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Morphological Variability of *Persea americana* Mill. in Vina Division (Adamawa, Cameroon)

Fawa Guidawa, Oumarou Haman Zephirin, Azis Bruno, Binwé Jean Baptiste, Mapongmetsem Pierre Marie

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ABSTRACT

Persea americana is a socio-economic species highly prized by the population of Vina. The aim of this study was to assess the morphological characteristics of this species in the Vina. Qualitative and quantitative descriptors were assessed. In each village, 10 avocado trees were selected. Dendrometric measurements were recorded. A total of 10 fruits and leaves were sampled and measured per tree. This study showed that the evaluation of morphological parameters revealed the existence of 25 descriptors, 15 quantitative and 5 qualitative. Principal Component Analysis (PCA) coupled with Hierarchical Ascending Classification (HAC) showed a structuring of diversity into six groups of morphotypes based on trees, fruits and leaves. Positive correlations were obtained between total tree height (TTH), diameter at breast height (Dbh), mean crown diameter (Mcd), crown area (CA), seed weight (SW), pulp weight (PW), fruit weight (FW), fruit length (FL), fruit width (Fw), seed length (SL), seed width (Sw). Similarly, petiole length (PL), petiole width (Pw), leaf length (LL) and leaf width (Lw) were also correlated. This study is an important step towards implementing a varietal selection program.

Keywords *Persea americana*, Variety, Characteristic, Morphological, Vina.

Fawa Guidawa[1], Oumarou Haman Zephirin[2]*, Azis Bruno[3], Binwé Jean Baptiste[4], Mapongmetsem Pierre Marie[5]

[1]Senior Lecturer
Department of Sciences and Techniques of Biological Agriculture, Faculty of Science, The University of Ngaoundéré, P.O. Box 454 Ngaoundéré, Cameroon

[2]Senior Lecturer
Department of Plant Sciences, Faculty of Science, The University of Bamenda, P.O. Box 39 Bambili, Cameroon

[3,4]Department of Biological Sciences, Faculty of Science, The University of Ngaoundéré, P.O. Box 454 Ngaoundéré, Cameroon

[5]Full Professor
Department of Biological Sciences, Faculty of Science, The University of Ngaoundéré, P.O. Box 454 Ngaoundéré, Cameroon

Email: oumarouzephirin@yahoo.fr
*Corresponding author

INTRODUCTION

Avocado (*Persea americana* Mill.) is a subtropical fruit tree native of Central America, belonging to the Lauraceae family, which comprises around 50 genera and 2,500 to 3,000 species (Ploetz *et al.* 1994). It varies in height from 9 to 20 m and is characterized by evergreen foliage (Amann *et al.* 2008). This species has spread very rapidly in many parts of the world due to its nutritional value and the desirability of its fruit (Omar *et al.* 2013). In the diet, *P. americana* is one of the most nutritious fruit crops (Galindo-Tovar *et al.* 2007). It is mainly eaten as a fresh fruit and is a very rich source of nutrients, making it one of the most energy-dense fruits and vegetables (FAO 2004). This fruit has been highly valued and used by indigenous populations for at least 9,000 years (Chanderbali *et* *al.* 2008). It is sometimes called the 'alligator pear', 'green gold' and 'butter fruit' because of its creamy texture, unique taste and immense nutritional value (Hebdo 2020). Avocado seeds contain highly valued mineral elements including Potassium, Phosphorus, Sodium and Calcium (Anthony and Cemaluk 2017).

Avocados are grown and marketed in over 50 countries around the world, with Mexico, the Netherlands, Peru, Chile, Spain, South Africa and Israel being the main avocado-producing countries (FAO 2008). The main importers of avocados are the United States, followed by Europe, Japan and Canada (FAO 2020). In 1994, average annual avocado production was estimated at 1.78 Mt, with Cameroon the twelfth largest avocado producer in the world at 0.33 Mt/year (Ploetz *et al*. 1994). In 2018, global avocado production was around 4.7 million tonnes. In Cameroon, around 50% of the population live in rural areas, with agriculture their main activity (FAO 2008). In the high Guinean savannahs of Cameroon, *Persea americana* is one of the most abundant species in home gardens. Unfortunately, there is a lack of scientific data providing information on the different genotypes of this species. There are also no single-variety orchards. What's more, most avocado trees, particularly in the Vina Division, are in a state of senescence and very few people are involved in the vegetative reproduction of this species.

Numerous studies have been carried out to assess the different morphotypes of *Persea americana,* including those by Poudel *et al*. (2018), who collected, assessed and compared the fruit characteristics of different avocado genotypes grown in the eastern hills of Nepal; those by Janice *et al.* (2018), who characterized *Persea americana* accessions at three locations in Ghana; Ibrahim *et al*. (2021), who characterized local Tanzanian avocado germplasm using qualitative and quantitative morphological traits; and Chandrakant *et al*. (2023), who assessed avocado genetic diversity by morphologically characterizing 72 avocado accessions in India. In Cameroon in particular, similar work has also been carried out on other species, *Moringa oleifera* and *Adansonia digitata* (Baye-Niwah and Mapongmetsem 2018, Fawa *et al*. 2021). The aim of this study was to assess the morphological variability of *Persea americana* Mill. in Vina Division.

