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Original Article

Variation in phenotypic traits of high oil yielding and early maturing shea trees (*Vitellaria paradoxa*) selected using local knowledge

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ABSTRACT

Shea trees (*vitellaria paradoxa*) grow in West Nile, Teso, Lango and Acholi subregions of Uganda existing in different forms called enthnovarieties. Farmers from each of these subregions use phenotypic characteristics to differentiate one ethnovariety from the other. We conducted phenotypic characterization of shea trees identified by farmers as high oil yielding and early maturing and verified the farmers' descriptors with standard phenotypic characterization. The study was conducted in the districts of Amuru, Arua, Katakwi, Moyo and Otuke between May and June 2017. One hundred eighty mature shea trees were purposively sampled from the five districts based on local knowledge. Descriptive statistics was then used to determine the variation among the different shea tree phenotypes characterized using standard descriptors. Twenty-seven ethnovarieties were recorded using farmers' descriptors which were later on reduced to sixteen phenotypic traits using standard phenotypic descriptors related to fruit shapes, texture and kernel color. Variation in the kernel weights, fruit length and fruit width were significant ($p < 0.05$) and the shea fruit and seed width were highly correlated (78.6%) to their weights. We identified significant variation in shea trees within sites and fruit and seed weights between sites ($p \leq 0.001$). Although variability within sites was significant, most parameters (height, diameter at breast height (dbh at 1.3 m), crown shape and height at first branching) were not. Shea fruit/kernel traits are important in characterizing varieties since they exhibit different forms across the sites since tree phenotypic attributes do not vary from location to location in Uganda. This lack of

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variability of ethnovarieties across the shea belt in Uganda is important in breeding for traits that can be acceptable by all the communities within the shea growing regions. The different shea ethnovarieties are therefore important in influencing policy decisions on their conservation.

Keywords: Trait, ethnovariety, Diameter at breast height, crown, kernel, fruit.

INTRODUCTION

Efforts have been made to characterize shea trees in Sudano-sahelan Africa using their morphological and phenotypic characteristics (Chevalier, 1943, http://www.geneconserve.pro.br/site/articles/lib/pastaup/artigo070.pdf). These morphological and phenotypic characteristics were based on the shapes and the sizes of fruits and leaves used in distinguishing shea varieties. Diarrassouba et al (2009) used five morphological and four physiological traits to describe nine shea tree varieties in Côte D'ivoire. Farmers in Uganda use different phenotypic characteristics to categorize shea tree ethnovarieties (Gwali, 2013). Given the vast knowledge farmers have on different shea trees, their local knowledge can be harnessed for tree improvement in Uganda. For example, Boffa *et al*., (1996) found out that tree size had a positive effect on the number of nuts produced and on fruit weight in Burkina Faso. The study aimed at determining the variation among tree size (diameter at breast height, total height and height at first branching) distribution, crown shape, and fruit pulp to kernel ratio/weight of the different shea tree populations in Uganda. Relationship between tree size and number of fruits and fruit weight could be used in selection for increasing yield in shea trees. Local knowledge is important to establish the relationship between phenotypic characteristics and oil yield related parameters in shea trees. These characteristics have been used by other researchers to characterize shea trees in Sudano-sahelan Africa parklands (Boffa *et al*., 1996, Diarrassouba *et al.*, 2009, Djekota *et al.*, 2014, Gwali 2013). This study aimed at determining the morphological and phenotypic variation among high oil yielding and early maturing shea trees in Uganda.

MATERIALS AND METHODS

Five districts were randomly selected for study from the list of districts where shea trees grow. From these districts, one hundred eighty high oil yielding and early maturing shea trees were purposively selected using local knowledge. Each tree was purposively sampled due to its preferred traits by the local community and marked with a permanent aluminum plate bearing an identification number. The trees were then geo-referenced using hand held global positioning system for future monitoring and seed/fruit collection for propagation. The stand structure of the fruit bearing stems was measured for total height; height of the first branch from the ground and diameter at breast height (dbh) per study site to assess their distribution. Total height (m) of the selected trees was measured from the different sites to show their height variation and population structure. Twenty freshly fallen and ripe fruits were randomly picked from the selected trees in June 2018 and their fruits/kernels weighed with and without the pulp upon manual removal. Fruits and kernels width and length were then recorded to determine fruit phenotypic variation. The descriptive data was analyzed using multivariate analysis in Genstat software.

