PHENOTYPIC VARIATIONS IN FRUITS AND SEED TRAITS OF *Chrysophyllum albidum* IN THREE AGROECOLOGICAL ZONES IN NIGERIA

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ABSTRACT

***Chrysophyllum albidum* is a priority indigenous fruit tree in Nigeria with a wide distribution across West Africa. This fruit tree has immense socio-economic, nutritional and medicinal importance. However, it may be under threat due to high consumption of the fruits and seeds and this may have led to serious genetic erosion of the species. This study was designed to assess the extent of phenotypic variation in fruits (mass, length, width) and seed (weight and number) traits in 106 trees. This was further complimented by socioeconomic characterization in three agroecological zones (arid, humid and mangrove). The results from the study indicated that in all the agro-ecological zones, 68.9% of the fruits were collected from naturally regenerated trees. The households own averagely 2 trees which yield an annual average of 126 to 378 kg of the fruits, (of about 42 kg per basket) with a market value ranging from US$ 187 to US$ 562. Phenotypic traits like fruits and seed mass varied continually and significantly (P<0.05) between trees and agroecological zones. Mean fruit and seed mass recorded in the humid zone were 59.5 ± 0.2 g and 6.9 ± 0.2 g respectively, compared to 56.7 ± 0.1 g and 6.5 ± 0.2 g in the mangrove and 56.8 ± 0.2 g and 6.8 ± 0.2 g in the arid zones. The heaviest fruit was from the humid zone (Tree EW/IK/CA/018) with a value of 98 ± 1.5 g; P<0.05 while the lightest fruit was from the arid zone (tree ET/IV/CA/004) with a value of 36 ± 1.7 g; P<0.05). A significant and positive correlation between all fruit traits (P<0.05) was observed with the strongest relationship between fruit mass and fruit width (R^2 = 0.76). These results obtained from this study represent the first quantitative assessment of tree-to-tree variation in fruit traits of *C. albidum* and will help in the development of cultivars through tree domestication techniques, and so promote poverty alleviation and sustainable agriculture in Nigeria and beyond.**

Keywords: Characterization, Domestication, Poverty alleviation, Regeneration of trees.

I. INTRODUCTION

Forest fruit trees in Nigeria are currently over exploited in their natural habitats due to demographic increases, unsustainable farming systems, absence of livelihood options, intensive human pressure on forests and poverty (Anegbeh *et al*., 2004). The swiftly declining fruit trees pose threats not only to food security but also to wildlife environment, health and genetic preservation.

African star apple (*Chrysophyllum albidum*) is a tropical edible fruit tree belonging to the family of Sapotaceae which has up to 800 species (Ehiagbonare *et al.*, 2008). The species is primarily a lowland rainforest tree and its natural occurrences have been reported in various ecological zones from Sierra Leone to East Africa (Bada, 1997). The species was among the most important 14 tropical hardwood species which dominated international timber trade in Africa from 1950 to 1975 (Last *et al.*, 1983). *C. albidum* is also among the forest tree species that provides Non Timber Forest Products (NTFPs) of immense domestic importance to rural and urban dwellers in West and Central Africa, with great export potentials (Nwoboshi, 2000). The tree ranges from a small to medium buttressed tree species, which grows up to 25 - 40 m in height with a mature girth varying from 1.5 to 2 m (Bada, 1997). The

economic importance of *C. albidum* has increased in recent years due to awareness of its nutritional importance, social, traditional and medicinal value (Onyekwelu and Stimm, 2006). Thus, the fruit plays an important role in household food security.

