KERNEL MORPHOMETRIC CHARACTERISTICS AND OIL CONTENT AMONG SHEA TREE GENOTYPES IN UGANDA

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ABSTRACT

Shea tree (*Vitellaria paradoxa* subsp. nilotica) is an important commercial tree for domestic oil and industrial products of cosmetics, chocolate and other confectionaries traded grown worldwide. We studied seed morphometric characteristics and crude oil content of Shea nuts in Uganda. Five populations, comprising of 16 ethnovarieties, were selected from Eastern, Northern and West Nile Sub-regions of Uganda, based on their attributes as judged by the farmers. Fresh kernel weight ranged from 2 to 18.85 mg per seed. Kernel weight increased with Shea fruit weight ($y = 0.1499x + 6.1887$, $R^2 = 0.306$). Moyo district had the highest oil content ($54.37 \pm 0.32\%$); while Amuru district had the lowest oil content ($50.5 \pm 1.32\%$). Oil content decreased with increasing kernel size ($y = -0.4541x + 57.303$, $R^2 = 0.2116$) and dry matter content ($y = 0.635x - 9.863$, $R^2 = 0.011$); and varied between ethnovarieties and Shea tree populations, $P = 0.003$ and $P < 0.001$, respectively. Tinny seeded (45.7 - 65.49%), Round fruited (45.41 - 65.91%), Dwarf tree (45.19 - 64.19%), Elliptical fruited (45.32 - 64.19%) and Soft pulped (42.16 - 69.77%) ethnovarieties had the highest oil content. Narrow sense heritability (h^2) for oil yield was 1.72; while response to selection (R) was 16.48 with genetic gain (Gs) of 2.21%, given 10% top selection intensity.

Key Words: Ethnovariety, narrow sense heritability, *Vitellaria paradoxa*

RÉSUMÉ

Le karité (*Vitellaria paradoxa* subsp. *Nilotica*) est un arbre commercial important pour l'huile domestique et les produits industriels de cosmétiques, de chocolat et d'autres confiseries commercialisés dans le monde entier. Nous avons étudié les caractéristiques morphométriques des graines et la teneur en huile brute des noix de karité en Ouganda. Cinq populations, comprenant 16 ethnovariétés, ont été sélectionnées dans les sous-régions de l'Est, du Nord et de l'Ouest du Nil en Ouganda, sur la base de

leurs attributs tels que jugés par les agriculteurs. Le poids des grains frais variait de 2 à 18,85 mg par graine. Le poids du noyau a augmenté avec le poids du fruit de karité (y = 0,1499x + 6,1887, R² = 0,306). Le district de Moyo avait la teneur en huile la plus élevée (54,37 ± 0,32 %) ; tandis que le district d'Amuru avait la plus faible teneur en huile (50,5 ± 1,32%). La teneur en huile diminuait avec l'augmentation de la taille du grain (y = -0,4541x + 57,303, R² = 0,2116) et de la teneur en matière sèche (y = 0,635x - 9,863, R²= 0,011) ; et variait entre les ethnovariétés et les populations d'arbres à karité, P = 0,003 et P < 0,001, respectivement. Les ethnovariétés à graines minuscules (45,7 - 65,49%), à fruits ronds (45,41 - 65,91%), à arbre nain (45,19 - 64,19%), à fruits elliptiques (45,32 - 64,19%) et à pulpe molle (42,16 - 69,77%) avaient la teneur en huile la plus élevée . L'héritabilité au sens strict (h^2) pour le rendement en huile était de 1,72 ; tandis que la réponse à la sélection (R) était de 16,48 avec un gain génétique (Gs) de 2,21 %, étant donné une intensité de sélection supérieure de 10 %.

Mots Clés : Ethnovariété, héritabilité au sens étroit, *Vitellaria paradoxa*

INTRODUCTION

Shea tree (*Vitellaria paradoxa*) is one of the important species for enhancing socio-economic well being of the communities in the tropics (Jamala *et al.,* 2013; Odoi *et al.,* 2020a). These species provide a number of useful raw materials for both industrial and domestic productions and other services (Seth, 2003). There is in fact, a growing concern in the recent past on oil producing and medicinal tree species and increasing research on their oil content and fatty acid profiles (Matthäus *et al.*, 2015; Dembélé *et al,*, 2019).

Shea species grows in 21 countries that comprise the Sudano-Sahelian Africa, from Senegal in West Africa to Uganda in Eastern Africa (Animasaun *et al.*, 2019). The tree's importance is derived from its products which include: edible fruits, oils and cosmetics (Jasaw *et al.*, 2015). Its oil/fats are highly traded both locally and internationally for cooking, traditional medicine, and in the confectionary and cosmetics industries. According to Jamala *et al*. (2013) and Addaquay (2004), Shea oil content varies greatly depending on the extraction methods and experience of the processors.