Data collection

This involved measuring tree height, Diameter at Breast Height (DBH at 1.3 m from the ground), height at first branching, and crown width. Twenty freshly fallen and ripe fruits were randomly picked in June 2018 from the selected trees and their fruits/kernels weighed with and without the pulp upon removal manually. Fruits and kernels width and length were then recorded to determine fruit morphology. Mean values were calculated for each variable.

Data analysis
The data was then subjected to principal component analysis (PCA) and analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Variability of shea tree traits

The structural arrangement of the shea trees in the six study sites revealed quite a clear difference between the shea populations distribution in those areas (figure 1). Amuru, Arua, Nakasongola and Otuke had normally distributed tree height structure. Katakwi district had left skewed or reverse J shaped whereas Moyo had right skewed or J shaped. The shortest shea trees (average. 4.6 m high) were recorded from Otuke district whereas the tallest (24.3 m) recorded from Arua district compared with average shea tree height in Uganda of 11.82 ± 0.06 m.

Although the tree height did not significantly differ from location to location, there was significant variation of the fruit shapes among the samples collected from Katakwi, Otuke, Amuru, Moyo, and Arua districts. Dwarf tree had significant variation in total height and diameter (DBH).

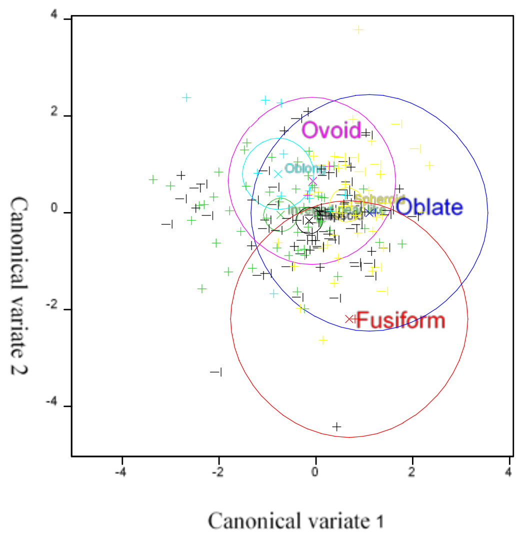

Figure 1: Similarity grouping based on fruit shape

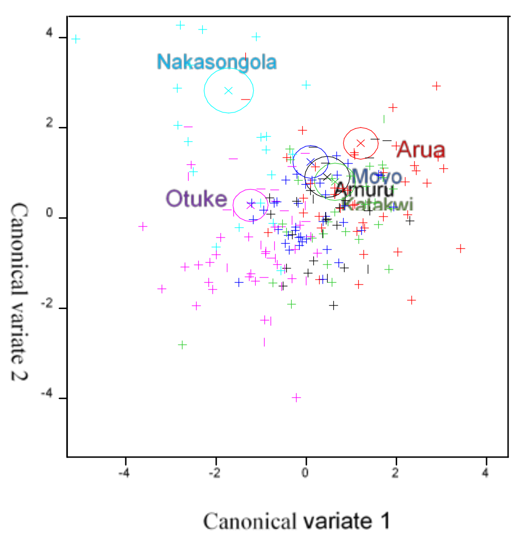

Figure 2: Similarity grouping based on tree trait

The shea tree phenotype in Uganda were characterized into 16 ethnovarieties differentiated into three fruit shapes similarity groups (Oblate, Ovoid and Fusiform). The means of the kernel/seed weights were significantly ($p<0.05$) different. We found more variation in fruit and seed weights of similar ethnovarieties across the study sites (table 1). Width variable was the major contributing factor for fruit and/or kernel/seed weight variation. Variation in the kernel/seed weights, fruit length and fruit width were significant. We identified high variation in shea trees within sites and significant variation of fruit and seed weights between sites.

