

Maintenance of *Balanites aegyptiaca* trees for fruit production in Kafta-Humera district, Western Zone of Tigray, Ethiopia.

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Research Article

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Abstract

Balanites aegyptiaca is a dryland tree species with multiple socioeconomic and ecological benefits. The tree is cultivated by farmers in their fields in the Kafta Humera District, but scientific information on the local fruit morphological characteristics, and its fruit production of the *Balanites aegyptiaca* tree were insufficient in the study area. This study was initiated to investigate the morphology and fruit production of *Balanites aegyptiaca* for conservation in Kafta-Humeradistrict. Fruit morphology was studied on 180 fruits from 18 trees representing three diameter classes and two flavors. The relationship between dendrometric parameters and fruit production was analyzed using Pearson's correlation test. In addition, ANOVA was used for fruit morphology and production. Results showed that fruit morphological characteristics and fruit production were significant ($p = 0.05$) and differed according to DBH grade and flavor. Overall, the multipurpose tree *Balanites aegyptiaca* has the potential to produce fruit and the conservation of this tree on agricultural land with proper management in drought-prone areas could increase food security and provide great potential for edible wild crops.

Background and justification

Balanites aegyptiaca is of great economic and ecological importance (Tesfaye & Minch, 2015). The fruits of *Balanites aegyptiaca* are edible and contain essential minerals (Sagna *et al.*, 2014). In addition, the leaves of this plant are a popular source of food for animals, which is why they can play an important role as a forage tree in the desert during severe drought. In addition, all parts of the plant have pharmacological effects and are used to treat diarrhea, hemorrhoids, abdominal pain, jaundice, yellow fever, syphilis and epilepsy (Yadav & Panghal, 2010). In general, *Balanites aegyptiaca* is an edible wild tea used for medicinal purposes, as animal feed, for human nutrition and to improve soil fertility.

Wild edible plants (WEP), including the habitats of *Balanites aegyptiaca*, are disappearing and edible plants are being selectively harvested for various purposes as growing human populations and need-based interventions continue to convert natural areas into cultivated areas (Asfaw, 2007). In Ethiopia, wild foods are a valuable livelihood supplement, complementing staple foods and ensuring food security, food diversity and income stability for the rural population (Asfaw and Tadesse, 2001; Bahru *et al.*, 2013; Kidane *et al.*, 2014). Despite the role those wild foods play in the livelihoods of rural Ethiopians, little attention has been paid to inventorying their crops and protecting species (Addis *et al.*, 2005; Berihun i Molla, 2017).

In some countries, *Balanities* varieties with bitter and sweet names are well known (Bassimbé *et al.*, 2014). However, this information is scarce in the study area. Therefore, understanding variation is necessary to identify superior genotypes and use them to increase fruit production and for management of *Balanites aegyptiaca* trees. Therefore, in order to fill these gaps, in this study, investigation of fruit morphology of scattered trees of *Balanites aegyptiaca* were initiated to improve fruit production in agricultural plots in Kafta-Humera district. The detailed objectives of the study were to quantify fruit abundance and study the morphological characteristics of *Balanites aegyptiaca* fruits in three diameter classes and taste varieties.

METHODS

Study area

The study was conducted in the Western administrative zones of the Tigray Regional State, Ethiopia. Qafta Humera Welkayit, and tsegedye districts were selected based on a preliminary assessment of *Balanites aegyptiaca* distribution in Tigray. Within these three districts, four sub districts were selected (Figure 1). The study area is characterized by hot to warm semi-arid lowlands agro-ecological zones (EIAR 2011). The study area has a unimodal rainfall pattern (June to September) with an average annual rainfall of 645 mm and mean temperature of 27.7°C (Figure.2).

The vegetation of the study area comes in three major types described as *Acacia-Commiphora* woodland, *Combretum-Terminalia* woodland, and riparian woodland (Friis et al. 2011). The wood species most frequently observed are *Balanites aegyptiaca*, *Diospyros mespiliformis*, *Adansonia digitata*, *Acacia Senegal*, *Acacia abyssinica*, *Acacia polyacantha*, *Tamarindus indica*, and *Ziziphus spina-Christi*. The land use of the study area is composed of mainly farmlands, grazing areas and forest (TAWoARD 2015; TAWoRLA 2015). Mixed crop-livestock farming is the primary livelihood system. Sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*) and maize (*Zea mays*) are the primary food crops, and sesame (*Sesamum orientale*) is the main cash crop in the area. Traditional gold panning and resin production from *Boswellia papyrifera* and *Acacia Senegal* are additional sources of income.

Sampling design and data collection

Key informants were pre-determined to help identify bitter and sweet *Balanites* varieties in the field. From a total of 30 key informants, from district participated in selecting 18 trees from both bitter and sweet *Balanites aegyptiaca* varieties during the fruiting season. The trees were classified into three diameter classes (15-30cm, 31-45cm, and 46-60cm) from which 6 trees were selected randomly from each class. Sample branches from upper, middle and lower canopy were harvested following Gwali *et al.* (2012). Mature fruits were collected from the trees selected for this study. Fruits were harvested by climbing onto the tree and picking after the fruit ripens. The studied fruits had no visible insect damage or disease symptoms. sixty fruit per diameter classes were randomly picked for morphological analysis (Lima *et al.*, 2015). This corresponds to a total of 180 fruits sampled in the selected study area.

From the fresh fruits, the following parameters were determined: fruit length (cm), seed length (cm), kernel weight (g) fruit width (cm), seed width (cm) measurements using a Vernier caliper (Ahmed, 2019). Individual fruit weight (g), seed weight (g), and Pulp mass was obtained by weighing using a sensitive balance (Abasse *et al.*, 2011). Pulp mass weighted after removing the seeds and skin of the fruit. The fresh pulps were dried at 70 °C for 24 hours in a drying oven until constant weight content was obtained following Boone and Wengert, (1998).

Fruit counting method by extrapolation (kouyate *et al.*, 2016) was applied in this study to assess fruit production per tree. According to the number of fruiting branches per DBH classes, selected from upper, middle and lower canopy, were counted according to the Sample branches as follow:

- Two branches when the number of fruiting branches was less than or equal to 5
- Three branches when the number of fruiting branches was between 5 and 10
- Four branches when the number of fruiting branches was more than 10.

The total numbers of fruits per branch class were obtained by multiplying the average number of fruits with the number of fruiting branches. The total number of fruits of the whole tree was obtained by summing the fruits number of all different branch classes (Ouédraogo *et al.*, 2019). For each *Balanites aegyptica* tree from which fruit was selected, certain dendrometric parameters such as diameter at breast height (DBH), number of branches, crown diameter and total height were measured.