Although many products, including medicinal values can be obtained from Shea tree, the method of oil extraction, geographical area and climatic conditions influence the kernel oil properties; which can intern influence the quality of the end product (Badu and Awudza, 2017)).

Since wet chemistry has been used elsewhere (Richter and Schellenberg, 2007) as a ground truthing method for dry chemistry with its better efficiency than other methods (Gwali *et al.*, 2012), this study used wet chemistry to evaluate the claims by the farmers on the existence and choice of high oil yielding Shea tree ethnovarieties in Uganda. The specific objective of this study was to investigate seed morphometric characteristics and crude oil content of Shea nuts in Uganda.

MATERIALS AND METHODS

Plant materials. Ripe freshly fallen Shea fruits were collected from 150 jointly selected Shea trees between June and July 2020 (Odoi *et al.,* 2020a). Thirty-six Shea trees of different ethnovarieties, were selected from each of the five purposively selected districts of Katakwi, Otuke, Amuru, Moyo and Arua for seed/fruit collection due to their possession of high densities of Shea trees. Twenty freshly fallen and ripe fruits were randomly collected from the selected Shea trees and weighed with and without the pulps following Nyarko *et al.* (2012). Shea kernel colour was also determined soon after depulping.

The Shea kernels were then dried at the National Forestry Resources Research Institute laboratory in the month of July 2020.

The drying temperatures for the nuts were varied after every 48 hours from 45 to 55 to 60 and then to 65 °C, until constant weights were attained at nut moisture content between 1-2%. At this moisture content, the kernels were believed to have dried well enough to prevent oil auto-oxidation before extraction. The dried nuts were then packed in separate air tight polythene bags and stored in cooler boxes, and transported to the Food Technology, Nutrition and Bio-engineering Technology Laboratory at Makerere University for oil content analysis following Okullo *et al.* (2010).

Sample preparation. The Shea kernels were cracked after drying and the hard shells removed to leave the inner nuts for grinding. Between 10-20 Shea nuts were milled for 2-3 minutes, using 500A Multifunctional grinder, with rotating speed of 25000r/min. The nuts were then crushed to complete powder, with fineness of 50 mesh; using 500A multifunction grinder (Herb Grinder - China). The milling machine was then thoroughly cleaned using 2 ply paper kitchen towel of the size of 215 mm x 250 mm (Kim-Fay EA Ltd) to remove any Shea nut powder from the previous samples before placing fresh ones for grinding.

The grounded powder was then placed in sealable polythene bags, labeled with the same identification code as for the tree from which the nuts were collected. The milled labeled samples were then kept in a larger cooler box, all through the oil extraction period to maintain uniform room temperature throughout the process.

Moisture content. Moisture content was determined using the method of AOAC (2012). About five grammes of sample was taken onto a pre-conditioned petri-dish, and dried in a hot air oven (Gallenkamp, UK) at 100 °C for about 16 hours. Dry samples were cooled in a desiccator for about 5 min and weighed. The moisture content was then calculated as shown in Equation 1.

$$\text{Moisture (\%)} = \frac{W2 - W3}{W2 - W1} \times 100 \quad .... \text{ Equation 1}$$

Where:

W_1 = weight of empty dish;
W_2 = weight of wet sample and dish;
W_3 = weight of dry sample and dish

Crude fat/oil content. Crude fat was determined using the Soxhlet extraction method as described by American Official Agricultural Chemists (AOAC, 2012). Oil is extracted with a continuous reflux of petroleum ether over dried tissue material in a Soxhlet extractor (Lee, 1981). About 4 grammes of sample was taken in triplicates into a dry thimble lined with filter paper. The rings were then attached on the thimbles and fixed in the Soxhlet system (AOAC, 2012).

About 50 ml of petroleum ether (extraction solvent) was put in a precondition and pre-weighed dry Soxhlet beakers which were fixed in Soxhlet equipment (Soxhlet system 1043 Tecator, Sweden). The thimbles with the samples were dipped in petroleum ether in Soxhlet beakers. Fat extraction was done by boiling the samples at 110 °C for 30 min. After the boiling, the extracted fat was washed down into Soxhlet beakers during rinsing for an hour. The collected fat in Soxhlet beakers was dried by putting the beakers in an oven 100 °C for 30 min. The dried oil collected in the beakers was then removed from the oven and placed in desiccator to cool down to room temperature before reweighing to establish the weight of oil extracted.