Thin pulped, black seeded, hairy and dwarf shea trees exhibited significant variations in fruit length whereas astringent tasting and round fruited shea trees had significant variation in seed length.

Table 1: Phenotypic characterization of shea trees in Uganda. The standard errors are appropriate for interpretation of the predictions as summaries of the data rather than as forecasts of new observations.

Identifier	Minimum	Mean	S.E	Maximum	
Tree height (m)	4.000	11.82	±0.0564	22.00	
First branch height(m)	0.000	2.649	±0.00611	6.00	
DBH (cm)	9.000	62.16	±0.0212	120.00	
Fruit weight (mg)	9.020	26.93	±0.318	62.93	
Seed weight (mg)	2.000	10.25	±0.0013	18.81	
Fruit length (cm)	2.650	4.148	±0.256	5.55	
Seed length (cm)	1.900	3.186	±0.422	8.43	Skew
Fruit width (cm)	2.230	3.605	±0.489	4.97	
Seed width (cm)	1.300	2.457	±0.0017	3.77	

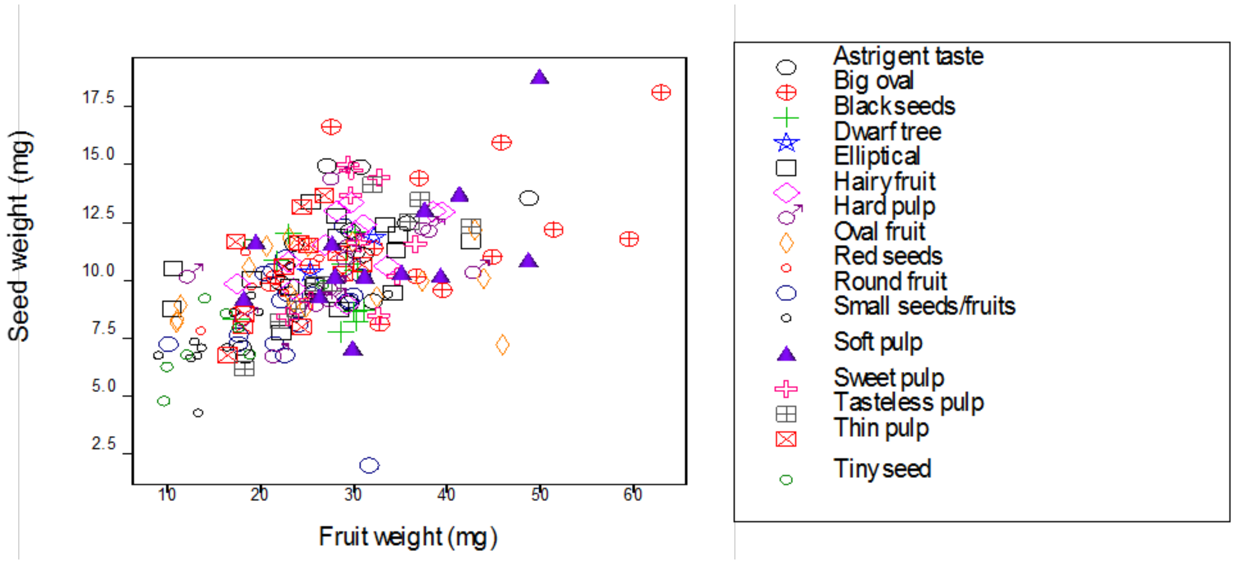

Figure 3: Relationship between fruit and seed weight of the different ethnovarieties

Otuke and Arua registered lesser fruit weight to seed weight ratio (pulp thickness) which is an indication that the shea fruits in these areas had thinner fruit pulp in average compared to the rest of the sites. These are the sites with the highest annual rainfall record (1300 mm and 1267 mm respectively) indicating that high rainfall has a negative influence on the fruit pulp but a positive impact on shea seed/kernel size increase. This was proved in Katakwi district which had the lowest mean annual rainfall (1111 mm and 850 mm respectively) and yet registered the highest fruit to seed ratio (thicker shea fruit pulps) on average than the rest of the sites.