MATERIALS AND METHODS

Study site

The study was carried out in the Adamawa region,

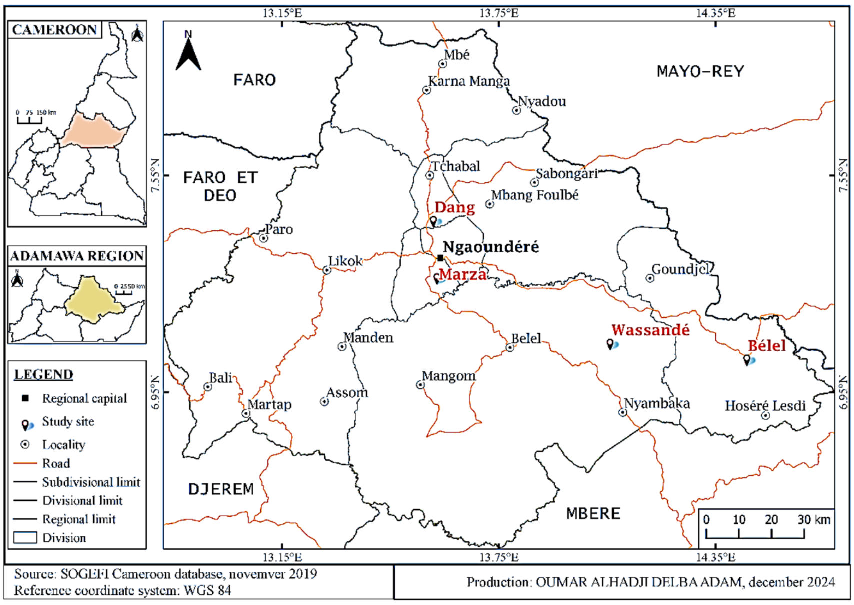


Fig. 1. Map showing location of study areas (Source: SOGEFI Cameroon database, November 2019).

located between the 6th and 8th degrees North latitude and between the 11th and 15th degrees East longitude (Fig. 1) from January to April 2023. The rainy season runs from April to October and the dry season from November to March (Mope 1997). Annual rainfall varies from 900 to 1500 mm depending on the locality. The soil in the region consists mainly of red ferralitic structures developed on old basalt (Yonkeu 1983). The region is covered by a humid tropical highland climate, also known as a highland Sudanian climate. Adamawa, also known as Cameroon's water tower because of the large number of rivers in the country that have their source there, has five plant formations, including gallery forests, open forests, tree savannas, shrub savannas and grassy savannas dominated by *Daniellia oliveri* and *Lophira lanceolata* (Letouzey 1968). This vegetation is under considerable threat from human activity.

Methodology

Sampling method for Persea americana trees

The localities of Bélel, Dang, Marza and Wassandé were chosen for this study. They are part of the avocado production basins in the Adamawa region.

The agro-morphological characterization of *Persea americana* was carried out using the avocado descriptor developed by IPGRI (1995). In each village, 10 mature trees (in full fruiting stage) were selected on a reasoned basis from the different agrosystems or home gardens. Trees are selected using the crossed diagonal method, which consists of considering the trees on the two diagonals crossing at the middle of the plantation (Tandjiékpon *et al.* 2005). In addition, a spacing of 20 m was considered in the selected plantations (Kouyaté 2005). A total of 40 trees were sampled throughout the study area, with 10 trees per locality.

Data collection

A total of 5 qualitative and 15 quantitative traits were measured on each tree on the base of the avocado descriptor as developed by Biodiversity International (IPGRI 1995). The quantitative data measured were those relating to the vegetation (dendrometric measurements), the leaf and the fruit. The experimental design used is a Completely Randomized Design in which the four (04) villages of Belel, Dang, Marza and Wassande constitute the treatment with ten replicates of avocado plants.

Table 1. Qualitative features of the morphological description of *Persea americana.*

Organs	Characteristics observed	Codes
Leaves	Leaf shape	LS
	Leaf color	LC
	Shape of leaf apex	SLA
	Shape of the base of the leaf	SBL
Fruit	Fruit shape	FS

Quantitative data.

Qualitative data

Qualitative data were collected using the method of Chipojola *et al.* (2009). This method is based on the avocado descriptors developed by Biodiversity International. Observations were made on the fruit and leaves (Table 1).

Measurement of dendrometric parameters

The dendrometric measurements relate to vegetative characteristics such as diameter at breast height, total height of the tree, mean crown diameter and crown area (Table 2).

Fruit and leaf parameters were also measured.

Table 2. Quantitative parameters measured.

Organs	Parameters measured	Codes
Tree	Diameter at breast height	Dbh
	Total tree height	TTH
	Mean crown diameter	Mcd
	Crown area	CA
Fruit	Fruit weight	FW
	Fruit length	FL
	Fruit width	Fw
	Seed weight	SW
	Seed length	SL
	Seed width	Sw
	Pulp weight	PW
Leaf	Leaf length	LL
	Leaf width	Lw
	Petiole length	PL
	Petiole width	Pw

Fig. 2. Measuring circumference at breast height.

These are fruit weight, fruit length, fruit width, seed weight, seed length, seed width, pulp weight, leaf length, leaf width, petiole length, petiole width (Table 2).

Diameter at breast height (Dbh)

This is determined from the circumference measured 1.30 m above the ground using a graduated tape measure. This Dbh was calculated using the formula: $DhP = \frac{C}{\pi}$ where C is the circumference of the tree measured 1.30 m above the ground (Fig. 2).

In order to obtain a single figure per tree, for trees with more than one stem, the formula $DBH=\sqrt{d_1^2+d_2^2+...+d_n^2}$ was used. The DBH is thus the root of the sum of the squares of each of the diameters of the stems measured (Rondeux 1999).

Total tree height (TTH)

The total height of the tree was determined by estimation.

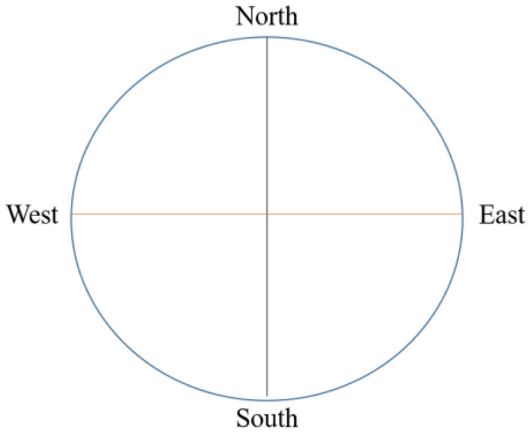


Fig. 3. Measuring crown diameters.