Crude Shea oil content was then calculated as shown in Equation 2.

$$\text{Total fat (\%)} = \frac{W_1 - W_2}{W_0} \times 100 .... \text{ Equation 2}$$

Where:

W_0 = Weight of the sample (g);
W_2 = Weight of the empty beaker (g) and

W_1 = Weight of the beaker and fat (g).

The pooled oil extracts were kept in a 15 mm falcon tubes at 4 °C temperature in a refrigerator. The oils were allowed to settle and solidify for a period of 24 hours, before their colours were determined and restored in a sealable plastic container, and returned to the refrigerator prior to analysis.

Fruit pulp, kernel and oil colours. Colour determination was done using the BS 4800 Decorative Colour Range Guide outlined by Sadoli (Akzonobel, 1987). Each sample to be determined was placed close to the colour ranges within the colour guide and matched to identify the closest colour with the Shea item.

Fruit pulp colour was determined soon after depulping the freshly fallen ripe fruit, before any colour changes took place. In the same manner, colours for the Shea kernels were also determined soon after depulping (Plates 1 and 2).

Expected gain (Gs), selection deferential, selection response and heritability. Expected gain was derived as:

$$Gs = i\sqrt{Vp} \; .h^2 \text{…….............…… Equation 3}$$

Where:

Gs   = Predicted genetic gain;
i   = Constant base on selection intensity;
$\sqrt{Vp}$ = Square root of phenotypic variance (sd);
h^2 = Heritability in the narrow sense

The selection response R, was given as: R = $h^2 S$

Where:

h^2 was determined from the regression slope

(bi) $\dfrac{\sum (x-\bar{x})(y-\bar{y})}{(x-\bar{x})^2} = \tfrac{1}{4}h^2$ … Equation 4

Where:

(*x-x*) represented parental oil yield deviation and (*y-y*) represents offspring mean deviation of the selected parents.

The selection deferential **"s"** is given by

$\overline{T}s - \overline{T}$ ....…………. Equation 5

Where

$\overline{T}s - \overline{T}$ represents the parental mean oil yield deviation from the mean of the off springs of the selected parents

Experimental design. Powder from each Shea genotype was randomly sampled in triplicates (4-5 mg) for oil extraction. The replication minimised unforeseen technical or other errors due to machine failures. The triplicate oil from each tree was later bulked into a single Falcone tube for storage at 2 °C, before fatty acids profiling (Okullo *et al.*, 2010).

Data analysis. Shea oil data were entered in Excel Spread Sheet cleaned and the top 10% genotypes selected for determination of fatty acid profiles. Data obtained were subjected to analysis of variance (ANOVA) in GenStat version 18 (Animasaun *et al.*, 2019). Kruskal Wallis one-way ANOVA was run to determine the variation between ethnovarieties and location and significance accepted at P<0.05 level (Nyarko *et al.*, 2012). Colours of different Shea components were analysed in
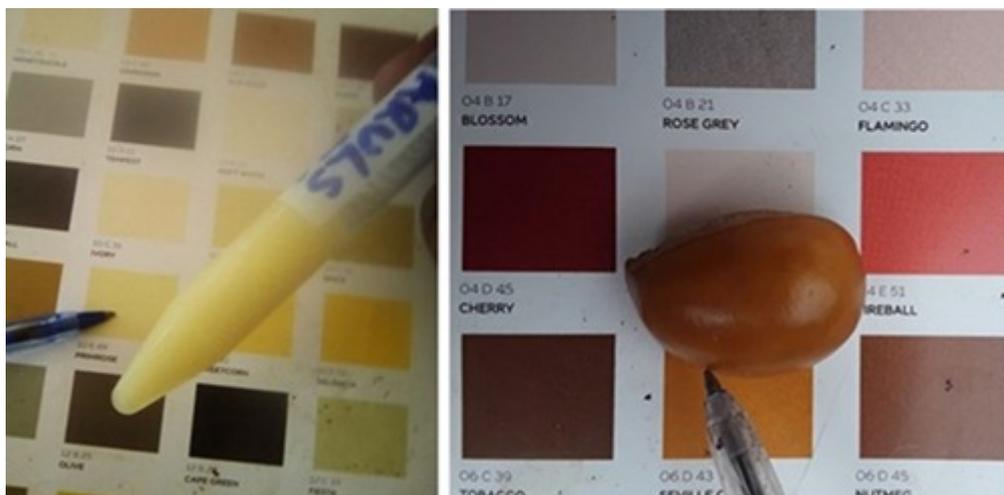
Plate 1a. Shea oil colour   Plate 1b. Shea kernel colour

Plate 1a - b. Shea products colour determination using Sadolin BS 4800 Decorative colour Range Guide

Soft white yellow   Ivory yellow   Mimosa yellow   Sweet corn yellow

Plate 2. Display of some oil colours stored in falcon tubes after extraction using Soxhlet machine. Mimosa, Primrose in plate 1a above and Ivory, respectively were the most predominant colours.

excel and presented in proportions (%) of occurrence (Hwang *et al.,* 2006).