On average, ethnovarieties like thin pulped, sweet pulped, round fruited trees, small and tiny fruited shea trees had smaller fruit to seed ratio (thinner pulp) (figure 3). This clearly explained the name given to one of the ethnovarieties "Thin pulp" which proved the phenotypic characteristics used by the farmers to give fork classification of some of the ethnovarieties (Gwali *et al.*, 2011). However, ethnovarieties like big oval; soft pulped; oval fruited, hairy and elliptical fruited ethnovarieties recorded higher fruit to seed ratio (thicker pulps) (figure 3). These ethnovarieties registered higher farmers' preference probably due to their sweet pulp for house hold food and nutrition security during famine period. These traits can play good synergies important for utilization in shea tree improvement in Uganda since breeding efforts will be targeted towards addressing needs and aspirations of the end users whom farmers form majority.

Seven morphological shea tree crown shapes (Figure 4); fruit shapes (Figure 5) were identified.

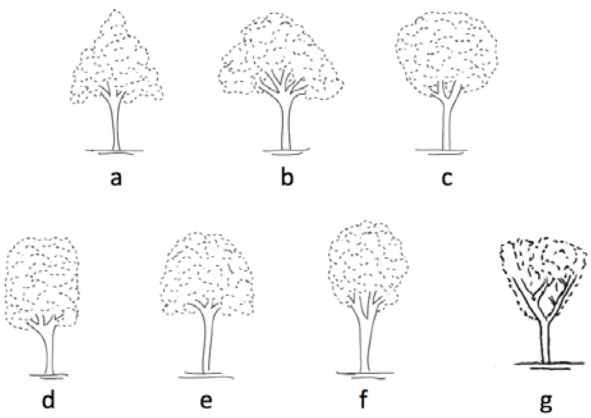

Figure 4: Shea tree crown shapes:
a. Pyramidal , b. Broom-like c. Spherical, d.Oblong; e. Semicircular, f. Elliptical; g. Inverted Pyramid

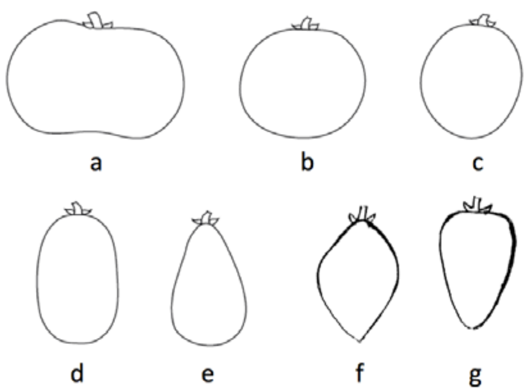

Figure 5: Shea fruit shapes:
a. Oblate; b. Spheroid; c. Ellipsoid; d. Elongated; e. Ovoid / Pear-like; f. Fusiform; g. Inverted Pear-like

The shea fruit weight distribution gives a clear indication of existence of the different ethnovarieties in the different sites. Shea fruit and seed lengths in Nakasongola, Otuke and Katakwi districts were longer than other sites (figures 6 and 7).