Wild harvesting of these fruits from forests and semi domesticated trees growing on-farm and homesteads can substantially boost rural income and employment opportunities (Ruiz-Perez *et al*., 2004; Leakey *et al*., 2005). Their commercial importance has led farmers to identify these local species as trees for domestication through Agroforestry (Franzel *et al* 1996). Tree domestication is the application of genetic principles to increase the value of tree crops and also to enhance economic returns from the end product. Increasingly, agroforestry trees are being improved in quality and productivity through the process of market driven domestication, by inventory of the natural resource and sustainable production of agroforestry products based on strategies that consider the needs of farmers and their priorities for domestication (Simons and Leakey 2004; Leakey *et al.* 2005). However, the high economic values of *C. albidum* has led to intense exploitation of its fruit resulting in scarcity and a declining rate of its availability, causing the species to be classified as endangered or threatened (FORMECU, 1999). *Chrysophyllum albidum* may be a victim of unsustainable exploitation characterized by high consumption of the fruits and seeds, high rate of male to female sex ratio and little or no regeneration programs. This may have led to genetic erosion of the species.

This study therefore aims to characterise the intra specific variability between *C. albidum* trees in Nigeria using fruit and seed traits, and to investigate relationships between these traits for the identification of superior trees for domestication.

Description of the species

C. albidum trees are indigenous to tropical Africa, it is predominantly found in tropical rainforests or moist semi deciduous forests. Sometimes, African star apple is found in riverine areas (WAC, 2008), village squares, home gardens and compound farms.

The bole of the tree is usually fluted, frequently free of branches from 21 m. The bark is thin, pale grey-brown which exudes copious white gummy latex, a characteristic of the Sapotaceae family. The mature leaves are dark green and are usually 30 cm long and 8.9 cm broad (Bada, 1997). *C. albidum* flowers once a year. The onset of flowering and fruiting season varies from one ecological zone to another. The flowers are cream-yellow hermaphrodite and are shortly pedicellate (Katende *et al.*, 1995; Bada, 1997).

The fruit of *C. albidum*, which is a large, fleshy and juicy edible berry. The fruits are shortly stalked, ovoid to ellipsoid, slightly pointed at the apex, with dense reddish-brown pubescence (WAC, 2008) and almost spherical in shape, up to 6.0 cm long and 5.0 cm in diameter. It is greenish-grey when immature, turning orange-red, yellowish-brown or yellow when mature with copiously milky juice and soft pulp when ripe (Onyekwelu and Akindele, 2002). The edible pulp within the peel may be orange, pinkish, or light yellow when ripe (Madubuike and Ogbonnaya, 2003). Fruit maturation is usually between December and April (Amusa *et al.*, 2003; Boateng and Yeboah, 2008), but could be earlier or later depending on the ecological zone. In the past, fruits are not usually harvested from the trees, but left to drop naturally to the forest floor, which promotes fungal infections (Amusa *et al.*, 2003). The fruit becomes bad within a period of three to five days after harvesting. Fruit deterioration starts with change in colour from uniform orange to one with patches and followed by shrinking of the fruit peel or skin (Adebisi, 1997; Amusa *et al.*, 2003).

The fruits are celled, containing an average of 5 dicotyledonous seeds, which could sometimes be fewer due to seed abortion (Gbile, 1997; WAC, 2008). The seed comprises an embryo and endosperm in a brown shiny protective hard coat with a length of 2.8 cm and width 1.2 cm (Aduradola *et al.*, 2005 and Kirkbridge *et al.*, 2006). Seed storage behaviour is recalcitrant (NG, *et al*., 1993). The seeds of *C. albidum* have been reported to lose viability easily upon drying even under ambient room temperature or exposure to slight heat, thus storage of the seed under dry environment is not recommended (Fayose, 2007).

II. Materials and Methods

Study site

The study was carried out in twenty four different villages in nine Local Government Areas (LGAs) in the arid, humid and mangrove agroecological zones of Edo State. They are Uhunmwode LGA with a geographical positioning system (GPS) coordinate of $N6^0$43.210′ and $E5^0$56.660′, Esan West LGA with a GPS coordinate of $N6^0$46.934′ and $E6^0$50.4′ and Esan Central LGA with a GPS coordinate of $N6^0$47.052′ and $E6^0$17.52′ representing the humid zone while Owan West LGA with a GPS coordinate of $N6^0$54.021′ and $E5^0$56.199′, Owan East LGA with a GPS coordinate of $N6^0$58.112′ and $E6^0$02.83′ and Etsako West LGA with a GPS coordinate of $N7^0$07.502′ and $E6^0$37.88′ which represents the arid zone while Ika north east LGA with a GPS coordinate of $N32^0$18.46'and $E7^0$42.11', Ovwie LGA with a GPS coordinate of $N32^0$01.84' and $E7^0$42.89' and Okpe LGA with a GPS coordinate of $N32^0$18.46' and $E7^0$42.89' which represents the mangrove zone. The state has a tropical climate characterized by two distinct seasons (wet and dry seasons). The temperatures across the state are relatively high, it ranges from 22^0C to 37^0C. The climate is humid tropical in the south to sub-humid in the north.