RESULTS

Shea fruit and kernel morphometric characteristics. The average Shea ethnovarieties fruit weight ranged from 12.08 ± 1.01 mg per fruit in Tinny seeded trees; to 62.93 ± 1.79 mg - standard deviation per fruit (SD) in Big oval fruited trees. Kernel weights ranged from 5.3 mg per seed in Tinny seeded to 44.8 mg in Big oval fruited Shea trees (Fig. 1 and Table 1).

Mean Shea fruit and kernel weights in the study areas were 27.84 ± 9.14 mg per fruit -
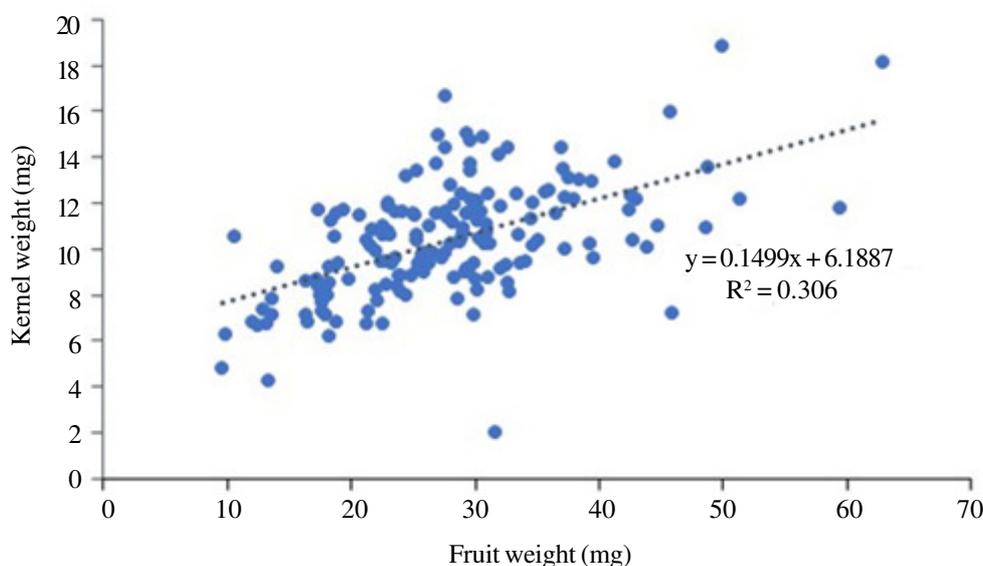
Figure 1. Regression analysis of Shea fruit weight and fresh kernel weight.

TABLE 1.   The mean kernel weight (mg) and standard errors of Uganda's Shea ethnovarieties

Ethnovarieties	Minimum	Mean ±SE	Maximum
Big oval fruited	8.11	12.44 ± 0.90	18.13
Soft pulped	7.09	11.54 ± 0.91	18.81
Sweet pulped	8.43	11.51 ± 0.78	14.99
Astringent taste pulped	7.08	11.2 ± 0.61	14.95
Dwarf tree	10.36	11.11 ± 0.75	11.86
Hairy	8.94	11.09 ± 0.49	12.98
Elliptical fruited	7.74	10.97 ± 0.5	13.38
Hard pulped	6.71	10.8 ± 0.58	14.39
Thin pulped	7.99	10.74 ± 0.53	13.68
Tasteless pulped	6.18	10.6 ± 0.89	14.13
Oval pulped	7.21	10.33 ± 0.43	12.19
Red seeded	7.82	9.91 ± 0.61	11.38
Black seeded	7.79	9.68 ± 0.56	12.07
Round fruited	2	8.62 ± 0.62	12.35
Small fruited	4.27	7.85 ± 0.48	10.64
Tinny seeded	4.78	7.85 ± 0.63	11.57

SD and 17.5 ± 1.31 mg per seed - SD, respectively. Shea kernel weight increased with fruit ($R^2 = 0.306$) (Fig. 1). There was also an exponential increase in Shea fruit pulp weight with increasing fruit weight ($R^2 = 0.9335$) (Fig. 2).

Katakwi district had the highest mean Shea kernel weight (11.67 ± 1.59 mg); whereas Moyo district (8.75 ± 0.32 mg) had the least (Fig. 3).