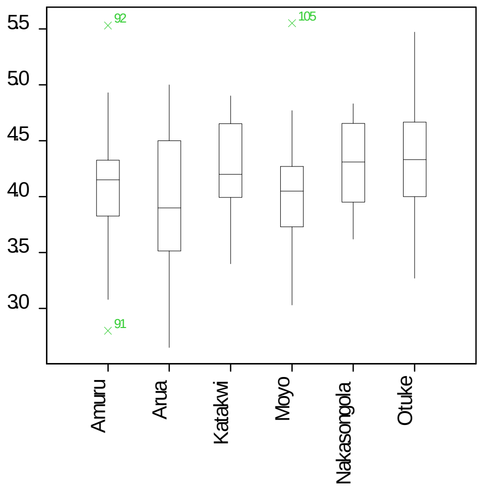

Figure 6: Boxplot for Fruit length (cm)

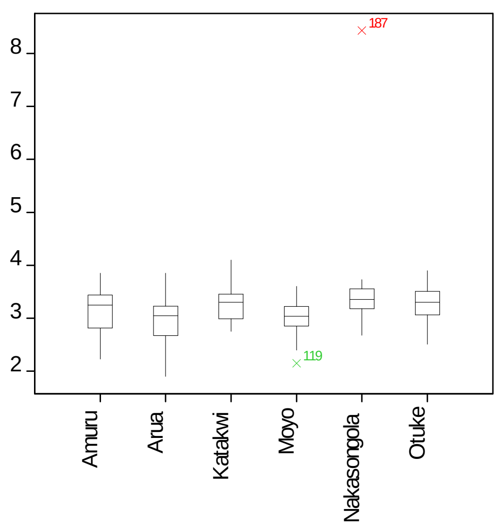

Figure 7: Boxplot for seed length (cm)

On the other hand, seed width for Nakasongola instead proved smaller than the rest of those from other sites indicating that the kernels are narrower at the middle diameter.

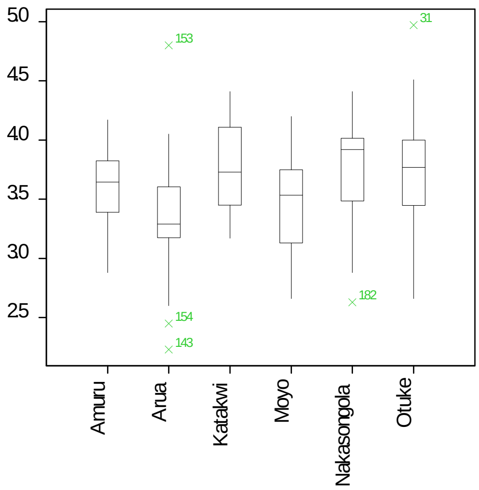

Figure 8: Box plot for fruit width (cm)

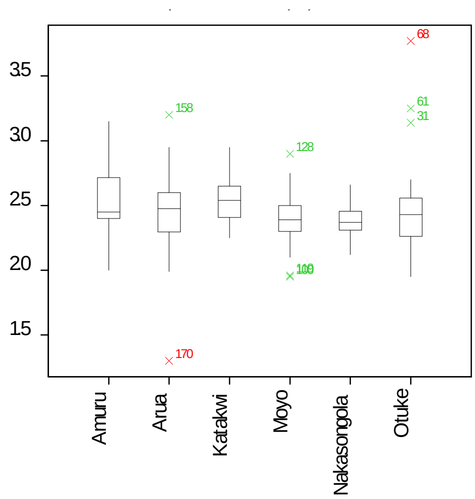

Figure 9: Box plot for seed width (cm)

Developing smaller high yielding shea trees will be beneficial to smallholder farmers with smaller pieces of land due to reduced surface area for above ground competition with agricultural crops. This kind of setting can encourage agroforestry system that promote deliberate planting of the improved shea trees on farm by diversifying smallholder farmers' resilience. It was noted that big oval; sweet pulped; thin pulped; hairy and oval fruited trees tended to be heavier on average as compared to the rest of the ethnovarieties. These are the very ethnovarieties which were selected by farmers as the preferred ethnovarieties for high oil yield (figure 8 and 9). Given farmers' local knowledge, there was clear indications that heavier fruits/seeds tend to produce more oil but this requires further research to prove this assertion.