Mean crown diameter (DmC)

This is determined from the North-South and East-West diameters of the canopy, which are measured using a decameter (Fig. 3).

The mean diameter results from the root mean square according to the formula of Rondeux (1999):

$$D = \sqrt{\frac{D_1^2 + D_2^2}{2}}$$

Where D = Average diameter of the top, D_1 = North-South diameter and D_2 = East-West diameter.

Ground surface of the crown (SC)

This is calculated using the formula of Rondeux (1999): $S = \frac{\pi \times D^2}{4}$, Where D = average top diameter.

A total of 10 mature fruits per genotype in the localities were sampled. Fruit length and width were measured by Electronic Digital Caliper as well as seed length and width. The weight of the fruit and seeds was weighed using an electric scale.

Data analysis

The data collected were analyzed using Statgraphic 5.0, Xlstat and Microsoft Office 2016. Duncan's test was used to separate significant means using

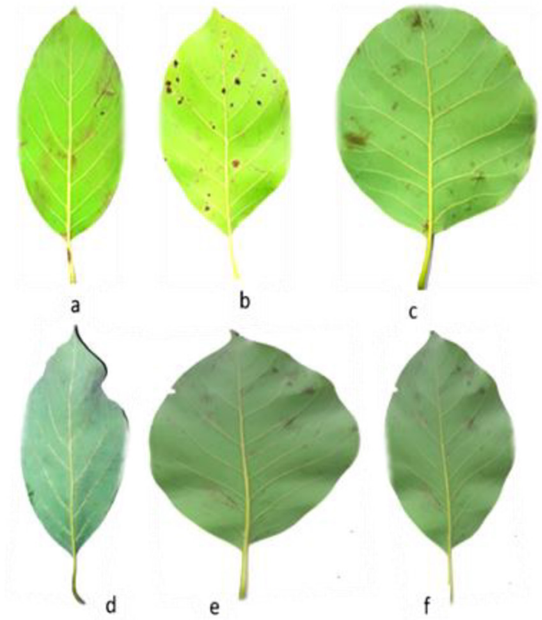


Fig. 4. Different leaves observed at the study sites.

Statgraphic 5.0. Quantitative characteristics of trees, leaves, fruits and seed were expressed in form of means±standard deviation. A Principal Component Analysis (PCA) and a Hierarchical Ascending Classification (HAC) were performed using Xlstat to explore the relationships between variables (TTH= Total tree height, Dbh= Diameter at breast height, Mcd= Mean crown diameter, CA = Crown area, SW= Seed weight, PW= Pulp weight, FW= Fruit weight, FL= Fruit length, Fw= Fruit width, SL= Seed length, Sw= Seed width, PL= Petiole length, Pw= Petiole width, LL= Leaf length, Lw= Leaf width) and the similarities between individuals, respectively, and to classify variables and individuals according to their similarity on a dendrogram.

RESULTS

Qualitative parameters

The qualitative parameters studied are the shape and color of the leaf, the shape of the leaf apex, the shape of the base of the leaf and the shape of the fruit.

Leaf characteristics

Leaf color and shape

Leaves in Vina have two main colors: Light green (Figs. 4 a–c) and dark green (Figs. 4 d–f). A total of 04 leaf blade shapes were observed. The lanceolate shape (65%) was prevalent in the 4 localities, followed by obovate (15%), oval (10%) and elliptical (10%). These leaves vary in shape. Leaves a and d are elliptical, leaves b and f are lanceolate and leaves c and e are oval and obovate respectively.

Leaf apex shapes

The leaf apex shapes observed in these different areas include: Apiculate (Leaf 1), acuminate (Leaf 2), obtuse (Leaf 3) and acute (Leaf 4), (Fig. 5).

Leaf base shapes

The following leaf base shapes were recorded: Acute, obtuse, acuminate, asymmetrical and rounded (Fig. 6). The base of leaf 1 is acute, that of leaf 2 is obtuse, while leaf 3 is asymmetrical, that of leaf 4 is acuminate and the base of the leaf is rounded.

The lanceolate leaf was found in Wassandé and Bélel with values of 9 and 8 respectively, corresponding to a rate of 65% for all localities. Leaves with a sharp apex were more common in Marza (6) and Wassandé (4), with an overall representativeness rate of 40%. Leaves with a sharp base were mainly observed in Dang (9) and Belel (8). Dark green leaves were mainly found in Wassandé (7) and Belel (8) (Table 3).

Fruit quality characteristics

Fruit shape

Four distinct fruit shapes were selected. These were elongated (f and g), piriform (a, b, d, h and i), spher-

Fig. 5. Various leaf apex shapes.

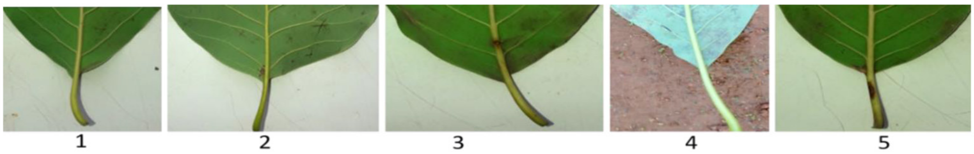


Fig. 6. Leaf base shapes.

Table 3. Different qualitative characteristics of leaves observed in the localities.