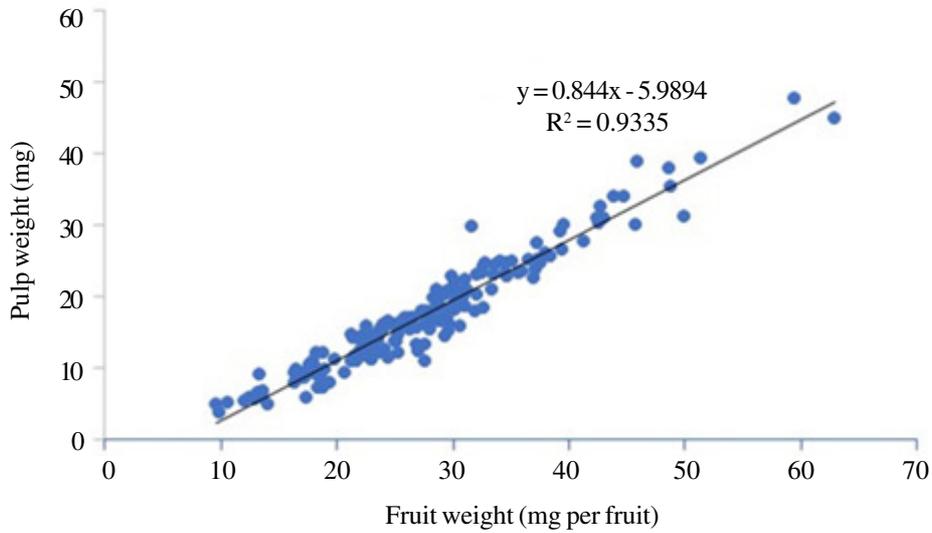Individual weights of each Shea kernel among the sixteen ethnovarieties were

Figure 2. Regression plot of the relationship between Shea fruit weight and fresh pulp weight in selected shea trees from five districts in Uganda.
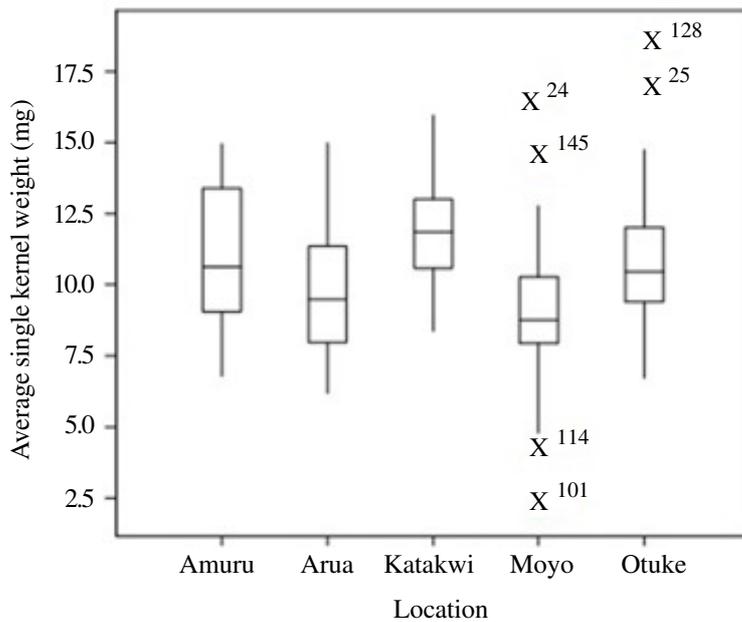

Figure 3. Mean Shea kernel weight per district of study.

presented per study area and ethnovariety (Table 1). Big oval fruited and Soft pulped ethnovarieties had the heaviest fruits, whereas Tinny seeded, small fruited and round fruited had the lightest fruits (Table 1)

Dry matter content of Shea kernels decreased with increasing moisture content ($R^2 = 0.9796$). There was a perfect linear negative relationship between Shea kernel dry matter content and its moisture content (Fig. 4).

Physical characteristics. Thirteen Shea kernel colours and seven colours in each of the fruit pulp and Shea oil were identified, respectively (Fig. 5). The most predominant kernel colours were Tobacco brown (35.8%); followed by Suede brown colour (13.5%). Lillopop yellow (42.9%), Primerose yellow (17.5%) and Lime yellow (14.3%) were the most predominant colours in the fruit pulp; Mimosa yellow (38.2%) followed by Primerose yellow (34.9%) and Ivory yellow (14.5%) were the predominant oil colours in the Shea trees. Oil