Sampling

The study focused on three agroecological zones of Edo State with naturally occurring populations of *C. albidum*. Identified villages producing *C. albidum* were randomly selected from nine LGAs where the fruit tree is produced on commercial basis. Farmers who are engaged in the cultivation of *C. albidum* fruit trees were identified and their farms visited. Interviews with *C. albidum* farmers, consumers and marketers and finally group discussions were used to obtain quantitative and qualitative information on the origin of their trees (cultivated or natural regenerated), its age and time to first fruiting, desired fruit characteristics preferred by the consumers and the sellers of *C. albidum*, how many fruits were sold per tree or basket both at farm gate and cities, level of cultivation, marketing and conservation of the species in the study areas. Participatory methods were used to gather information from farms. These methods includes: farm visits, structured interviews with households. The structured questionnaire were conducted at 3 levels: their individual characteristics, knowledge on *C. albidum* trees and consumers and sellers preference on the fruit characteristics. The information collected from the respondents were used in identifying the desired characteristics of the species, the problems associated with the species and selecting better trees for domestication.

A recognizance survey was carried out in the year 2013 fruiting season and the land use systems with *C. albidum* fruiting trees were identified and selected. With the assistance of the farmers, One hundred and six fruiting *C. albidum* trees (35 individuals from arid, 36 from humid and 35 from the mangrove zone) were identified and selected based on the following criteria; size of the fruits, good taste, yield, disease resistance and off season fruits with different physical and social properties (Table 1). These trees were labeled and their locations were determined using a Global Positioning System in relation to home gardens, farms and forest areas. The identified trees were visited in the year 2014, the fruits were collected from these trees as they ripened over the fruiting season (February – April) based on the information obtained from the focus group discussion on the peak of fruit maturation and ripening. A diameter tape was used in measuring the diameter at breast height (dbh), a tag was used to mark each tree as this helps in identification of the tree during cultivar development (Waruhi, *et al*.,2004; Onyekwelu *et al*., 2011).

Data collection

The sampling procedure used was based on a study to develop an experimental protocol used by Leakey *et al*., (2002). Fourty undamaged fruits, were collected randomly from each tree, 10 fruits from each quadrant in each agroecological zone for phenotypic characteristic investigation (Anegbeh *et al* 2003; Waruhiu *et al*, 2004). The fruits collected from each sampled tree were bagged and

labeled to avoid loss of tree identity and assessed for fruit physical characterization. The assessment included; fruit length (cm) and fruit width (cm), using calipers graduated in 0.1 cm. Fresh fruit mass (g) were determined using electronic digital scale graduated to 2 decimal places (0.00g). Fruits were opened and seeds extracted for weight (g) determination. Number of seeds per fruit was also recorded. The jute bags containing the *C. albidum* fruits were also labeled with a permanent marker for easy identification, transportation and to reduce deterioration (Adebisi 1997). The fruit/skin colour was determined using a colour chart. Also, the standard market prices of the fruiting season in the year 2014 was used to estimate the market price for each baskets per farmer.

Data analysis

Data were collated in Microsoft Excel and were tested for normality using Genstat (Genstat V.13). Descriptive statistics and Analysis of Variance procedure at 5% level of probability was performed to determine statistical differences in each trait between the trees, using SPSS 16.0. The relationship between fruit parameters were determined using correlation analysis. Separation of means were carried out using Duncan multiple range test (DMRT) while coefficient of determination (R^2) and Standard Error of Estimates (SEE) were used in the actual comparison of fruit parameters and fruit types.