Leaf descriptors		Dang	Marza	Wassandé	Bélel	Total number	Total percentage (%)
LS	Lanceolate	5	4	9	8	26	65
	Obovale	3	1	1	1	6	15
	Oval-shaped	1	0	1	2	4	10
	Elliptical	0	4	0	0	4	10
SLA	Acuminate	3	0	4	3	10	25
	Sharp	2	6	4	4	16	40
	Apiculate	3	5	1	3	12	30
	Obtuse	2	0	1	1	4	10
SBL	Sharp	9	4	5	8	26	65
	Rounded	0	0	1	1	2	5
	Obtuse	0	3	2	0	5	12.50
	Acuminate	1	1	1	1	4	10
	Asymmetrical	0	0	2	1	3	7.50
LC	Light green	6	5	3	2	16	40
	Dark green	4	5	7	8	24	60

Legend: LS : Leaf shape, LC : Leaf color, SLA : Shape of leaf apex, SBL : Shape of the base of the leaf.

ical (e) and oval (c and j) (Fig. 7) with 35%, 30%, 25% and 10% respectively.

Quantitative descriptors of Persea americana

Several quantitative descriptors were studied, in particular those relating to the tree (total height of the tree, diameter at breast height, average diameter of the crown and surface area of the crown), the leaf (length/width of the leaf, length/width of the petiole) and the fruit (length/width of the fruit and seed, weight of the fruit, pulp and seed). These descriptors constitute differentiation criteria between *Persea americana* individuals.

Tree morphological descriptors

The longest avocado trees were obtained in Wassandé and Bélel, each with 18.80 ± 4.9 m and 19.90 ± 4.01 m respectively (Table 4). This inter-population variation is significant (0.0000 < 0.001). Diameter at breast height varied from 0.26 ± 0.16 m in the Marza avocado trees to 1.05 ± 0.09 m in the Wassandé trees. Analysis of variance shows a significant difference (0.0000 < 0.001). Trees with a large crown diameter were noted in Bélel and Wassandé with 7.10 ± 1.71 m and 8.55 ± 1.18 m respectively. Analysis of variance shows a significant difference (0.0000 < 0.001). Similarly, the Bélel and Wassandé avocado trees had

Fig. 7. Diversity of *Persea americana* fruit shapes.

Table 4. Quantitative tree traits.

Tree descriptors	Sites				
	Dang	Marza	Wassande	Belel	Mean
TTH (m)	12.30 ± 4.19^{a}	10.20 ± 2.20^{a}	18.80 ± 4.91^{b}	19.90 ± 4.01^{b}	15.30 ± 5.65
Dbh (m)	0.77 ± 0.30^{b}	0.26 ± 0.16^{a}	1.05 ± 0.09^{c}	0.86 ± 0.11^{b}	0.74 ± 0.34
Mcd (m)	6.85 ± 2.04^{b}	4.76 ± 2.23^{a}	8.55 ± 1.18^{c}	7.10 ± 1.71^{bc}	6.81 ± 2.23
CA (m^2)	39.77 ± 23.16^{b}	21.35 ± 19.69^{a}	58.38 ± 15.58^{c}	41.68 ± 18.01^{bc}	40.29 ± 22.82

Means with the same letters in the different rows are not significantly different at the 5% level.
Legend: TTH= Total tree height, Dbh= Diameter at breast height, Mcd= Mean crown diameter, CA = Crown area.

considerable canopy areas, with values of 41.68 ± 18.01 and 58.38 ± 15.58 m^2 respectively (Table 4). Analysis of variance shows a significant difference (0.0017 < 0.01).

Leaf morphological descriptors

Leaves with high elongation were observed in the Bélel and Dang avocado trees with 175.46 ± 44.70 mm and 180.48 ± 30.08 mm respectively (Table 5). Analysis of variance did not show a significant difference (0.3639 > 0.05). Broad leaves were observed in Marza and Dang with 74.38 ± 11.72 mm and 78.59 ± 15.02 mm respectively (Table 5). Analysis of variance showed a significant difference (0.0113 < 0.05). In terms of petiole length, the leaves of Bélel and Wassandé were more slender, at 26.42 ± 5.86 mm and 27.89 ± 4.84 mm respectively (Table 5). Analysis of variance did not show a significant difference (0.7542 > 0.05). In terms of petiole width, the thickest petioles were observed at Dang and Wassandé, with values of 2.59 ± 0.50 mm and 2.59 ± 0.41 mm respectively (Table 5). The analysis of variance did not show a significant difference (0.6407 > 0.05) for this quantitative parameter studied.

Fruit and seed characteristics

Fruit weight ranged from 145.31 ± 62.19 g in Marza plants to 237.75 ± 44.00 g in Wassandé plants (Table 6). Analysis of variance shows a significant difference (0.0018 < 0.01). Pulp weight ranged from 100.68 ± 48.41 g for fruit harvested at Marza to 170.86 ± 33.42 g for fruit harvested at Wassandé (Table 6). The variability observed shows a significant difference (0.0010 < 0.01). Seed weight fluctuated between 36.49 ± 15.81 g at Marza and 67.90 ± 38.65 g at Dang (Table 6). Analysis of variance shows a significant difference (0.0012 < 0.01). The longest fruits were found in Marza and Wassandé, with values of 94.79 ± 23.22 mm and 124.47 ± 54.78 mm respectively (Table 6). Analysis of variance for this parameter did not show a significant difference (0.0501 > 0.05). Fruit width ranged from 60.77 ± 19.11 mm for Marza fruit to 71.99 ± 6.43 mm for Wassandé fruit (Table 6). However, analysis of variance did not show a significant difference for this parameter despite this variation (0.1577 > 0.05). The longest seeds were found in Marza and Wassandé with values of 48.14 ± 9.18 mm and 52.68 ± 6.61 mm respectively (Table 6). Analysis of variance did not show a significant

Table 5. Descriptive quantitative parameters of *Persea americana* leaves.