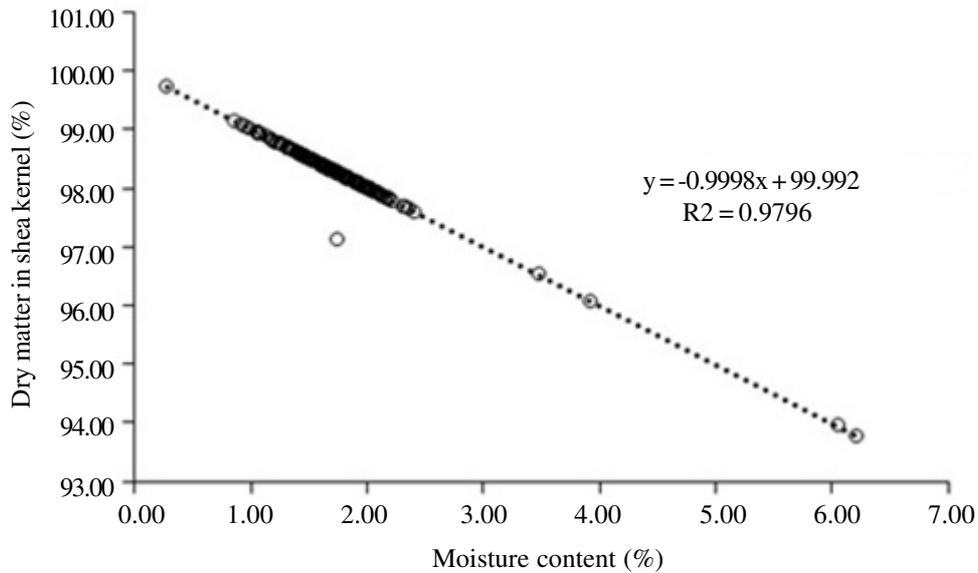$$y = -0.9998x + 99.992$$
$$R^2 = 0.9796$$

Figure 4. Regression plot of the relationship between Shea kernel moisture content and dry matter content.
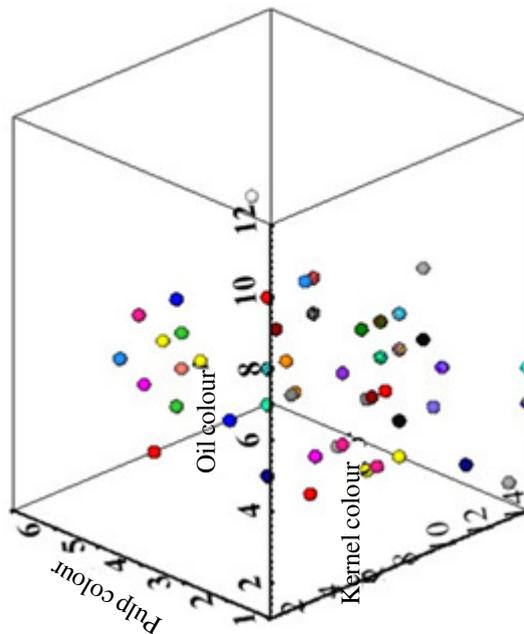

Figure 5. 3D display of the relationship between Shea kernel, fruit pulp and oil colour.

colour was more closely linked with pulp colour than kernel colour. PCA Latent vectors (loadings) 1 produced closer loadings of Shea oil colour and pulp colour of 0.51 and 0.59, respectively; than the kernel colour (-0.98).

Oil content. Shea oil content ranged from 37.41% in the hairy to 69.77% in the soft pulped ethnovariety. These have been the highest range achieved so far when compared with the past studies. There were significant variations in oil content between the ethnovarieties (P = 0.003) and populations (P<0.001) (Table 2).

Oil content among Shea tree ethnovarieties decreased with increasing kernel weight (R^2 = 0.2116) (Fig. 6). Hairy ethnovariety, for example had heavy kernels and yet had the lowest oil content, as compared to the rest.

Ethnovarieties with the highest oil contents were the Tinny seeded (55.41% ± 1.008), Round fruited (54.29% ± 0.66), Dwarf tree (53.53% ± 0.869) and Elliptical fruited (53.53% ± 0.869) ethnovarieties had the highest oil content. Meanwhile, Hairy (49.78 ± 0.775), Thin pulped (51.5 ± 0.533) and Hard pulped (51.6 ± 0.551) had the least oil contents (Table 3).

Thirty genotypes were selected as the top 10% high oil yielding genotypes from eleven ethnovarieties. Moyo (13 genotypes) and

Otuke (9 genotypes) had the highest numbers of individuals selected as the top 10% oil yielding Shea trees. The top 10% high oil yielding genotypes comprised of eleven ethnovarieties from across the population. Of these, Round fruited ethnovariety had nine genotypes selected, followed by Tinny seeded and Elliptical fruited ethnovarieties; which had four selected genotypes for each, respectively (Table 4).