Otherwise, shea tree breeding programme in Uganda can use the beneficial traits for oil production in these ethnovarieties to generate improved shea tree varieties with all such preferred traits for commercialized shea tree farming. Whereas some shea tree fruits were known to be with thick pulp which greatly affects fruit weight, the thick pulps do not contribute to oil yield but are eaten to subsidize on household food and nutrition. The seeds from such fruits are smaller compared to the fruit size/weight.

Table 2**.** Correlations between morpho-phenotypic characters (adjusted for ties).

Tree height (m)	1	1.000							
1st branch height (m)	2	0.571*	1.000						
DBH (cm)	3	0.585*	0.315	1.000					
Fruit weight (mg)	4	-0.165	-0.158	-0.114	1.000				
Seed weight (mg)	5	-0.085	-0.146	0.027	0.570*	1.000			
Fruit length (cm)	6	-0.111	-0.215	-0.034	0.621*	0.417	1.000		
Seed length (cm)	7	-0.156	-0.242	-0.098	0.398	0.587*	0.594*		
Fruit width (cm)	8	-0.132	-0.181	-0.112	0.768*	0.417	0.613*	0.379	
Seed width (cm)	9	0.043	0.000	0.167	0.315	0.699*	0.176	0.341	0.245
		1	2	3	4	5	6	7	8

*The significant values

The correlation matrix (table 2) showed that fruit width was correlated with fruit weight 76.8%; kernel/seed width and kernel/seed weight were correlated (69.9%), fruit width and fruit length with 63.1%, fruit length and fruit weight 62.1%; kernel/seed length and fruit length 59.4%; kernel/seed length and kernel/seed weight 58.7% and fruit weight and kernel/seed weight 57.0%; Tree parameters were weakly correlated where tree height was correlated with diameter at breast height (DBH) with 58.5% and shea tree height with the height at first branching with 57.1% (Table 2). In addition, there was significant variation of the means of fruit length and fruit width among the samples collected from Katakwi, Otuke, Amuru, Moyo, Arua and Nakasongola districts. The means of the kernel/seed weights were equally significantly different.

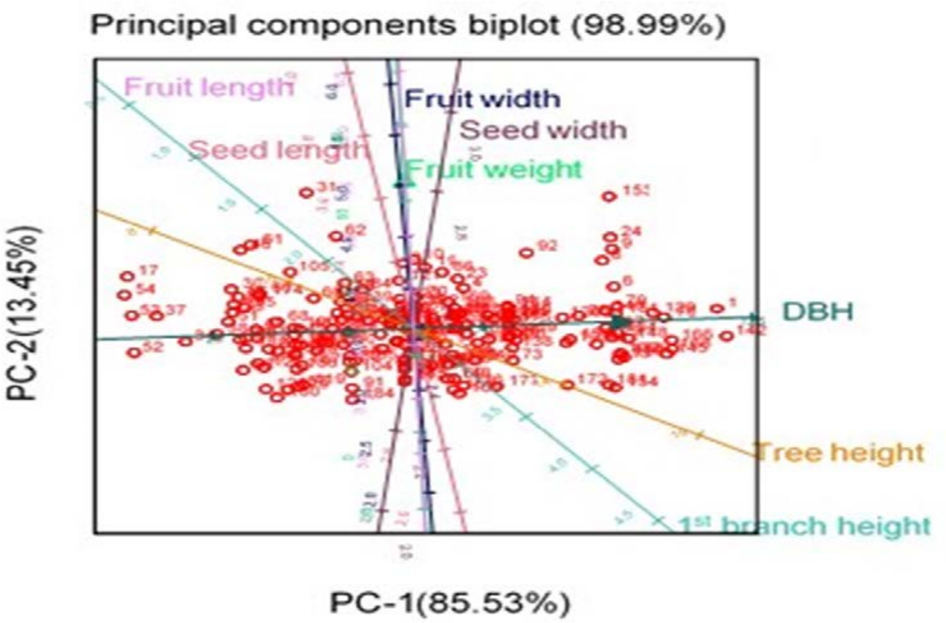

Figure 10: Principle Component Analysis of shea tree morpho-phenotypic traits in Uganda

Principal Component Analysis showed that the two principal axes explained 98.99% of the variance observed. The first axis expressed 85.53% of the total variance (Figure 10). The variables were seed length, seed width fruit width and fruit length. The second axis expressed 13.45% of the total variance. Total shea tree height, height at first branching and diameter at breast height were the variables.