Quantitative parameters	Sites				
	Dang	Marza	Wassande	Belel	Mean
LL (mm)	180.48 ± 30.08^{a}	162.81 ± 26.75^{a}	157.54 ± 23.73^{a}	175.46 ± 44.70^{a}	169.07 ± 32.45
Lw (mm)	78.59 ± 15.02^{b}	74.38 ± 11.72^{ab}	63.32 ± 9.00^{a}	64.76 ± 8.43^{ab}	70.26 ± 12.69
PL (mm)	26.17 ± 6.35^{a}	25.40 ± 3.22^{a}	27.89 ± 4.84^{a}	26.42 ± 5.86^{a}	26.47 ± 5.08
Pw (mm)	2.59 ± 0.50^{a}	2.42 ± 0.19^{a}	2.59 ± 0.41^{a}	2.46 ± 0.34^{a}	2.52 ± 0.37

Means with the same letters in the different rows are not significantly different at the 5% level.
Legend: LL= Leaf length, Lw= Leaf width, PL= Petiole length, Pw= Petiole width.

Table 6. Quantitative characteristics of fruits and seeds.

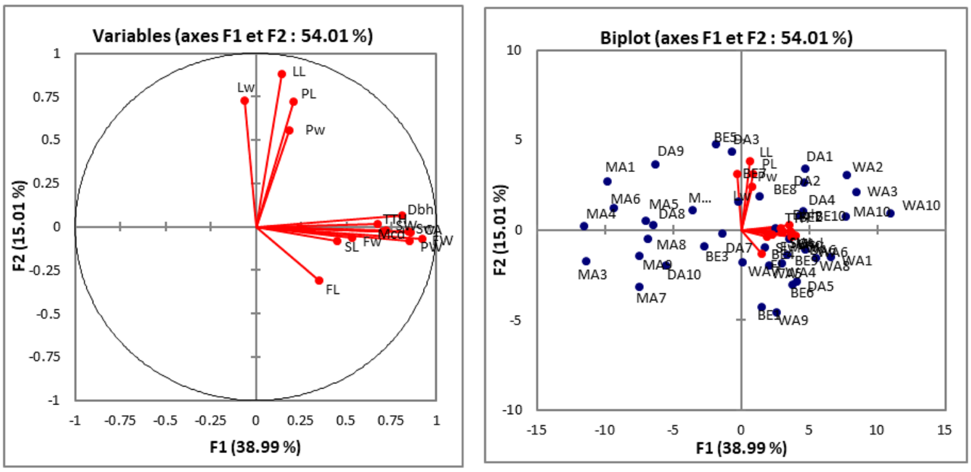
Fruit and seed descriptors	Sites				
	Dang	Marza	Wassandé	Bélel	Mean
FW (g)	193.32 ± 53.61[ab]	145.31 ± 62.19[a]	237.75 ± 44.00[b]	193.38 ± 25.60[ab]	192.44 ± 57.01
FL (mm)	88.81 ± 7.48[a]	94.79 ± 23.22[a]	124.47 ± 54.78[a]	92.89 ± 11.51[a]	100.24 ± 32.65
Fw (mm)	67.33 ± 7.22[a]	60.77 ± 19.11[a]	71.99 ± 6.43[a]	68.76 ± 5.02[a]	67.21 ± 11.35
PW (g)	116.48 ± 36.71[a]	100.68 ± 48.41[a]	170.86 ± 33.42[b]	125.04 ± 23.53[a]	128.26 ± 44.00
SW (g)	67.90 ± 38.65[b]	36.49 ± 15.81[a]	60.74 ± 17.19[b]	65.32 ± 18.13[b]	57.61 ± 21.21
SL (mm)	47.43 ± 4.90[a]	48.14 ± 9.18[a]	52.68 ± 6.61[a]	47.13 ± 5.95[a]	48.84 ± 6.96
Sw (mm)	48.95 ± 6.57[b]	35.68 ± 5.07[a]	46.08 ± 5.04[b]	46.86 ± 5.75[b]	44.39 ± 7.51

Means with the same letters in the different rows are not significantly different at the 5% level.
Legend: FW= Fruit weight, FL= Fruit length, Fw= Fruit width, PW= Pulp weight, SW= Seed weight, SL= Seed length, Sw= Seed width.

difference (0.2500 > 0.05). Seed width varied between 35.68 ± 5.07 mm at Marza and 48.95 ± 6.57 mm at Dang (Table 6). Analysis of variance shows a significant difference (0.0000 < 0.001).

Principal component analysis

The representation of individual avocado trees according to their variables shows that the distribution of avocado trees in the department of La Vina is not uniform in space (Fig. 8). The results of the Principal Component Analysis (PCA) show that the first two axes explain 54.01% of the total variability. These two axes can be used to describe the relationships between quantitative variables and individuals of *Persea americana* (Fig. 8). Axis 1 is defined by eleven (11) descriptors, including total tree height (TTH), diameter at breast height (Dbh), mean crown diameter (Mcd), crown area (CA), seed weight (SW), pulp weight (PW), fruit weight (FW), fruit length (FL), fruit width (Fw), seed length (SL) and seed width (Sw) (Fig. 8a). F1 is therefore the axis that describes tree, fruit and seed morphology. Axis 2 is defined by four (4) descriptor traits, namely petiole length (PL), petiole width (Pw), leaf length (LL), leaf width (Lw). (Fig. 8a). F2 is the leaf descriptor. The 11 parameters



a) b)

Fig. 8. Spatial distribution of quantitative variables (a) and individuals and quantitative variables (b) of *Persea americana.*

Legend: TTH= Total tree height, Dbh= Diameter at breast height, Mcd= Mean crown diameter, CA = Crown area, SW= Seed weight, PW= Pulp weight, FW= Fruit weight, FL= Fruit length, Fw= Fruit width, SL= Seed length, Sw= Seed width, PL= Petiole length, Pw= Petiole width, LL= Leaf length, Lw= Leaf width.

Table 7a. Correlations between variables and axis (b).

Variables	F1	F2
Dbh	0.812	0.064
TTH	0.675	0.019
Mcd	0.856	-0.030
CA	0.842	-0.024
FW	0.924	-0.071
FL	0.351	-0.307
Fw	0.531	-0.066
SL	0.447	-0.081
Sw	0.702	-0.029
SW	0.720	-0.019
PW	0.850	-0.084
PL	0.209	0.720
Pw	0.182	0.554
LL	0.146	0.879
Lw	-0.065	0.727

Table 7b. Contributions of variables (%) to axis.

