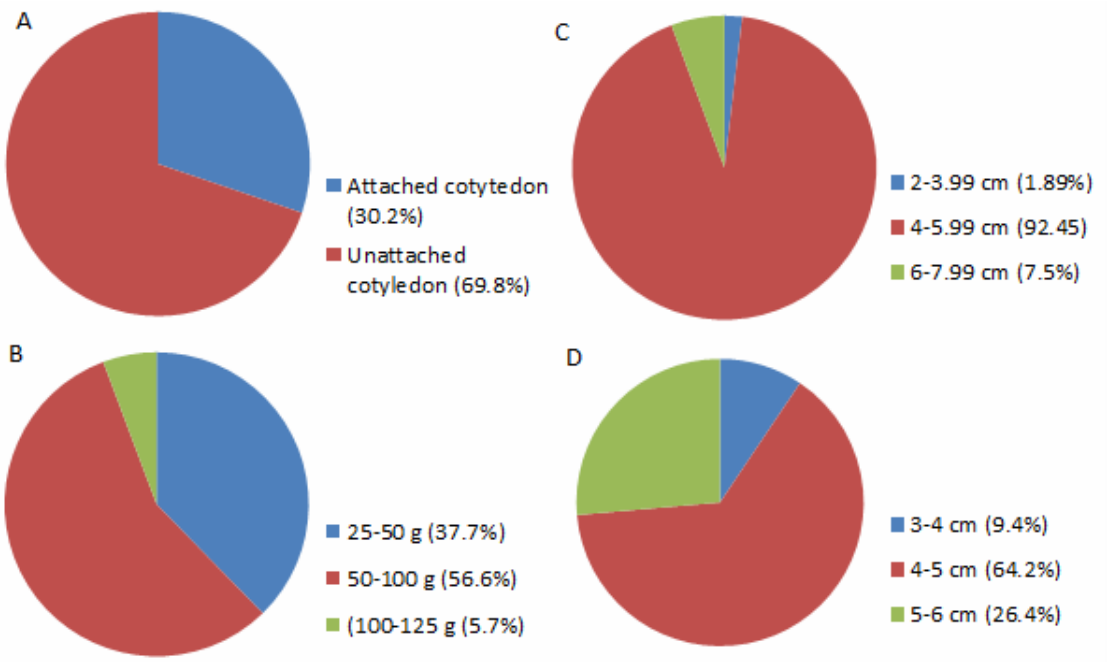

Figure 8. Percentage of seeds with cotyledon attached or not attached (A), seed weight (B), diameter of seed cavity (C) and diameter of seeds (D) of avocado fruits studied.