3.3. Data analysis

All data were compiled and prepared with Excel 2010 computer program and analysis conducted with R software version 3.6.2 (Crawley, 2013). One and two-way ANOVA was used based on data type and the hypothesis to be tested. Morphological characteristic of fruit was analyzed using two-way ANOVA. Shapiro-Wilk normality test was used to check whether the data had come from a normally distributed population. Leaven tests were used for homogeneity of variance which indicates whether the variance scores were the same for all the groups. Correlation analyses were done to assess the relationships between quantities of fruit and dendrometric parameters, using Pearson correlation. A clustering and PCA (principal component analysis) multivariate analysis was done to show if there was a natural differentiation in the fruit properties and the associated data collected using past v.3 (Hammer *et al.*, 2001). $LSD_{0.05}$ Tukey's test was used to separate the significant means.

RESULTS AND DISCUSSION

Density of *Balanites aegyptiaca* by cultural group and land use

Balanites aegyptiaca densities varied noticeably between areas in the two land use types (p. 05, Kruskal Wallis test, Figure 3). The forest had a much higher *Balanites aegyptiaca* density than all the farmland combined. The diameter class distribution of *Balanites aegyptiaca* in both land use types followed a bell-shaped curve rather than an inverted J shape, indicating recruitment or regeneration issues (Figure 4). There were very few *Balanites aegyptiaca* specimens found in farmlands and none in the forest habitat in DBH class 15-30 cm, indicating serious recruitment issues. Large diameter trees (DBH classes 31–45 cm and 46–60 cm) were slightly more prevalent in farmlands than in forests (see data on supplemental file).

Phenotypic characteristics of the fruits of *Balanites aegyptiaca* local morphotypes

Community knowledge of morphotypes

All communities reported that there are two original morphotypes of *Balanites aegyptiaca* with distinct original names. crucial snitchers distinguished between sweet and bitter trees by taste, cover number, cover size, and color of growing. The bitter trees produce smaller fruits, have a thinner cover, and a light brown color at growing. In addition, the wood of bitter trees is hard and brittle, meaning it's fluently broken. Grounded on these characteristics, bitter *Balanites aegyptiaca* is considered to be 'manly' by communities. By comparison, the sweet tamarind variety is considered womanish because it produces further fruits each year, has thicker pods that are sanguine at maturity, and its wood is neither hard nor brittle.

Fruits morphological diversity

The *Balanites aegyptiaca* fruits were characterized in terms of their physical structures and morphology similar as fruit weight, seed weight, pulp weight, seed weight, fruit length, seed length, fruit range, and seed range. The fruit shape was diversified in the observation of globular and round (egg- shaped). The vividness of the bitter variety of *Balanites aegyptiaca* fruits of both the fruit cover and pulp is lighter brown while the sweet fruit cover and fresh pulp are typically deep brown (Figure 17).

The mean values recorded for fruit weight, fruit width, seed width, and pulp weight variables showed significant differences at ($p < 0.05$) among bitter and sweet type variety and with tree DBH classes of *Balanites aegyptiaca* trees (Table 7). Seed weight, seed coat weight, kernel weight, and fruit length were no having significant difference ($p > 0.05$) between bitter and sweet type of *Balanites aegyptiaca* tree.

Table 7: Mean ($\pm$ Sd) values of Morphological characterizations of *Balanites aegyptiaca* fruit, small (15-30cm), middle (31-45cm) and large (46-60cm).

Parameter	Taste type	DBH class			CV%	LSD _{0.05}	P-value
		large	Middle	Small			
fruit weight(g)	sweet	10.34 $\pm$ (0.735) ^a	10.09 $\pm$ (0.77) ^a	8.74 $\pm$ (0.68) ^b	6.46	1.24	*
	bitter	8.38 $\pm$ (0.74) ^a	8.82 $\pm$ (0.33) ^a	7.79 $\pm$ (0.61) ^b	6.56	1.17	***
seed weight(g)	sweet	5.93 $\pm$ (0.73) ^a	5.82 $\pm$ (1.3) ^a	4.73 $\pm$ (0.86) ^b	16.84	1.75	**
	bitter	5.21 $\pm$ (0.31) ^a	5.67 $\pm$ (0.45) ^a	4.78 $\pm$ (0.67) ^b	12.41	1	*
pulp weight(g)	sweet	3.06 $\pm$ (0.54) ^a	3.45 $\pm$ (0.16) ^a	2.22 $\pm$ (1.35) ^b	15.4	0.89	*
	bitter	3.02a $\pm$ (0.21) ^a	2.81a $\pm$ (0.48) ^a	1.56 $\pm$ (0.21) ^b	13.41	0.66	**
kernel weight(g)	sweet	0.92 $\pm$ (0.28) ^a	0.93 $\pm$ (0.08) ^a	0.73 $\pm$ (0.09) ^b	12.7	0.35	*
	bitter	0.86 $\pm$ (0.15) ^{ab}	0.96 $\pm$ (0.06) ^a	0.57 $\pm$ (0.06) ^b	12.66	0.21	**
seed coat weight(g)	sweet	2.16 $\pm$ (1.3) ^a	2.47 $\pm$ (0.5) ^a	2.1 $\pm$ (0.24) ^a	13.24	1.64	NS
	bitter	2.1 $\pm$ (0.1) ^a	2.15 $\pm$ (0.4) ^a	2 $\pm$ (0.12) ^a	10.82	0.52	**
fruit length(mm)	sweet	35.4 $\pm$ (0.44) ^a	37.3 $\pm$ (0.29) ^a	34.4 $\pm$ (0.07) ^b	8.75	0.62	*
	bitter	38.1 $\pm$ (0.32) ^a	37 $\pm$ (0.18) ^a	35.5 $\pm$ (0.36) ^b	8.2	0.6	*
seed length(mm)	sweet	31.73 $\pm$ (0.43) ^a	37.7 $\pm$ (0.69) ^a	32.4 $\pm$ (0.11) ^b	14.1	0.95	**
	bitter	35.3 $\pm$ (0.35) ^a	34.4 $\pm$ (0.13) ^a	32.6 $\pm$ (0.3) ^b	8.2	0.56	**
fruit width(mm)	sweet	25.7 $\pm$ (0.19) ^a	25.6 $\pm$ (0.15) ^a	21.6 $\pm$ (0.1) ^b	6.67	0.3	***
	bitter	23.4 $\pm$ (0.68) ^a	22.2 $\pm$ (0.11) ^a	20 $\pm$ (0.02) ^b	12.98	0.8	**

Treatments with the same letter are not significantly different ($p < 0.05$) Where, * = $P < 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$, NS = $p > 0.05$, DBH = diameter at breast height

The analysis of variance mean values of fruit weight, pulp weight, fruit width, and seed width shows significant differences ($p < 0.001$) between taste varieties of *Balanites aegyptiaca* trees.

The mean value of seed weight, seed coat weight, kernel weight, fruit length, and seed length were shows significant difference ($p > 0.05$) between the two distinct varieties. The differences expressed in the morphology of *Balanites aegyptiaca* fruit within the different taste type varieties within the same agro-ecology zone could mean that it has high genetic variation.

In general, this result shows that the bitter and sweet trees were distinct varieties found within the study area as much confirmed with the local knowledge as traditionally distinguished morphotypes of these *Balanites aegyptiaca* varieties.