Variables	F1	F2
Dbh	11.262	0.180
TTH	7.786	0.015
Mcd	12.542	0.041
CA	12.107	0.026
FW	14.581	0.226
FL	2.101	4.197
Fw	4.825	0.196
SL	3.418	0.292
Sw	8.433	0.036
SW	8.860	0.016
PW	12.339	0.310
PL	0.744	23.025
Pw	0.566	13.607
LL	0.362	34.334
Lw	0.072	23.500

Legend: TTH= Total tree height, Dbh= Diameter at breast height, Mcd= Mean crown diameter, CA = Crown area, SW= Seed weight, PW= Pulp weight, FW= Fruit weight, FL= Fruit length, Fw= Fruit width, SL= Seed length, Sw= Seed width, PL= Petiole length, Pw= Petiole width, LL= Leaf length, Lw= Leaf width.

linked to axis 1 are positively correlated with each other (Table 7a). This means that the individuals located on the side of this axis have high mean values for these parameters (Fig. 8b) similarly, the 04 parameters linked to axis 2 are positively correlated with each other (Table 7a) and the *Persea americana* genotypes located on the side of this axis have high mean values for these parameters such as Leaf length (LL) leaf width (Lw), petiole length (PL), petiole width (Pw) (Fig 8b). The avocado accessions in .Vina are therefore distributed in the plane defined by the axes by a set of two clouds of points.

Tables 7 a –b show the correlation values (positive or negative) of each parameter studied on the F1 and F2 axis and thus their contributions to the different discriminant axis. The variable that contributes most to an axis is the one that is most correlated with that axis (Tables 7a– b).

The dendrogram generated from the means of the quantitative characters measured in the *Persea americana* accessions at the different localities enabled us to identify six groups of morphotypes (Fig. 9). These morphotypes are distinguished from each other by the similarity index r = 0.9515. The first morphotype represents 62.5% of the total individuals and is made up of individuals DA1, DA2, DA4, DA5, DA6, DA7, DA10, MA10, WA1, WA2, WA3, WA4, WA5, WA6, WA7, WA8, WA10, BE1, BE2, BE3, BE4, BE6, BE7, BE9 and BE10. The discriminating criterion is diameter at breast height (Dbh), total tree height (TTH), mean crown diameter (Mcd), crown area (CA), seed weight (SW), pulp weight (PW), fruit weight (FW), fruit length (FL), fruit width (Fw), seed length (SL), seed width (Sw), petiole length (PL), petiole width (Pw) (Table 8). The second morphotype represented 12.5% of the individuals sampled. It is made up of individuals DA3, DA8, MA3, MA6 and BE8. This morphotype correlated well with the variables diameter at breast height (Dbh), crown area (CA), seed width (Sw), seed weight (SW), petiole length (PL), petiole width (Pw), leaf length (LL) and leaf width (Lw) (Table 8). The third morphotype represents 10% of the individuals sampled. It consists of DA9, MA1, MA4 and BE5. This morphotype has high values for the variables total tree height (TTH), petiole length (PL), leaf length (LL) and leaf width (Lw) (Table 8). The fourth morphotype represents 10% of the individuals sampled. It is made up of individuals MA2, MA7, MA8 and MA9. This morphotype has high values for the variables mean crown diameter (Mcd), fruit length (FL), fruit weight (FW), seed length (SL), pulp weight (PW) and leaf width (Lw) (Table 8). The fifth morphotype represented 2% of the individuals sampled. It consists of individual MA5. This morphotype had high values for the variables fruit width (Fw), petiole width (Pw) and leaf length

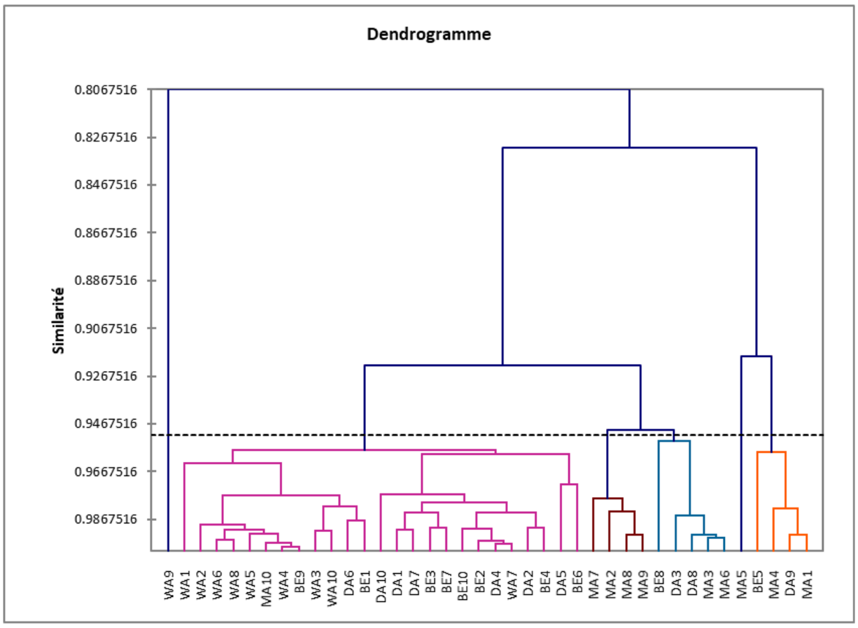


Fig. 9. Dendrogram showing the morphotypes of *Persea americana.*

Legend: DA = Dang, MA = Marza, WA = Wassande, BE = Belel.