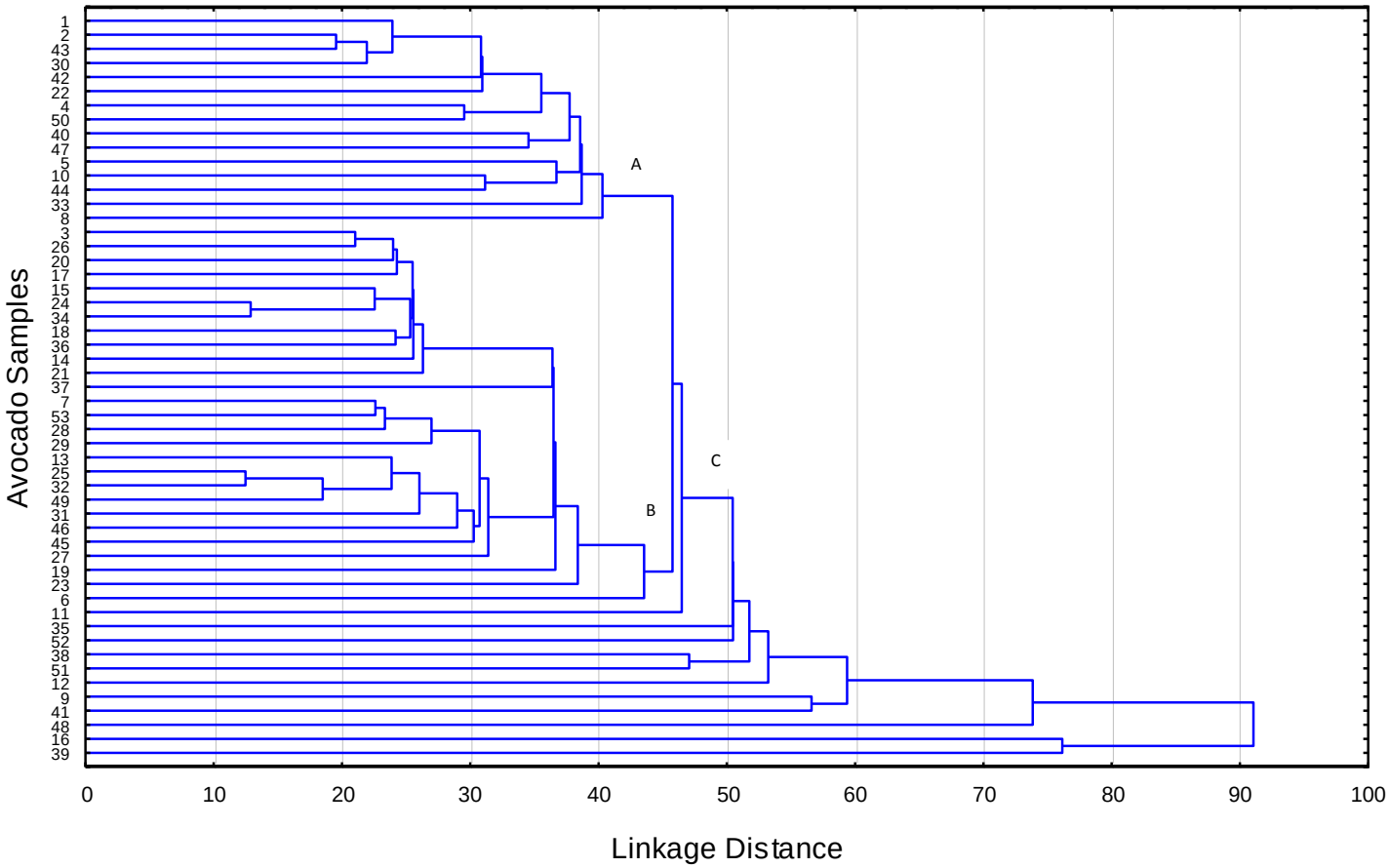

Figure 9. Single-joining tree of avocado individual plants, using Euclidean distances from morphological parameters.

51, 12-41 and 48-39.

DISCUSSION

All the avocado plants studied had heights above 5 m, suggesting that all the plants were fully matured. In terms of management, it has been suggested that avocado plants between the heights of 3 and 4.5 m are relatively easier to manage and more productive than taller plants (Partida Jr., 1996). This implies that, it will be very difficult for the farmers to manage their tall plants. It is therefore necessary for breeders to try to cross the existing trees with improved accessions that have shorter heights to enhance commercialisation and easy harvest of fruits. This is because harvesting from tall trees is very difficult and expensive. Shorter avocado trees with good canopy development produce more fruits than taller ones.

In California, it has been reported that, avocado fruit yield reduced from about 2,177 to 725 kg/ha over a three year period when the canopies were crowded such that there was not enough sunlight through (Partida Jr., 1996). When such trees were pruned to open up the canopy to allow more light through, and the tree heights limited to about 3.6 m, yield increased again (Partida Jr., 1996). It has also been observed that not only did the fruit yield increase but cost of harvesting was significantly reduced on pruned trees. It is thus possible that, Ghanaian avocado farmers might have better yield and income from their avocado farms and plantations when the trees are pruned down to between 3 m and 4.5 m in height. The average canopy spread of avocado plants studied was 8.4 m, and the crowns ranged between 4.9 and 13.17 m. Such large crowns may be too much for proper management. Management of such trees will be relatively easier when the crowns are pruned.

The trunk circumference of avocado trees range between 46.30 and 283.10 cm which is equivalent to diameters between 14.74 and 90.11 cm. Such plants are considered very large fruit plants. However, the sizes of the avocados are evidence of good and healthy growth.

The most common branching distribution of the plants studies was irregular. However, Paz-Vega (1997) noted that horizontal branching could enhance flowering. By tipping the branches, more side shoots were formed. This created complex branching systems in avocado. This method could thus be effectively used to control the size and shape of avocado plants, as well as enhance yield. Removal of excess branches by girdling could reduce vegetative growth; and thus increase flowering and fruiting (Núñez-Elisea and Crane, 2000; Kim et al., 2017). The study results showed that, nearly half of the avocado plants had intensive branching.