This finding was similar to Kala and Dubey, (2014) has reported similar results for fruit length, fruit diameter and fruit weight of *Balanites aegyptiaca*. They observed fruit length 36 to 58mm, fruit diameter 18.7 to 28.5mm and fruit weight 5.5 to 10.5g study in humid subtropical climatic condition of Agra, India. similarly Abasse *et al.*, (2011) reported that Fruit weight (6.28g) fruit length (2.78 cm) fruit width (2.22 cm) seed length (2.51cm) seed width (1.82cm) and kernel weight (0.58g) of fruit morphology of *Balanites aegyptiaca* was recorded in the Maradi region of Niger.

There was a significant difference ($p < 0.05$) in fruit morphology across the DBH class. The medium and large DBH classes were shown significantly different ($p < 0.05$) within the corresponding lower DBH class of *Balanites aegyptiaca*. The middle DBH class had the highest fruit weight (9.45g), pulp weight (3.1g), thickness (23.9mm), seed width (15.7mm) and in contrast to lower DBH class that recorded 8.27g, 1.9g, 20.8mm, and 13.3mm respectively. , seed coat weight were not a significant difference ($p < 0.05$) among tree DBH classes, but slightly decreasing the fruit attribute to tree DBH classes increase.

The middle diameter class had also fruit weight, pulp weight, kernel weight, highest fruit length, thickness and seed thickness in contrast to high and lower diameter class. Fruit weight found to be in the range of (7.8g–10.3g) this result was higher than reported by Ahmed *et al.* (2019) 5.8-8.7g. Similarly the length of fruit was higher than previously reported by Arbonnier, (2002) 21.6-35.2mm long. Fruit thickness found to be in the range of (20.8-25.7mm). This result was lower than reported by Abasse *et al.* (2011) 27.8–30.5mm.

Likewise seed thickness found to be in the range of (13.3-16.8mm). This result was lower than reported by (El Feel and Warrag, 2006) who reported seed thickness of the fruit that ranges from 19-23mm.

The climatic conditions were similar at our study so the important factors that may have affected the intraspecific variation in phenotypic or morphological traits of the fruits are the reflection of age and genetic variability (Assogbadjo *et al.*, 2006). The differences expressed in morphology of *Balanites aegyptiaca* fruit across the different diameter class and taste type variety with in the same agro ecology zone could mean that it has high genetic variation. This indicates great potential for further improvement or breeding through selecting super provenance for domestication.

The Mean moisture content of *Balanites aegyptiaca* fruit pulp of sweet and bitter varieties found that 20.38% and 17.76% mean values respectively. That shows significant difference ($p < 0.05$) fruit pulp moisture content between

the two taste type *Balanites aegyptiaca* fruits. Sweet fruit type varieties were higher by 12.8% from bitter fruit type varieties of *Balanites aegyptiaca* tree. This result may be due to fruit size and genetic varieties of the *Balanites aegyptiaca* tree of the study area. Such result was in agreement with that reported by; Roy and Joshi, 1995; ; Groller *et al.*, 1998; Girma, 2014). 18.5%, 22.6 – 69%) and 20% of moisture content in fruit pulp respectively. In contrast, 15.80 % of moisture content of the fruit (Amit *et al.*, 2011) which is observed lesser than in this case.

4.5.2. Fruit production of *Balanites aegyptiaca* tree

Fruit production varied significantly ($p < 0.01$) among the tree DBH classes of *Balanites aegyptiaca* tree (Table 8), But not statistically significant ($p > 0.05$) between bitter and sweet type variety. Similarly, in fruit quantity the analysis result shows significant differences ($p < 0.05$) among DBH classes and between taste type *Balanites aegyptiaca* tree varieties. Higher values recorded on larger DBH classes than in middle and lower DBH classes. According to test variety, the bitter type was produced slightly higher fruit quantity than sweet type.

In fruit moisture content The ANOVA analysis indicated that, these mean values showed that significant differences ($p < 0.05$) in moisture content between these distinct varieties and DBH classes at ($p < 0.05$).

Table 8: Mean ($\pm$ Sd) values of *Balanites aegyptiaca* fruit production

Parameter	Taste	DBH class			CV%	LSD _{0.05}	P-Value
		large	Middle	Small			
Moisture cont. (%)	sweet	20.33 $\pm$ (1.04) ^{ab}	22.55 $\pm$ (1.98) ^a	18.25 $\pm$ (2.12) ^b	9.7	3.95	**
	bitter	17.48 $\pm$ (0.58) ^{ab}	20.23 $\pm$ (0.84) ^a	15.57 $\pm$ (2.6) ^b	9.15	3.2	* *
Fruit production(kg)	sweet	34.23 $\pm$ (0.35) ^a	27.82 $\pm$ (2.07) ^b	17.55 $\pm$ (2.7) ^c	4.78	2.53	***
	bitter	28.44 $\pm$ (1.1) ^a	26.95 $\pm$ (0.79) ^b	23.78 $\pm$ (0.95) ^c	5.2	2.74	** *
Quantity of fruit/tree	sweet	2377.9 $\pm$ (165.9) ^a	2034.1 $\pm$ (92.3) ^b	1432.8 $\pm$ (575.5) ^c	4.57	248.3	**
	bitter	2484 $\pm$ (83.9) ^a	2398.3 $\pm$ (228.6) ^b	2148.5 $\pm$ (380) ^c	8.6	520.6	**

Treatments with the same letter are not significantly different ($p < 0.05$) where * = $P < 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$, NS = $p > 0.05$, DBH = diameter at breast height

Accordingly, the mean values of fruit per tree DBH were varied from 31.33Kg for large DBH class, 27.38Kg middle, and the corresponding lower class 20.66Kg. At middle DBH (31–45cm) and lower DBH (15–30cm) lower by 12.6% and 34 % respectively as compared with large DBH (46 – 60cm). The result noted that the total quantity of fruits increased with stem diameter. This determination was similar to (Ouédraogo *et al.*, 2019) report on *Balanites aegyptiaca* in fruit production increases with stem DBH increase. Likewise, (Lompo *et al.* 2018) study on *Ximenia Americana* the total number of fruits increased with stem diameter.

The result suggests also in agreement with Miller & Dietz, (2004) that larger trees (large DBH) generally have greater fruit quantities than those of smaller trees. Large trees produce more fruits; because they have larger

crowns; as crown volume increases exponentially with DBH, so does fruit production (Charoensuk *et al.*, 2018).

The small trees use their energy for both vegetative growth and reproduction. Additionally, the small tree crown size and the root developments (which contribute significantly to nutritive substances synthesis) are less than those of the larger trees. Therefore, the highest fruit production observed in the large trees could be related to their greater ability to assure the photosynthesis (Demir *et al.*, 2014; Snook *et al.*, 2005). Since DBH is an easily accessible dendrometric parameter, it could be used to evaluate the fruit potential of this species that is highly exploited for economic purposes throughout its distribution range.