Table 3: Results of Analysis of variance for height, crown shape, fruit shape, fruit weight and seed weight of 180 shea trees sampled from six districts of Uganda

Source of variation	d.f.	Mean squares					
		Tree height	Crown shape	Fruit shape	Fruit weight	Seed weight	Ethno varieties
Sites	5	43.202*	51.46*	70.396*	709.66*	31.657*	55.825*
Ethnovarieties within sites	15	10.698*	15.703*	5.47	345.32*	18.417*	12.837*
Ethnovarieties between sites	15	7.597	2.178	4.941	310.86*	16.958*	7.769
Sites x ethnovariety	52	4.311	2.717	1.707	35.52	3.657	4.132
Residual	111	4.574	4.932	4.893	50.59	3.838	4.456
Total	189	6.391	6.391	6.391	87.97	5.809	6.391

*Variables where the differences were significant at level of significance 95%

Phenotypic traits of shea trees showed significant variation within sites but non-significant variation between sites with exception of fruit and seed weights (table 3). These variations confirm Gwali *et al.*, (2012)'s report for Uganda and gave similar results with those reported by Djekota *et al.*, 2014, Mawa *et al.*, 2017, Nyarko *et al.*, 2012, Sanou *et al.*, 2004 in Chad; Burkina Faso; Ghana and Mali respectively.
Percentage variance accounted for 32.0, Wald statistic = 2.291. Plant phenotypic variations have been associated elsewhere with natural and/or human selection, gene flow and soil characteristics (Djekota *et al.*, 2014, Sanou *et al.*, 2006).

DISCUSSIONS

Tree species composition and structure are important for determining any plant ecosystem sustainability. A species with un-uniform structure and composition may portray some complication in the future status of the species. Low rainfall levels didn't affect shea tree size significantly. Differences in soil types had a closer link with shea tree size distribution.
Low rainfall and/or high temperature promotes fruit to seed ratio (increased fruit pulp thickness) reduced seed sizes in retrospect. This was linked with the morpho-phenotypic variation among shea trees in Uganda. This information is useful for developing a breeding population of shea trees suitable for different agro-ecological regions in Uganda, given the fact that shea fruits from drier and hotter sites had thicker fruit pulps and smaller seeds. The reason behind this could have been because the thicker pulp acts as food and water storage and protection for the developing seeds.
This therefore indicates that shea tree size characteristics do not much affect fruit or seed size and weight. Implying that tree breeding efforts that targets reduction of tree height and size will not have a significant impact on the size and weight of the fruits and or seeds.
Seed length and width and fruit width and length are quite useful in classification of shea tree ethnovarieties in Uganda. This is in agreement with the finding of Djekota *et al.*, (2014) in Chad. However, there is no specific fruit shape attached to a specific ethnovariety, could be due to a long period of gene flow since shea tree is a wide outcrossing species. Small fruit/seeded and tiny seeded ethnovarieties had spherical/semicircular crown shape unlike the rest of ethnovarieties that spread across all types of crown shape. Width variable was the major contributing factor for fruit and/or kernel/seed weight increase. This therefore means that for a successful shea tree breeding programme for high oil yield in Uganda, the breeding strategy must aim at increasing fruit width and to a less extent length.
There was a negative correlation between shea tree variables and fruit/seed variables. This is in line with other studies in Mali (Sanou *et al.*, 2006).

CONCLUSION

i. Shea tree ethnovarieties in Uganda vary greatly within sites and this is important for genetic diversity conservation within particular areas.
ii. Preferred traits do not vary from site to site within the shea tree growing areas in Uganda and if we are to breed, they are likely to be accepted everywhere.

ACKNOWLEDGEMENT

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