(LL) (Table 8). The sixth morphotype represents 2% of the individuals sampled. It consists of individual WA9. This morphotype has high values for the variables diameter at breast height (Dbh), total tree height (TTH), mean crown diameter (Mcd), crown area (CA), fruit weight (FW), fruit length (FL), fruit width (Fw), seed length (SL), seed width (Sw), seed weight (SW), pulp weight (PW) (Table 8).

Table 8. Parameters according to morphotypes identified.

Morphotypes	Dbh (m)	TTH (m)	Mcd (m)	CA (m^2)	FW (g)	FL (mm)	Fw (mm)	SL (mm)
1	0.915	17.480	7.960	51.574	223.409	100.328	71.232	49.486
2	0.517	11.400	4.830	24.538	144.057	82.954	59.910	44.616
3	0.474	13.250	4.750	17.953	109.324	81.478	53.222	43.313
4	0.334	10.750	4.875	19.768	153.306	109.128	54.388	55.393
5	0.127	10.000	4.500	15.890	117.470	70.990	111.640	35.410
6	0.840	12.000	6.500	33.160	224.300	253.450	66.300	63.440

Table 8. Continued.

Morphotypes	Sw (mm)	SW (g)	PW (g)	PL (mm)	Pw (mm)	LL (mm)	Lw (mm)
1	48.566	68.445	148.559	25.932	2.548	165.189	68.436
2	40.204	44.363	93.506	28.738	2.606	181.600	70.174
3	37.780	38.810	65.121	29.663	2.518	208.360	82.510
4	33.420	33.506	111.177	23.670	2.300	147.603	75.793
5	34.960	28.179	78.128	27.370	2.630	170.110	67.930
6	41.030	54.305	165.950	26.340	2.190	131.330	47.710

Legend: TTH= Total tree height, Dbh= Diameter at breast height, Mcd= Mean crown diameter, CA = Crown area, SW= Seed weight, PW= Pulp weight, FW= Fruit weight, FL= Fruit length, Fw= Fruit width, SL= Seed length, Sw= Seed width, PL= Petiole length, Pw= Petiole width, LL= Leaf length, Lw= Leaf width.

Table 8 shows the contribution of each variable to the six morphotype groups.

DISCUSSION

Variability of quality characteristics of *Persea americana*

Leaf characteristics

Leaf shape is an important attribute because it can express the extent of leaf area, and therefore the seasonal integral of light interception that can directly affect plant yield (Nkansah *et al*. 2013). In the present study, the avocado accessions sampled had 04 leaf shapes which were lanceolate (65%), oval (15%), elliptical (10%) and oval (10%). All these shapes have been previously reported by Janice *et al.* (2018) and Nkansah *et al.* (2013), who described seven leaf shapes among avocado trees in Ghana. Ismadi *et al.* (2018) reported only lanceolate (73.33%) and oblong lanceolate (26.67%) leaf forms among 15 avocado accessions in Indonesia. The higher number of leaf forms (04) found in the present study could be due to a larger sample size. The observation made on leaf color showed two main colors, namely light green and dark green (Fig. 4). These qualitative data are comparable to the work of Baye-Niwah and Mapongmetsem (2018) on *Moringa oleifera* in the Sudano-Sahelian zone of Cameroon. These authors showed that the leaves of the latter had two colors, brown and green. The predominance of the acute form of the leaf base (40%) and apex (65%) in avocado germplasm has also been reported in previous work on avocado accessions grown in other parts of the world (Janice and Takrama 2014, Chandrakant *et al*. 2023).

Morphological characteristics of the fruits

The shape of the avocado fruit is a commercially important morphological characteristic that attracts consumers to markets. According to Barrett *et al.* (2010), shape, size and vibrant external color attract customers and stimulate purchases. So having a wide diversity in fruit shape offers an asset to interest various customers. In the present study, 04 fruit shapes were recorded in the sampled trees, including elongated (35%), piriform (30%), spherical (25%) and oval (10%) (Fig. 7). These shapes have already been reported among avocado cultivars in Tanzania (Ibrahim *et al.* 2021). In India, Chandrakant *et al.* (2023) described 02 fruit base shapes: Depressed (48.61%) and swollen (38.89%); 02 fruit apex shapes: Asymmetrical and central; 04 distinct colors: Light green (37.50%), green (23.61%), purple (22.21%) and dark green (5.54%). The fruit variability observed in the previous study is similar to the present one. Furthermore, Muralidhara *et al.* (2023) in India reported that most accessions had a narrow obovate fruit shape (24.10%) followed by obovate (21.69%) and ellipsoid, clavate, rhomboid (10.84%). In Ghana, Janice *et al.* (2018) observed that fruit shapes studied included piriform, narrow obovate, ellipsoid, clavate, rhomboid, oblate and spheroid. Other fruit shapes included high spheroid and obovate. Variation in fruit shape could be governed by the genetic composition of the accession rather than environmental effects (Ranjitha *et al.* 2021).

Quantitative characteristics

Tree characteristics

All the avocado trees studied were over 5 m tall (Table 4), which suggests that all these plants are mature. It has been shown that avocado trees between 3 and 4.5 m are relatively easier to manage and more productive than taller plants (Partida 1996). This characteristic means that it will be very difficult for farmers to manage their taller plants. It is therefore necessary for breeders to cross existing trees with improved accessions that are shorter in height to facilitate harvesting and increase commercial production. Harvesting tall trees is very difficult and costly. Shorter avocado trees with good canopy development produce more fruit than taller ones. In California, it has been reported that avocado fruit yields fell from around 2177 to 725 kg/ha over a three-year period when the canopies were overcrowded so that there was insufficient sunlight (Partida 1996). When these trees were pruned to open up the canopy to allow more light through, and the height of the trees was limited to around 3.6 m, the yield increased again. It was also observed that not only did the fruit yield increase, but that the cost of harvesting was considerably reduced on the pruned trees. It is therefore possible that avocado growers in Vina will get a higher yield and better income from their agrosystems and avocado plantations when the trees are pruned to between 3 m and 4.5 m in height. The average canopy spread of avocado trees studied in the present work ranged from 4.76 ± 2.23 m in Marza avocado trees to 8.55 ± 1.18 m in Wassande avocado trees, having 21.35 and 58.38 m^2 of surface area, respectively (Table 4). These results are comparable with those of Janice *et al.* (2018), who showed that canopy extent ranged from 4.9 m to 13.17 m. Diameter at breast height ranged from 0.26 m (Marza) to 1.05 m (Wassande). In addition, Lovett and Haq (2000) have shown that the diameter at breast height (1.30 m) of *Vitellaria paradoxa* individuals varies with land-use units.