4.5.3. Correlation of fruit production with tree morphological variable

The Pearson correlation tests showed that DBH exhibited the strongest positive relationship with fruit production ($r=0.59$, $p<0.0001$), and tree height exhibited the weakest correlation with fruit production of the species ($r = 0.26$, $p<0.0001$). The results displayed also DBH and height as the highest and lowest parameters correlated with the number of fruits respectively (Table 9).

Correlation studies provide information on the nature and extent of association between any two things (Mayavel *et al.*, 2018). The Pearson correlation showed that the quantity of fruit per tree, fruit production with a DBH, crown diameter, and the number of branches was observed, that strong and positively correlated.

Table 9: Pearson correlation analysis between tree morphological parameters and fruit production

Parameters	DBH	H	CD	CA	NB	FP
DBH	1					
H	0.26NS	1				
CD	0.78**	0.44ns	1			
CA	0.79**	0.42ns	0.99***	1		
NB	0.68**	0.21ns	0.68**	0.63**	1	
FP	0.59**	0.16ns	0.67**	0.63**	0.82***	1

Where * = $p \leq 0.05$, ** = $p \leq 0.01$, NS = non-significant at $p < 0.05$, r = correlation DBH = Diameter at breast height, H = total height of the tree; CA = Crown cover area (m²) NB = number of branches, CD = Crown diameter (m) n = number of trees FP = Fruit production

Balanites aegyptiaca fruit production increases with DBH, the crown cover area, and the number of branches. Various works on tropical fruit-bearing trees have reported similar results on local fruit-bearing trees (Bondé *et al.*, 2019; Lankoandé *et al.*, 2017; Nacoulma *et al.*, 2017; and Ouedraogo *et al.*, 2014). This study showed that, first of all, predictive variables, the fruit production are a function of the tree trunk size. Therefore, DBH is a judicious parameter to facilitate fruit production (Kainer *et al.*, 2007).

Balanites aegyptiaca was positively related to tree diameter, suggesting that the bigger the tree, the greater its ability to flower and bear fruits. This confirms with a study on *Haematostaphis barteri* tree species provided that tree size positively correlated with fruit production (Sourou *et al.*, 2016). It also found a significant and positive

correlation between fruit production and crown width. A similar result has been observed study on *Persea Americana* Miller that the productivity of avocado trees had shown a significant correlation with canopy width (Biazin *et al.*, 2018). Trees that received more sunlight tended to produce more fruits (Londres *et al.*, 2017). Such Strong and positive correlations are useful in tree provenance selection. However, the amount of fruit was not significantly correlated ($p > 0.05$) with total tree height. Weak correlation fruits production with height is that height does not allow estimating the fruit production due to there is the tall tree with small diameter and short tree with a large big diameter (Abdou *et al.*, 2015).

The hierarchical clustering analysis on *Balanites aegyptiaca* fruit morphology diversity was distributed into three main clusters. The first cluster included sweetS (S denotes small DBH class) and bitterS sub clusters, the second cluster included sweetM (M denotes medium DBH class) and bitterM, the third group was sweetL (L denotes large DBH class) and bitter L (Figure 18). A factor found in the same cluster indicates the factors have a similarity effect on fruit morphology and found at a different cluster shows the factors had different effects on fruit morphology and diversity. The hierarchical clustering shows DBH classes have significant impact to fruit morphology diversity when compared to taste variety types. Additionally the three groups of hierarchical clustering shows the three DBH cases have different effect on fruit morphological diversity and fruit production. . Generally, the clustering analysis indicates the natural differentiation of *Balanites aegyptiaca* fruit morphology characteristics was more affected by tree DBH and followed by taste type variety of the tree.

A principal component analysis (PCA) of the DBH class groups was run for fruit morphology diversity values as presented in (Figure 19). As can be seen with respect to the principal components (PC) 1 and 2, the score of the principal component analysis showed that two components explained 58.07% of the total variation contributed by all characteristics for the *Balanites aegyptiaca* tree fruit morphology, the first component presented 41.03%, the second component 17.04% on the total variation of fruit morphology.

The first component presented 41.03% of the variation in which fruit weight, pulp weight, fruit quantity, fruit production, moisture content and seed width had the highest loadings to varied fruit morphology among DBH classes and taste type *Balanites aegyptiaca* tree. The second component 17.04% of the variation in this variation seed coat weight and kernel weight was higher loadings on the total variation of fruit morphology.

Both the PCA and cluster analysis show that the fruit characteristics is mostly determined by DBH rather than variety, though variety also has a secondary effect. The DBH effects of small trees are shown at a higher distance than the medium and large. All of this is congruent with existing knowledge, that small and mature trees give different dimensions in fruits. Varieties also show a secondary effect, with it being again congruent with existing studies that varieties also affect fruit characteristics. It should also be noted that this study clearly shows that there are two distinct varieties of *Balanites aegyptiaca*. Similarly to this study Grygorieva *et al.* (2014) reported on morphological characteristics of fruits, drupes and seeds in genotypes of *Ziziphus jujuba mill* through multivariate analysis (PCA and clustering) shows varied on genotypes of *Ziziphus jujube mill*.

CONCLUSION AND RECOMMENDATIONS

Fruit morphology and production differences were observed among morphological characteristics of *Balanites aegyptiaca* varieties of taste types and DBH classes in Kafta-Humera district. Using morphological characters of fruit, this study pointed out that there is a high variation in fruit weight, seed weight, kernel weight, fruit length, seed

length, fruit thickness, seed thickness and moisture content of fruit pulp of *Balanites aegyptiaca* among the sweet and bitter type varieties of the tree.

Furthermore, fruit production per tree was significant varied among the DBH classes and highly positively correlated with crown diameter (CD), and Crown area (CA) but not more related to the tree height. This study contributes to highlighting the knowledge on parameters influencing fruit production of *Balanites aegyptiaca* in tropical zones. Finally, *Balanites aegyptiaca* as a multipurpose tree added a significant amount of nutrients to the soil. Thus, retaining these important tree species on farmland played a positive role and have a good potential fruit production that augments food security.

5.2. Recommendations

The research results enable us to draw the following recommendations:

- retaining these important *Balanites aegyptiaca* tree species on farmland played a positive role and have a good potential fruit production that augments food security.
- The morphological evidence and community knowledge differentiating these two morphotypes highlights the need for conservation of their populations in northern Ethiopia. While this research demonstrated phenotypic variation between the morphotypes recognized by local communities, a more detailed study that includes genetic analyses is necessary for conservation of intraspecific diversity.
- Further botanical investigations are needed, taking into consideration variations in fruit characteristics according to the fruit shape and tree location and the effect of environmental and genetically conditions and different types or varieties of this species may be identified.