Oil content significantly varied among the ethnovarieties (P = 0.003) and between locations (P<0.001). The selection represents 75% Shea tree ethnovarieties in Uganda with Round fruited, Tinny seeded, Black seeded and Elliptical fruited ethnovarieties dominating (Table 4). Top selection for high oil yielding Shea tree genotypes with high heritability, when combined with collaborative selection approach, is likely to improve oil yield from 52.59% to over 62.1%.

Kernel dry matter content increased with oil content; although there was a weak relationship (R^2 = 0.0111). On the other hand, there was negative relationship between kernel moisture content and oil content (R^2 = 0.0098) (Fig. 7). It is clear from Figure 7 that the coefficient of determination (R^2), is an indication that 62.91% of the mean offspring oil content can be predicted using the parental oil content.

TABLE 2. Mean Shea kernel oil content (%) for the different study sites and the overall mean

District	Oil content (%)
Moyo	54.37 ± 0.32
Otuke	53.33 ± 2.81
Katakwi	52.58 ± 1.59
Arua	52.18 ± 0.14
Amuru	50.50 ± 1.32
Mean	52.59 ± 1.09

Variation in oil content was significant both between the ethnovarieties and Shea tree populations; P = 0.003 and P<0.001, respectively
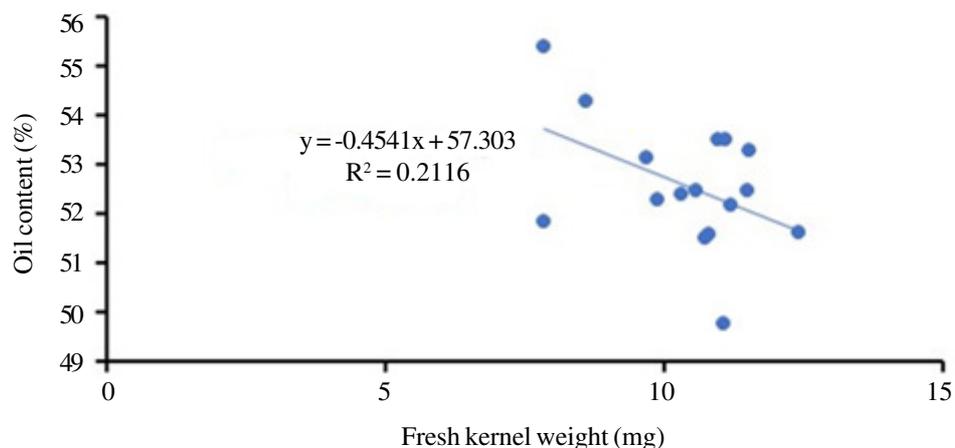
Figure 6. Relationship between fresh Shea kernel weight and oil content among the sixteen ethnovarieties in Uganda.

TABLE 3. Distribution of oil content for individual Shea tree ethnovariety indicating their means and standard deviations

Descriptor	Shea oil content (%)		
	Minimum	Mean ± SD	Maximum
Tinny seeded	45.47	55.41 ± 4.94	65.49
Round fruited	45.41	54.29 ± 4.72	65.91
Dwarf tree	45.19	53.53 ± 4.38	64.19
Ellipsoid fruited	45.32	53.53 ± 4.38	64.19
Soft pulped	42.16	53.28 ± 5.39	69.77
Black seeded	40.79	53.13 ± 5.73	64.23
Sweet pulped	42.73	52.47 ± 4.87	64.18
Tasteless pulped	42.73	52.47 ± 4.87	64.18
Oval fruited	45	52.4 ± 3.18	59.48
Red seeded	41.29	52.29 ± 4.27	59.51
Astringent taste fruited	42.85	52.19 ± 3.40	57.33
Small fruited	43.72	51.86 ± 3.93	59.1
Big oval fruited	37.41	51.62 ± 5.65	63.98
Hard pulped	43.35	51.6 ± 3.31	58.47
Thin pulped	44.23	51.5 ± 3.33	57.15
Hairy	40.4	49.78 ± 4.45	59.47

With selection intensity of 10%, the slope (bi) for the regression line (Fig. 7), and the narrow sense heritability are given below:

$$bi = h^2 = \frac{0.07 * 0.03}{0.0049}$$

Being half sibs

$$= \frac{1}{4} h^2 = 0.4286 \text{ or } 0.43 * 4$$

$$= 1.72$$

TABLE 4. The top 10% high oil yielding Shea genotypes selected from five districts in Uganda