Leaves variability

Avocado leaves vary in length. They can be as long as 22 cm or 40 cm (Irvine 1961, Morton *et al.* 1987). The avocado leaves sampled in this study had a blade length of between 157.54 ± 23.73 mm (Wassande) and 180.48 ± 30.08 mm (Dang) (Table 5). The large leaves are distinctive of both the West Indian and Guatemalan varieties and their hybrids (Bergh and Lahav 1996). Thus, the plants studied could well belong to these varieties.

Fruit morphology

An avocado fruit weighs approximately 200 to 300 g fresh weight (Paz-vega 1997). In the present study, the weight of fresh fruit ranged from 145.31 ± 62.19 g (Marza) to 237.75 ± 44.00 g (Wassande) (Table 6). These results are comparable to those of Sari *et al.* (2024) in Indonesia, who assessed the phenotypic variability of quantitative fruit character of 238 accessions of avocado and noted an average mass of 256.19 ± 69.35 g. In the same area, Anu *et al.* (2021) recorded a mean mass of 282g for 25 accessions of this Lauraceae. In Ghana, Janice *et al.* (2018) reported that fruit weight of avocado studied was variable; however, more than half (58.6%) of them weighed between 220 and 370 g. The length of the avocado fruit, ranging from 88.81 ± 7.48 mm (Dang) to 124.47 ± 54.78 mm (Wassande) (Table 6), is comparable to previous measurements for West Indian avocado, with an average of 150 mm (Crane 2008). The work of Tripathi *et al.* (2020) in India on 33 accessions of avocado revealed a variation in fruit size ranging from 74.6 mm to 113.1 mm. The Wassande avocados had an average length of over 100 mm, suggesting that the avocado trees in the area are of the West Indian variety (Bergh and Ellstrand 1986). The pulp weight ranged from 100.68 ± 48.41 g (Marza) to 170.86 ± 33.42 g (Wassande) and the seed weight from 36.49 ± 15.81 g (Marza) to 67.90 ± 38.65 g (Dang) (Table 6). In India, the mass of the seeds varied from 35.80g to 126.80g (Tripathi *et al*. 2020). These values are higher than those obtained in Congo on *Dacryodes edulis,* where the highest pulp weight was 46.4 g in the Central Congo ecotypes and that of the seed 18.2 g observed in the Kinshasa ecotype (Biloso *et al.* 2018).

The study of the morphological traits of the *Persea americana* fruit showed that there are phenotypic variations. These results corroborate those obtained by Atangana *et al.* (2001) on *Irvingia gabonensis,* as well as those of Waruhiu *et al.* (2004) on *Dacryodes edulis* and Janice *et al*. (2018) on avocado. Variability in fruit morphological characteristics is important for selecting species whose pulp is consumed (Biloso *et al.* 2018). These observed variations therefore suggest considerable scope for selection within each provenance.

Correlations between quantitative variables

Total tree height (TTH), diameter at breast height (Dbh), mean crown diameter (Mcd), crown area (CA), seed weight (SW), pulp weight (PW), fruit weight (FW), fruit length (FL), fruit width (Fw), seed length (SL) and seed width (Sw) were positively correlated. Similarly, petiole length (PL), petiole width (Pw), leaf length (LL) and leaf width (Lw) were positively correlated (Fig. 8a). Correlation between useful traits could be important for early selection of plants with improved traits, or can be used to select for more than one trait simultaneously. Indirect selection for less complex traits with high heritability and easy evaluation can reduce costs and improve the rate of genetic progress of related complex traits compared to their direct selection (Silva *et al.* 2016).

Classification and characterization of *Persea americana* accessions

The dendrogram based on quantitative characteristics showed six main groups (Fig. 9). The avocado accessions sampled, although collected at different locations, share certain similar morphological traits indicating a genetic resemblance of avocado accessions from home gardens. Each group has different morphological characteristics; hence accessions in the same group have different characteristics from other groups. This suggests that accessions from the same cluster may have a common ancestor.

Analysis of the grouping of populations into classes revealed that accessions from populations with morphotypes 1, 4 and 6 had better characteristics of interest to breeding program in terms of fruit, pips and vegetative development (Table 8). The different morphological variations suggest a genetic diversity and ecological adaptability of accessions that share a common ancestor. This may be due to the different environmental conditions in which the seeds were planted. In addition, cross-pollination between populations from the same location over a long period of cultivation may have led to the variation observed (Janice *et al.* 2018). The similar character observed between accessions from different villages may result from the retention of a parental gene over a long period of crossing with other accessions (Katsvanga *et al.* 2007, Kalinganire *et al.* 2008).

CONCLUSION

The aim of the study was to evaluate the agro-morphological characteristics of *Persea americana* in Vina (Adamawa, Cameroon). The investigations showed significant morphological variability and the most distinctive quantitative morphological traits were diameter at breast height, total tree height, mean crown diameter, crown area, seed weight, pulp weight, fruit weight, fruit length, fruit width, seed length, seed width, petiole length and petiole width. The varietal improvement program should take these different discriminating characteristics into account. This study highlighted a variability that led to the identification of six groups of interesting morphotypes. This stage is essential for implementing varietal selection. It enables accessions to be identified that respond to the concerns of farming communities, with a view to improving the food situation and increasing the incomes of local populations.

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