Declarations

Author Contribution

Details of each author with his or her contribution to this paper are as follows: Types of contribution
Halefom Weldu: research proposal development, Study Execution, Data collection, Data entry and analysis, Report writing and first draft manuscript development.
Sarah Teweldebrhan- Research proposal development, Supervision data analysis, report writing and editing
Gebrehanns Grimay - Supervision ,data analysis, editing

References

1. A. M. KOUYATE, B. M. I. NACOUUMA, A. M. L. & A. T. (2016). *ESTIMATION DE LA PRODUCTION FRUITIÈRE DES ESPÈCES LIGNEUSES ALIMENTAIRES EN AFRIQUE SUB-SAHARIENNE*. (April).
2. Abasse, T., Weber, J. C., Katkore, B., Boureima, M., Larwanou, M., & Kalinganire, A. (2011). Morphological variation in *Balanites aegyptiaca* fruits and seeds within and among parkland agroforests in eastern Niger. *Agroforestry Systems*, 81(1), 57–66. <https://doi.org/10.1007/s10457-010-9323-x>
3. Abdou, L., Guimbo, I. D., Chaibou, I., & Mahamane, A. (2015). Original Research Article Fruit Production of *Prosopis africana* (G. et Perr.) Taub., An Overexploited Species in the Southeastern Niger. *Int.J.Curr.Microbiol.App.Sci*, 4(5), 50–56. Retrieved from <http://www.ijcmas.com>

4. Addis, G., Urga, K., & Dikasso, D. (2005). *Ethnobotanical Study of Edible Wild Plants in Some Selected Districts of Ethiopia*. 33(1). <https://doi.org/10.1007/s10745-005-1656-0>
5. Amit Kumar Sinha, S. P. and A. V. (2011). *Performance evaluation studies on tamarind dehuller-cum- deseeder*. 3(Plate 1), 269–274.
6. Anun CHAROENSUK, M. J. and K. J. (2018). *Seed Production and Seedling Establishment of Parah Trees (Elateriospermum tapos, Euphorbiaceae) in*. 15(3), 213–223.
7. Asfaw, Z., & Tadesse, M. (2001). *PROSPECTS FOR SUSTAINABLE USE AND DEVELOPMENT OF WILD FOOD PLANTS IN ETHIOPIA 1*. (1951).
8. Bahru, T., Asfaw, Z., Demissew, S., Ababa, A., Management, B., Ababa, A., & Ababa, A. (2013). *WILD EDIBLE PLANTS: SUSTAINABLE USE AND MANAGEMENT BY INDIGENOUS COMMUNITIES IN AND THE BUFFER AREA OF*. 36(2), 93–108.
9. Bassimbé, M., Khoudia Sène Niang, A. G., & Goffner, D. (2014). *Balanites aegyptiaca (L.) Delile : geographical distribution and ethnobotanical knowledge by local populations in the Ferlo (north Senegal)*. (December 2015).
10. Belay Manjur, T. A. and A. A. (2014). *Effects of F. albida (Del) and C. macrostachyus (Lam) tree species on key soil physicochemical properties and grain yield of maize : A case study at Umbulo Wacho watershed, Souther ...* (March 2014).
11. Berihun, T., & Molla, E. (2017). *Study on the Diversity and Use of Wild Edible Plants in Bullen District Northwest Ethiopia*. 2017.
12. Biazin, B., Haileslassie, A., Zewdie, T., Mekasha, Y., Gebremedhin, B., Fekadu, A., & Shewage, T. (2018). Smallholders' avocado production systems and tree productivity in the southern highlands of Ethiopia. *Agroforestry Systems*, 92(1), 127–137. <https://doi.org/10.1007/s10457-016-0020-2>
13. Bondé, L., Ouédraogo, O., Ouédraogo, I., Thiombiano, A., & Boussim, J. I. (2019). Variability and estimating in fruiting of shea tree (*Vitellaria paradoxa* C.F. Gaertn) associated to climatic conditions in West Africa: implications for sustainable management and development. *Plant Production Science*, 22(2), 143–158. <https://doi.org/10.1080/1343943X.2018.1541712>
14. CHEVALLIER, M., BENSaid, S., DIALLO, O., SAHKI, R., GANABA, S., SANOU, J., ... BABIN, D. (2003). Biodiversité et multidisciplinarité: méthodologie pour les zones arides. *Bois et Forêts Des Tropiques*, 276(276), 33–40.
15. Chothani, D. L., & Vaghasiya, H. U. (2011). A review on *Balanites aegyptiaca* Del (desert date): phytochemical constituents, traditional uses, and pharmacological activity. *Pharmacognosy Reviews*, 5(9), 55–62. <https://doi.org/10.4103/0973-7847.79100>
16. Demir, N., Yildiz, O., Alpaslan, M., & Hayaloglu, A. A. (2014). Evaluation of volatiles, phenolic compounds and antioxidant activities of rose hip (*Rosa L.*) fruits in Turkey. *LWT - Food Science and Technology*, 57(1), 126–133. <https://doi.org/10.1016/j.lwt.2013.12.038>
17. Elfeel, A., & Warrag, E. (2006). *Variation in morphological and chemical characteristics of fruits and seeds among eleven geographical sources of Balanites aegyptiaca (L.) Dell in Sudan*. (February 2016).
18. Fahmi, M. K. M., Dafa-Alla, D.-A. M., Kanninen, M., & Luukkanen, O. (2018a). Impact of agroforestry parklands on crop yield and income generation: case study of rainfed farming in the semi-arid zone of Sudan. *Agroforestry Systems*, 92(3), 785–800. <https://doi.org/10.1007/s10457-016-0048-3>
19. Fahmi, M. K. M., Dafa-Alla, D. A. M., Kanninen, M., & Luukkanen, O. (2018b). Impact of agroforestry parklands on crop yield and income generation: case study of rainfed farming in the semi-arid zone of Sudan.