Avocado leaves have variable lengths. They may have lengths of up to 22 cm (Irvine, 1961) or 40 cm (Morton, 1987). The leaves of the avocado plants sampled in this study had leaf blade length between 12.92 and 28.40 cm long. Large leaf is distinctive of both West Indian and Guatemalan races, and their hybrids, but the West Indian species are said to have the largest leaf size among the species (Bergh and Lahav, 1996). Hence, the plants studied might very well relate to these two species. Almost 50% of the trees had leaves with acute apex. This is a feature of a normal avocado leaf. However, improved cultivars have some leaf shape variations. The observation therefore means that new improved cultivars have not been introduced in the study area. The accessions spreading are the ones which were introduced over a century ago. There is therefore the need to introduce come improved cultivars to the area to bring more diversity and enhance the commercial value of the existing plants. This will make commercialisation of the plants more attractive to farmer.

The average avocado fruit length of 11.10 ± 1.52 in this present study is comparable to previous measurements of West Indian Avocados averaging 15 cm (Crane, 2008). Most of the avocados had fruit lengths above 10 cm which suggest that there are more West Indian avocado than Guatemalan in Ghana. Indeed, about 72% of all avocados studied had ridges on them. This is also a characteristic morphological feature of West Indian avocado. The shapes of the avocado fruits studied, including obovate, rhomboid, pyriform and ellipsoid are typical of West Indian avocados. Over 70% of all the avocados studied had these shapes, pointing to the West Indian as the origin of these avocados. These facts strongly suggest that there were more West Indian avocado in Ghana. Furthermore, more than 70% had medium to strong glossy skin. Very few (13.2%) had rough skin which is characteristic of Guatemalan avocado (Bergh and Ellstrand, 1986).

A typical avocado fruit weighs about 200 to 300 g fresh weight (Paz-Vega, 1997). In the study, more than 50% of the avocado fruits sampled weighed between 220 and 370 g. These weights are impressive in a developing country like Ghana where no plant growth regulators (PGR) (Lovatt, 2005) are used to enhance growth and development of crops. This implies that, there are potentially a lot of avocado accessions in Ghana that could do without the use of PGRs. Majority of the fruits had thin skin thickness with a few thick skin thickness of 5 mm. Thin and medium fruit skin thickness is a characteristic feature of West Indian species and their varieties.

The results showed five different seed shapes. Majority of the fruits had large seeds, while a few had small seeds. Literature shows that large seeds are characteristic features of Mexican and West Indian races while small seeds are typical characteristic features of the Guatemalan race (Bergh and Lahav, 1996).

Three major clusters were obtained using the characters measured in a dendrogram. This indicates that avocado samples from the various districts in the Ashanti and Central Regions of Ghana were not

exclusively different. It is likely that the same set of planting materials circulates in the study areas and that one should not expect much morphological variations in these areas. Many farmers in Ghana are migratory whose produce are sold in other parts of the country such as the Greater Accra, part of the Western, Central and some parts of the Volta Regions. The seeds of the fruits they sell are used as propagules in these places.

Avocado samples with similar morphological characters were grouped together such that samples 1, 2, 43 and 30 though collected from different locations shared a lot of morphological characters as compared to samples 1 and 3 which were collected from the same location. These two samples did not have many characters in common. The samples in the second distinct group were closely linked. This implies that these samples share a lot of morphological features together when compared with the samples in the third distinct group which appear to have much diversity within the group. Some of the samples in the third group (e.g. sample 48) stood independent almost to the end of the link before joining the group. Samples 16 and 39 were joined to the tree at the last cluster; this showed that they share very few morphological characters with the other samples. This showed that there were some degree of morphological diversity between the avocado accessions found in the study area.

These diverse morphological variations suggest genetic diversity and ecological adaptation of accessions which have common ancestor. This may have resulted from the different climatic and soil conditions in the environment in which the seeds were planted. In addition to the environmental adaption, cross pollination between the populations found at a place over a long period of cultivation may have led to the variation observed. The similar feature observed between accessions from different locations may have resulted from the retention of some parent gene over the long period of crossing with other accession. There is therefore the need for identification of these genes to enhance breeding and commercialisation of the plant if the traits are good.

Conclusion

All the avocado trees studied had height above the 3 and 4.5 m range which is recommended for high fruit productivity. This means that the trees studied may not reach their optimum productivity as expected and harvesting may be expensive for the farmers. The leaves and other morphological characters of the avocados studied exhibited characteristics that relate to the West Indian and Guatemalan races. Moreover, the results of the field work indicate the samples from the various districts were not exclusively different from each other. A probable reason may be that the seeds of the same accessions might have been used as propagules by migratory farmers. The accessions in the area might be the same as the ones introduced over a century ago. There is the need to introduce some commercially improved accession to the old stock to bring more genetic diversity and enhance the chances of commercialisation and export of the avocado to make farming and propagation attractive to farmers. There is need for germplasm collection of the existing stock to enhance conservation of genes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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