III. RESULTS

Agroecological zones

Phenotypic traits in mean fruit mass, fruit length, fruit width, seed mass and number of seeds were significantly different between trees and agroecological zone.

Phenology

The ripening period of fruits of *C. albidum* varied among the 106 trees across the 3 agroecological zones. Fruiting of this species ranged from early December to mid-April, but the most dominant ripening period of this species was January- February which coincides with the main ripening period of the species, when 50% of the fruits were harvested from each tree. Early ripening occurred in the arid zones while late ripening occurred in humid zone (Table 2). 68.9% of the fruits were collected from naturally regenerated trees (Fig 1). Households own 2 trees on the average with average annual yield of 3 to 9 baskets (each basket weighing about 42 kg) (Fig 2). Market value of each basket of *C. albidum* range from US$ 187 to US$ 562. The use of this very important tree crop ranges from the fruits being utilized as food and medicine, to the tree serving as timber, providing shade and contributing to the environment by carbon sequestration and the leaves litter which greatly improves soil fertility (Akpan-Ebe *et al*., 2016) (Table 3).

Fruit / skin colour

Differences were observed in the skin colour of matured *C. albidum* fruits between trees. Three different colours were identified (yellow, yellowish brown and orange). The most reoccurring skin colour was orange with a total share of 47%.

Land use system

In the arid zone, *C. albidum* tree we commonly found in home gardens while in the humid zone and mangrove, it occurred most as accompanying trees in cash crop farms (Fig 3).

Table 1: Characteristics of *C. albidum* collection sites in Nigeria.

Agroecological zones	GPS	Altitude	Vegetation	Rainfall	Temperature	Interviewed farmers	Number of fruits per tree	Number of identified trees. N=Naturally Regenerated C= Cultivated
Arid	N7^{0}00.71' E6^{0}03.72'	135 m	Derived Savanna	1750 m m	22^{0}C - 36 °C	30	40	N=30 C=5
Humid	N6^{0}04.34' E5^{0}05.61'	279 m	Rain forest	2000-3000 mm	20^{0}C – 30 °C	30	40	N=19 C=17
Mangrove	N5^{0}05.42' E6^{0}01.44'	46 m	Mangrove/ coastal	2673 mm	32.8^{0}C- 37 °C	30	40	N=24 C=11

Table 2: Fruiting period of *C. albidum* observed in the study (%)

Agroecological zone	Early fruiting (Nov. – Dec.)	Main fruiting (Jan. – Feb.)	Late fruiting (March – April)
Arid	33	50	17
Humid	23	52	25
Mangrove	20	48	32

Table 3: Different uses of *C. albidum* from respondents

Uses	Parts of the plant	Nutritional and medicinal value
Food	Fruit (Pulp)	Vitamins (Ascorbic and B-carotene) Protein Moisture Dextrose Minerals (K,P, Na)
Pharmaceutical industry	Leaf, bark, root , seeds	
Cultural	Seeds and leaf	Rattles for traditional dancers,
Timber	Softwood	
Environment	Tree, root	carbon sequestration and the leaves litter greatly improves soil fertility (Akpan-Ebe *et al*., 2016)