- Agroforestry Systems, 92(3), 785–800. <https://doi.org/10.1007/s10457-016-0048-3>
20. Girma, Y. (2014). *Development of fruit leather from indigenous Tamarind (Tamarindus indica L.) fruit*.
 21. goran i. agren Asfaw Zebene. (2007). *Farmers' local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia*. 35–48. <https://doi.org/10.1007/s10457-007-9087-0>
 22. Groom, Q. (2011). François Malaisse (2010) How to live and survive in Zambezian open forest (Miombo Ecoregion). *Plant Ecology and Evolution*, 144(3), 377–378. <https://doi.org/10.5091/plecevo.2011.679>
 23. Grygorieva, O., Abrahamová, V., Karnatovská, M., Bleha, R., & Brindza, J. (2014). Morphological characteristics of fruits, drupes and seeds in genotypes of ziziphus jujuba mill. *Potravinárstvo*, 8(1), 306–314. <https://doi.org/10.5219/414>
 24. Gwali, S., Nakabonge, G., Okullo, B. L., Eilu, G., Nyeko, P., & Vuzi, P. (2012). *Morphological variation among shea tree (Vitellaria paradoxa subsp. nilotica) 'ethnovarieties' in Uganda*. (June 2014). <https://doi.org/10.1007/s10722-012-9905-8>
 25. Kainer, K. A., Wadt, L. H. O., & Staudhammer, C. L. (2007). Explaining variation in Brazil nut fruit production. *Forest Ecology and Management*, 250(3), 244–255. <https://doi.org/10.1016/j.foreco.2007.05.024>
 26. Kala and Dubey. (2014). Diversity in Balanites Aegyptiaca: A Lesser Known Tree Species in the Yamuna Ravines. *Indianforester*, (November).
 27. Kidane, B., Maesen, L. J. G. Van Der, Van, T., Asfaw, Z., & Sosef, M. S. M. (2014). *Ethnobotany of Wild and Semi-Wild Edible Fruit Species used by Maale and Ari Ethnic Communities in Southern Ethiopia*. 12(September), 455–471.
 28. Lankoandé, B., Ouédraogo, A., Boussim, J. I., & Lykke, A. M. (2017). Identification of determining traits of seed production in Carapa procera and Pentadesma butyracea, two native oil trees from riparian forests in Burkina Faso, West Africa. *Biomass and Bioenergy*, 102(June), 37–43. <https://doi.org/10.1016/j.biombioe.2017.04.002>
 29. Lima, J. O., Rios, J. B., Salles, M. T., & Gallão, M. I. (2015). Morphological characterization of fruits and seeds of Jatropha (Magnoliopsida: Euphorbiaceae). 263–269.
 30. Londres, M., Schulze, M., Staudhammer, C. L., & Kainer, K. A. (2017). *Population Structure and Fruit Production of Carapa guianensis (Andiroba) in Amazonian Floodplain Forests: Implications for Community-Based Management*. <https://doi.org/10.1177/1940082917718835>
 31. Manji, A. J., Sarah, E. E., & Modibbo, U. U. (2013). Studies on the potentials of Balanites aegyptiaca seed oil as raw material for the production of liquid cleansing agents. *International Journal of Physical Sciences*, 8(33), 1655–1660. <https://doi.org/10.5897/IJPS07.049>
 32. Mayavel, A., Nagarajan, B., Muthuraj, K., Nicodemus, A., & Prabhu, R. (2018). Correlation and Path Coefficient Analysis of Selected Red Tamarind (Tamarindus indica var rhodocarpha) Genetic Resources. *International Journal of Current Microbiology and Applied Sciences*, 7(04), 794–802. <https://doi.org/10.20546/ijcmas.2018.704.089>
 33. Michaela Schaller, Elena Barth, Darinka Blies, Felicitas Röhrig, M. S. (2017). *Climate Smart Agriculture CONCERNS*. (CC), 1–4. Retrieved from <http://www.climatesmartagconcerns.info/>
 34. Miller, K. E., & Dietz, J. M. (2004). *Fruit Yield, not DBH or Fruit Crown Volume, Correlates with Time Spent Feeding on Fruits by Wild Leontopithecus rosalia*. 25(1).
 35. Nacoulma, B. M. I., Lykke, A. M., Traoré, S., Sinsin, B., & Thiombiano, A. (2017). Impact of bark and foliage harvesting on fruit production of the multipurpose tree Afzelia africana in Burkina Faso (West Africa).

- Agroforestry Systems, 91(3), 565–576. <https://doi.org/10.1007/s10457-016-9960-9>
36. OKELLO, J. (2010). *Morphological and Nutritional Characteristics of Tamarindus Indica (Linn) Fruits in Uganda*. (October).
 37. Ouedraogo, I., Nacoulma, B. M. I., Ouedraogo, O., Hahn, K., & Thiombiano, A. (2014). Productivité et valeur économique des calices de *Bombax costatum* Pellegr. & Vuillet en zone soudanienne du Burkina Faso. *Bois et Forêts Des Tropiques*, 68(319), 31–41. <https://doi.org/10.19182/bft2014.319.a20550>
 38. Ouédraogo, S., Bondé, L., Ouédraogo, O., Thiombiano, A., Boussim, I. J., Ouédraogo, S., ... Ouédraogo, A. (2019). To What Extent Do Tree Size, Climate and Land Use Influence the Fruit Production of *Balanites aegyptiaca* (L) Delile in Tropical Areas (Burkina Faso)? To What Extent Do Tree Size, Climate and Land Use Influence the Fruit Production of *Balanites aegypt*. *International Journal of Fruit Science*, 0(0), 1–18. <https://doi.org/10.1080/15538362.2019.1619216>
 39. Ounyambila Lompo, Anne, M. L., Benjamin, L., & Amadé, O. (2018). Influence of climate on fruit production of the yellow plum, *Ximenia americana*, in Burkina Faso, West Africa. *Journal of Horticulture and Forestry*, 10(4), 36–42. <https://doi.org/10.5897/jhf2017.0517>
 40. Raj, A., & Lal, S. (2014). *Agroforestry: Theory and Practices*. Retrieved from [https://books.google.com/books?hl=en&lr=&id=vPc1DwAAQBAJ&oi=fnd&pg=PR1&dq=Raj,+J.+A.,+%2526+Lal,+B.+S.+\(2014\).+Agroforestry+Theory+and+Practices+.+Jodhpur:+Scientific+Publishers.+&ots=RczK-M7I32&sig=xyMxuZIPstMPvG9oUC08FUBspGM](https://books.google.com/books?hl=en&lr=&id=vPc1DwAAQBAJ&oi=fnd&pg=PR1&dq=Raj,+J.+A.,+%2526+Lal,+B.+S.+(2014).+Agroforestry+Theory+and+Practices+.+Jodhpur:+Scientific+Publishers.+&ots=RczK-M7I32&sig=xyMxuZIPstMPvG9oUC08FUBspGM)
 41. Sagna, M. B., Niang, K. S., Guisse, A., & Goffner, D. (2014). *Balanites aegyptiaca* (L.) Delile: Geographical distribution and ethnobotanical knowledge by local populations in the ferlo (North Senegal). *Biotechnology, Agronomy and Society and Environment*, 18(4), 503–511.
 42. Snook, L. K., Cámara-Cabrales, L., & Kelty, M. J. (2005). Six years of fruit production by mahogany trees (*Swietenia macrophylla* King): Patterns of variation and implications for sustainability. *Forest Ecology and Management*, 206(1–3), 221–235. <https://doi.org/10.1016/j.foreco.2004.11.003>
 43. Sourou, B., Ouinsavi, C., & Sokpon, N. (2016). Ecological Structure and Fruit Production of Blood Plum (*Haematostaphis barteri* Hook. F) Subpopulations in Benin. *International Journal of Plant & Soil Science*, 9(2), 1–12. <https://doi.org/10.9734/ijpss/2016/22059>
 44. Tarun Kant and Vinod Singh gour. (2015). *Report and Opinion 2015*;7(2) [http://www.sciencepub.net/report.7\(2\),61-64](http://www.sciencepub.net/report.7(2),61-64).
 45. Tesfaye, A., & Minch, A. (2015). *International Journal of Modern*. 2(189), 189–193.
 46. Yadav, J., & Panghal, M. (2010). *Balanites aegyptiaca* (L.) Del. (Hingot): A review of its traditional uses, phytochemistry and pharmacological properties. *International Journal of Green Pharmacy*, 4(3), 140. <https://doi.org/10.4103/0973-8258.69158>
 47. Zeynab, J., Azadi, H., Taheri, F., Zarafshani, K., Gebrehiwot, K., Van Passel, S., & Lebailly, P. (2017). Organic Farming and Small-Scale Farmers: Main Opportunities and Challenges. *Ecological Economics*, 132, 144–154. <https://doi.org/10.1016/j.ecolecon.2016.10.016>

Figures

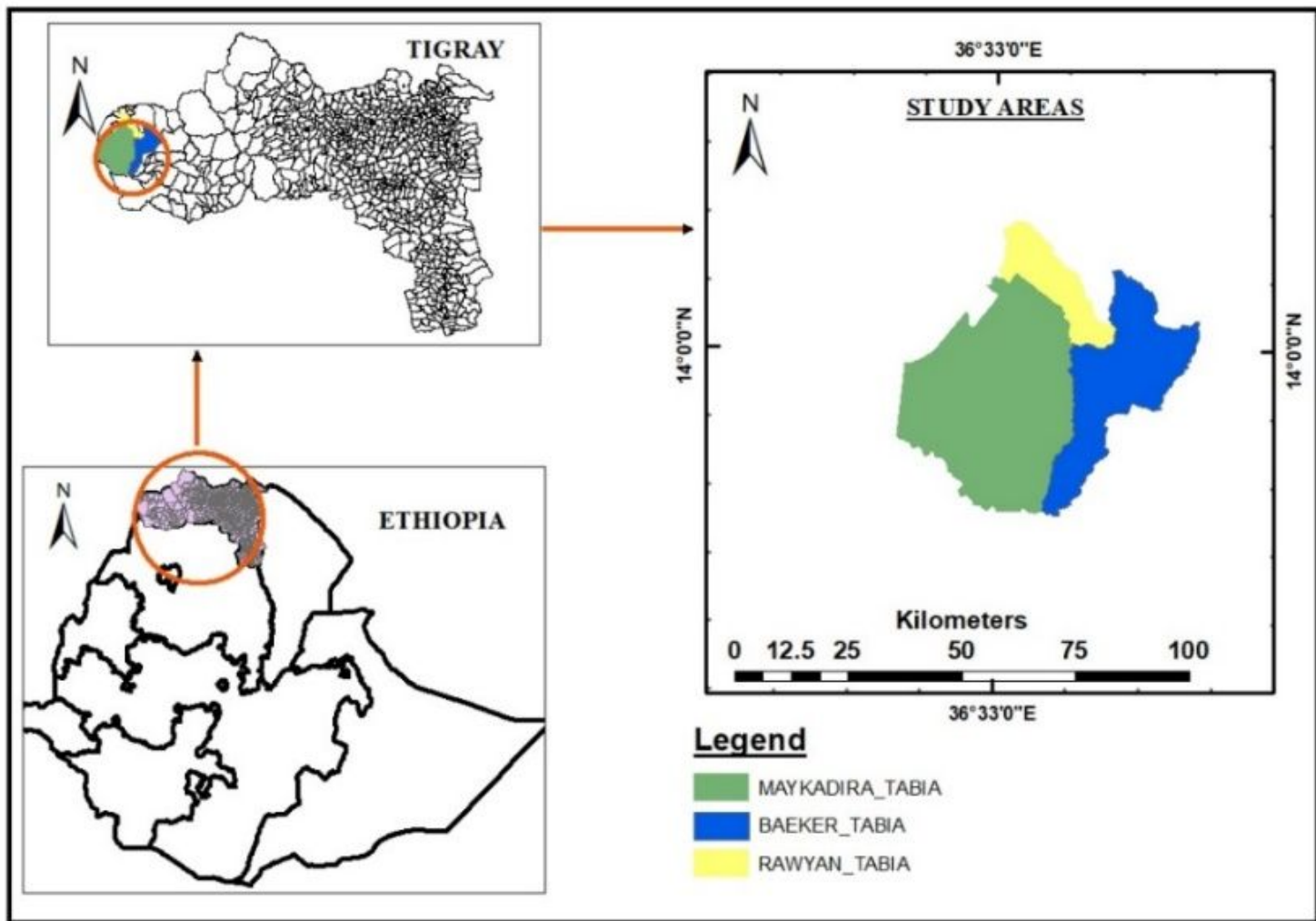


Figure 1

Location of the study area

Kafta_Humera: 14° 26'34.90" N and 37° 33'71.00" E (1204.5 m)
Yr:2003-2015 29.4C 645 mm

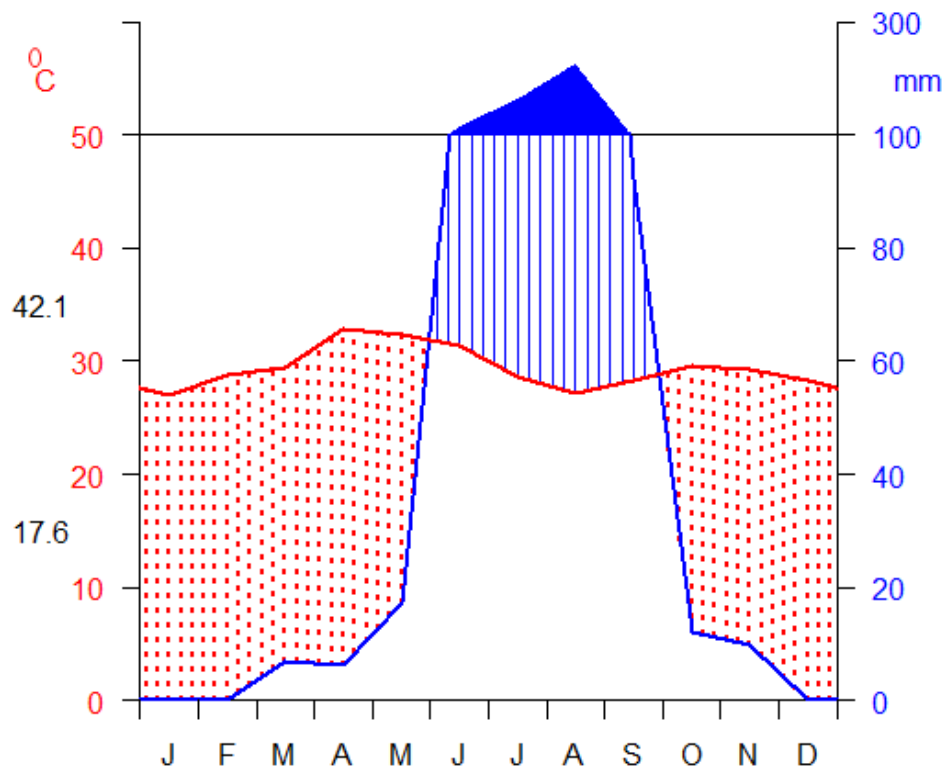


Figure 2

Kafta-Humera climodiagram (Tigray Meteorological Agency).