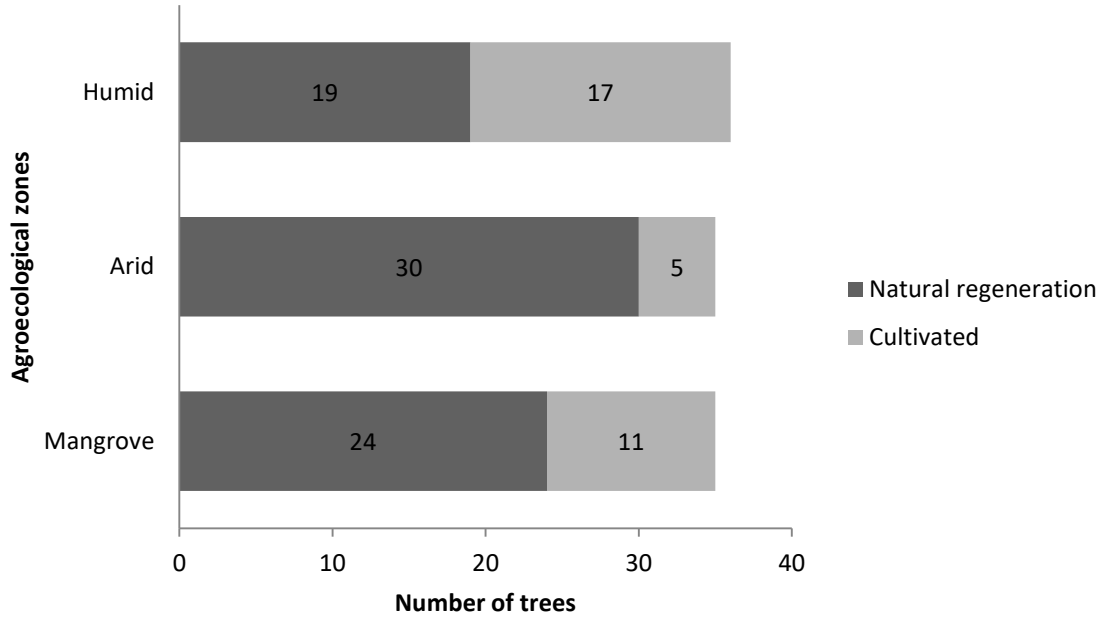

Figure 1: Regeneration of *C. albidum* used in this study

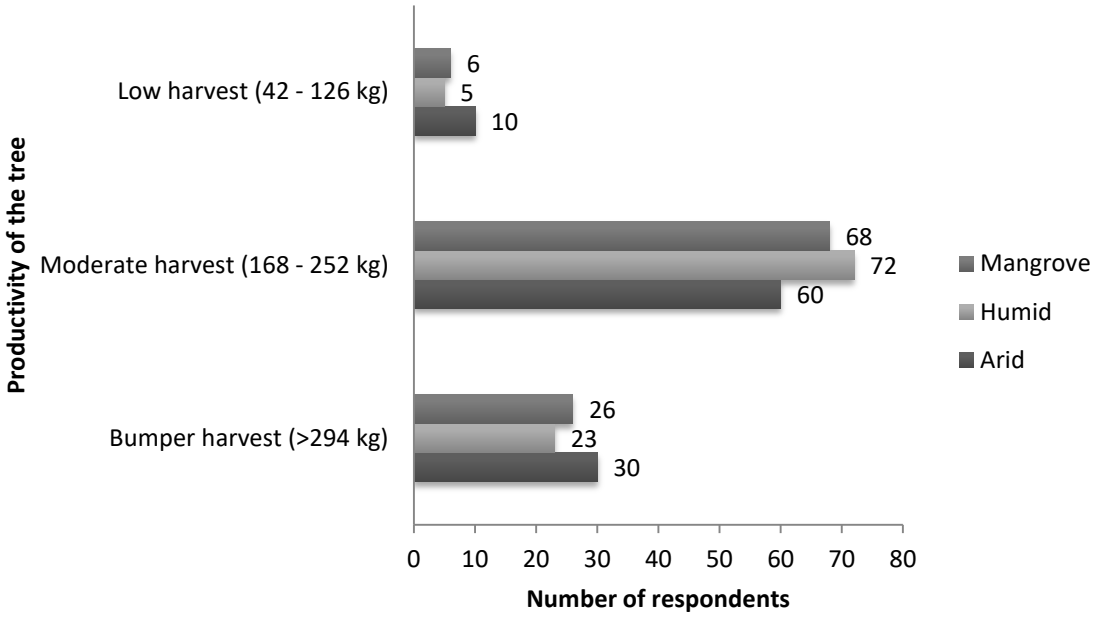

Figure 2: Productivity of *C. albidum* trees

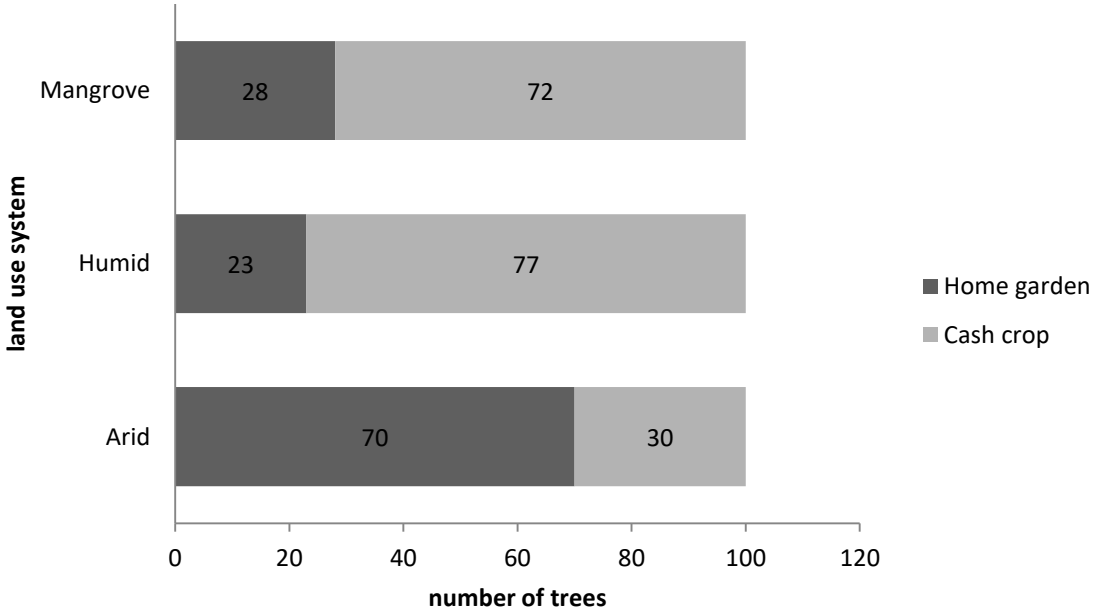

Figure 3: Percentage occurrence of *C. albidum* in land use systems

Fruit and seed mass

Tree-to-tree differences for fruit and seed mass were highly significant (Table 4). The overall mean fruit and seed mass was 57.7 g and 6.7 g respectively. The heaviest fruit was from the humid zone (Tree EW/IK/CA/018; 98.4 g) while the lightest fruit was from the arid zone (tree ET/IV/CA/004; 36 g) (Table 6).

Fruit length and width

Mean fruit length and width were significantly different between trees with continuous tree-to-tree variation. The overall mean fruit length and width were 4.9 cm and 4.2 cm respectively (Table 4). The longest fruit was from the arid zone (tree OE/IH/CA/005; 6.6 cm) while the shortest fruit was also from the arid zone (tree ET/UG/GA/002; 5.5 cm). The widest fruit was from the humid zone (tree EW/IK/CA/018; 5.2 cm) while the smallest width was from the arid zone (tree OE/IH/GA/004; 4.6 cm) (Table 4). There was a highly significant and strong relationship between fruit mass and fruit width (R^2= 0.76) (Table 5).

Table 4: Mean and coefficient of variation in fruit traits of sampled *C. albidum* fruits.

	Arid			Humid			Mangrove			Total		
	mean	SD	CV	mean	SD	CV	mean	SD	CV	mean	SD	CV
Fruit mass	56.9	11.9	20.9	59.5	11.9	20.02	56.79	11.45	20.2	57.74	11.72	20.3
Seed mass	6.8	1.38	20.1	6.95	1.39	20	6.56	1.4	21.3	6.79	1.39	20.5
Fruit length	4.6	0.48	10.3	5.19	0.4	7.7	4.85	0.49	10.1	4.9	0.51	10.4
Fruit width	4.1	0.27	6.5	4.34	0.33	7.6	4.23	0.25	5.9	4.24	0.29	6.8
No. of seeds	4.5	0.31	6.8	4.61	0.28	6.1	4.44	0.28	6.3	4.53	0.3	6.6

Table 5: Correlation matrix of the fruit parameters

	Fruit mass	Fruit length	Fruit width	No of seeds	Seed weight
Fruit mass.	-	0.361**	0.761**	0.107**	0.404**
Fruit Length	-	-	0.394**	0.073**	0.191**
Fruit width	-	-	-	0.101**	0.303**
No of seeds	-	-	-	-	0.524**
Seed weight	-	-	-	-	-

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6: Analysis of variance for physical characteristics of the ten best values for each fruit trait of C. *albidum*

Fruit mass (g)			Fruit length (cm)			Fruit width (cm)			No of seeds			Seed mass (g)		
Tree ID	Mean		Tree ID	Mean		Tree ID	Mean		Tree ID	Mean		Tree ID	Mean	
EW/IK/GA/018 (H)	98.49	a	OE/IH/GA/005	6.69	a	EW/IK/GA/018	5.27	a	EW/IK/GA/018	5	a	EW/IK/GA/018	10.17	a
OE/IH/GA/012 (S)	86.6	b	EW/IK/GA/018	6.40	ab	EC/OP/GA/002	5.08	b	EW/UK/GA/006	5	a	OE/IH/GA/012	9.58	ab
OE/IH/GA/001 (S)	85.8	b	UH/EH/GA/007	6.02	bc	OE/IH/GA/012	4.99	b	EW/EA/GA/002	5	a	EW/ID/GA/011	9.51	abc
UH/EH/GA/007 (H)	83.34	b	OE/IH/GA/012	5.89	bcd	UH/EH/GA/007	4.96	bc	EW/IK/GA/017	5	a	EC/OP/GA/005	9.08	bcd
EC/OP/GA/002 (H)	81.44	bc	UH/EH/GA/004	5.77	bcde	ET/UG/GA/001	4.81	cd	EW/IK/GA/019	5	a	EW/EA/GA/001	9.04	bcd
ET/UG/GA/001 (S)	76.62	c	EW/IK/GA/019	5.67	cdef	UH/EH/GA/004	4.78	de	OE/IH/GA/008	5	a	OW/OK/GA/009	8.99	bcd
OE/IH/GA/005 (S)	74.51	cd	UH/OB/GA/030	5.58	cdefg	EC/OP/GA/006	4.76	def	UH/EH/GA/007	4	b	OW/SO/GA/007	8.91	bcde
EC/OP/GA/006 (H)	74.16	cd	EW/EM/GA/015	5.56	cdefg	UH/OB/GA/030	4.76	def	EW/UK/GA/008	4	b	OE/IH/GA/011	8.89	bcde
EW/EA/GA/001 (H)	73.81	cd	EW/ID/GA/011	5.54	cdefgh	EW/EM/GA/015	4.707	defg	EW/UK/GA/009	4	b	ET/UG/GA/002	8.83	bcde
0W/EO/GA/001 (S)	71.42	d	ET/UG/GA/002	5.52	cdefghi	OE/IH/GA/004	4.69	defgh	OW/OK/GA/009	4	b	EC/OP/GA/006	8.82	bcde

KEY: Mean values in the rows with different superscripts are significantly ($p \leq 0.05$) different.

The highlighted trees in different colours represent superior/elite mother trees with desirable traits. Humid (H), Savanna (S)

IV. Discussion

Fruits of *C. albidum* are the most important product of the tree as it is a good source of income, food and nutrition for the rural poor. Despite the socio-economic importance of this species in Nigeria, only few of the trees sampled were cultivated. Farmers in the arid zone indicated that no deliberate effort was made to plant the species other than spontaneous natural regeneration. The trees in the humid zone were generally retained on farms after selective clearing of other woody species for shade, accompanying crops and for fruits derived from this species. This may suggest that more effort should be geared into domesticating the species. Thus, it is assumed that maybe most of the sampled trees are from the wild population. This assumption is supported by the range of fruit variations recorded for the fruiting trees. Possible reasons for the low percentage in the cultivation of this species may be attributed to its long juvenile stage (gestation phase), losing viability easily and also high rate of male to female sex ratio thus, discourages the rural farmer to establish a plantation of this species (Onyekwelu, *et al*., 2011) despite its nutritional and medicinal value.