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Figure 3

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Figure 4

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Figure 5

Figure 17: Photo of *Balanites aegyptiaca* taste types varieties fruits

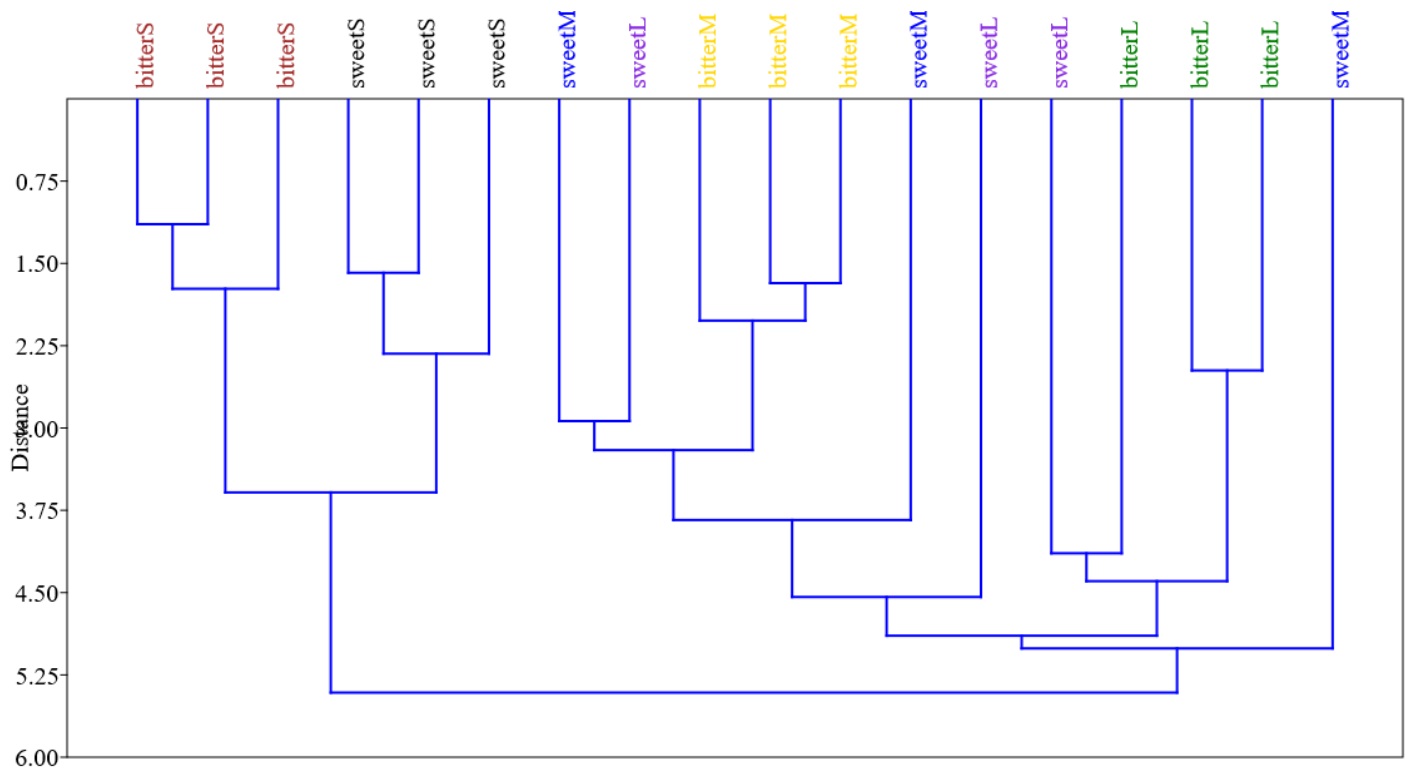


Figure 6

Figure 18 - Dendrogram results from UPGMA method of hierarchical cluster analysis of fruit morphology under DBH class and taste type varieties of *Balanites aegyptiaca* tree fruits.

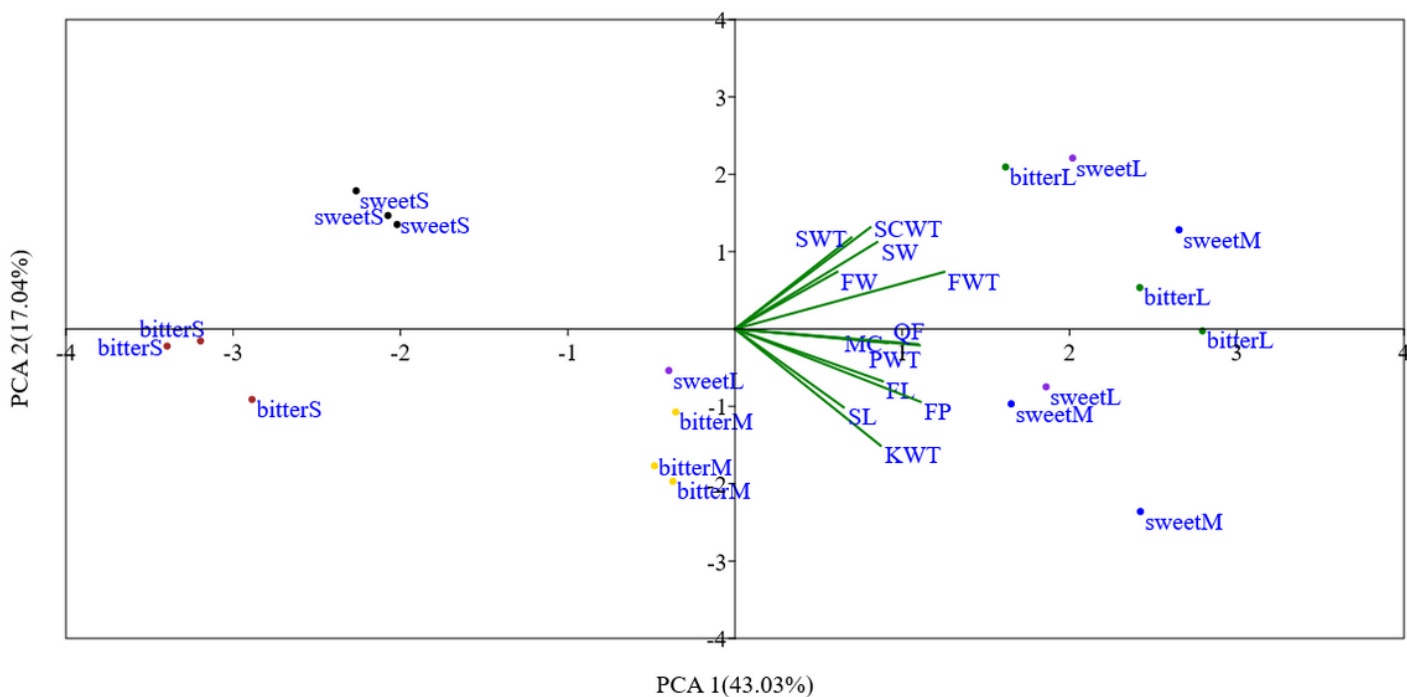


Figure 7

Figure 19: PCA of fruit morphology values based on DBH cases and a taste type variety of *Balanites aegyptiaca* tree