The tree-to-tree variation observed in all the traits that were measured is typical of that found in an outbreeding species. However, some traits were more variable than others. Fruit mass varied at 25.4 g to 98.4 g while fruit length and width varied at 5.5 cm to 6.6 cm and 4.6 cm to 5.2 cm respectively. It is evident from this study that the dispersion/variation in fruit mass (20.3) and seed mass (20.4) were higher than the dispersion/variation observed in fruit length (10.4), fruit width (6.8) and number of seeds (6.6). These differences reflects that fruit mass integrates all other fruit traits and this suggests that variations exist in *C. albidum* fruit sizes and these variations also cut across into the seed sizes; that is, the bigger the fruits, the bigger the seeds or the smaller the fruits, the smaller the seeds of the species in consideration, and this trend appears to be consistent with fruits of a particular mother trees (Ekeke *et al*., 2006; Onyekwelu, *et al*., 2011; Oyebade *et al*., 2011). This can also be further emphasized by the strong correlation observed between fruit mass and fruit width ($R^2 = 0.76$). The large variation in the fruit mass suggests that there are considerable opportunities for phenotypic selection for qualitative improvement in productivity. This variations observed could be attributed to the different genetically, environmental and growing conditions of the fruits (Ekeke *et al*., 2006; Onyekwelu, *et al*., 2011; Oyebade *et al*., 2011, In this study, the variation maybe genetic or effect of the environment, this is because the humid zone was significantly different from the arid and mangrove zone. More emphasis should be geared towards domesticating this species, focusing on separate ideotypes for fruit and seed production, as the seeds losses viability easily and are also valuable by the rural people due to its high medicinal potential.

Commercially, sellers and consumers preference are for large fruits with very good taste. In the long term, this could be achieved through breeding but in the short term, it is more practical to use clonal approaches to tree improvement and to propagate elite tree with desirable combinations of traits (Leakey and Jaenicke, 1995; Leakey and Simons 2000). Trial studies on clonal propagation of this species are on-going e.g. grafting, air layering and rooting of cuttings using auxins. The result from this study revealed that there could be few better trees which are good candidates for vegetative propagation. Also, there is a strong correlation between the fruit mass and from width in the humid agroecological zone. Atangana *et al*., (2002) observed that fruit producing cultivars conformed well to the fruit ideotype; large fruit with good taste, while a few others conform well to the seed ideotype large seeds, based on the results obtained in the current study which suggests that there could also be a *C. albidum* ideotype.

Thus, the results obtained in this study provides the first quantitative confirmation of tree-to-tree variation in *C. albidum* in Nigeria, and quantifies the previously observed differences in fruits and seeds (Onyekwelu *et al.,* 2011), as this will provide a firm base for the domestication of this species. This is important to the wider implementation of participatory domestication (Tchoundjeu *et al*., 1998), which is based on village-level implementation and is dependent on the inherent genetic diversity, the presence of innovative farmers, and the active participation of national agricultural research and extension teams.

V. Conclusions

This study established a methodology for identifying and selecting superior trees of *C. albidum* for cultivar development, and it has clearly shown that consumers and sellers of this fruits in local and urban communities who use the fruits and other components of the species are highly knowledgeable about the cultivation, conservation and desirable traits to be considered in the selection and improvement of the species. The superior trees as observed in the humid agroecological zone are clear indications that farmers have been slowly domesticating the species through on farm conservation. The challenge therefore, will be to sensitize farmers, local communities, and policy makers on modern approaches to protect and maintain the genetic diversity of this intangible genetic resource.

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