Genotype	% Oil	Genotype	% Oil	Genotype	% Oil
OTOGSP56	69.77	MOMOBO34	63.03	OTOTRO12	60.52
OTOGRO34	65.91	AMATSW32	63	MOMOTA11	60.02
OTOGDT22	65.64	MOMORO24	62.56	ARULTS29	59.96
ARULTS27	65.49	ARULTS24	62.42	OTOGRO31	59.62
MOMOBS29	64.23	MOMORO26	61.63	KAOMRS111	59.5
ARULEL13	64.19	OTOGDT26	61.34	MOMOEL53	59.49
MOMOTA14	64.18	OTOTRO17	60.93	KAOMOV32	59.48
MOMOBO37	63.98	MOMORO210	60.9	OTOGHA110	59.47
MOMOTS24	63.15	MOMOBS27	60.61	KAOMOV28	59.26
OTOGRO35	63.07	MOMOBS23	60.58	MOMOEL51	59.1

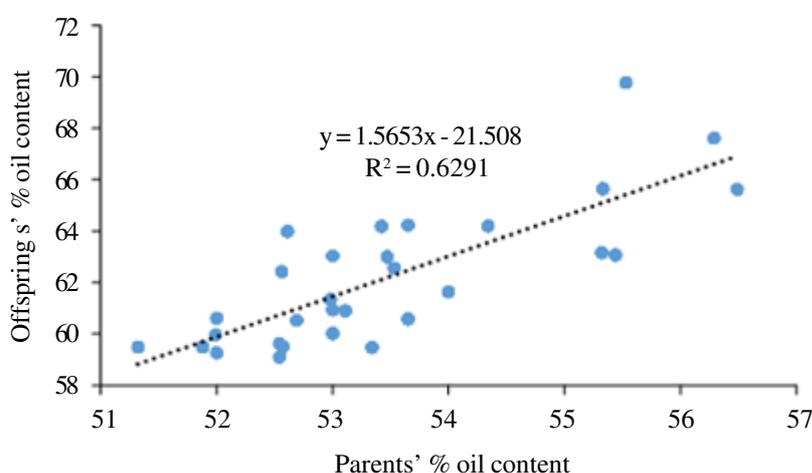
Figure 7. Change in offspring Shea kernel oil content given selected parents.

Given that the selection deferential S was 62.1 - 52.53 = 9.58

+ the response to selection R = 1.72 * 9.58
$$= 16.48\%$$

The genetic gain (Gs) given a 10% selection intensity will therefore be:

Gs = 1.755 * $\sqrt{0.03}$ * 1.72
= 1.755 * 0.1732 * 1.72
= 2.21% from 54.4 to 56.61% of kernel dry matter oil content

DISCUSSION

Shea fruit, kernel and oil physical characteristics. The analysis of Shea kernel weight revealed a clear variation between ethnovarieties (Table 1). Katakwi district havinh the largest kernel size and Moyo district having the smallest kernel size. The variation could have been caused by the differences in environmental, genetic effect and intensity of influence during selection under farmer managed natural regeneration, with different preferred traits from location to location (Sanou *et al.*, 2005).

Soil characteristics, rainfall intensity and levels of stress factors in a particular location could have also greatly contributed to the variations in the fruit and kernel sizes/weights. The variations in fruit to kernel ration (pulp thickness) has been used elsewhere in characterising Shea trees in the region (Djekota *et al.*, 2014). This study also found relevance to this assertion among the local communities in Uganda, where a number of ethnovarieties were characterised and named based on fruit and kernel characteristics (Gwali *et al.*, 2011; Odoi *et al.*, 2020a).

Figure 1 reveals some Shea trees with larger fruit to kernel ratio (Thicker pulp – smaller kernels) than the others. This attribute could be taken advantage of to breed for a number of traits that could offer end users with various options to satisfy their aspirations over a longer period of time. In that way, larger ethnovarieties with high fruit to kernel ratio like Soft pulped, Sweet pulped and big oval fruited could be bred for sweet, bigger and fleshy fruits, to meet food and nutrition security among the small farmer households in Uganda.

Kernel coat colour ranged within the brown colours, with Tobacco and Suede brown as the most predominant colours (Plate 1b). This finding is in line with other reports of similar studies in West Africa (Nafan *et al.*, 2007; Agúndez *et al.*, 2019; Aimasaun *et al.*, 2019). Shea pulp and oil colours have close linkages, which have been as noticed on Primrose yellow colour (one of the most predominant colours) in both traits. Although Agúndez *et al.* (2019) reported oil colour range between grey - yellow, this study found a congruence of the afore mentioned as the oil colour ranged within the yellows (Mimosa, Primrose, Ivory to soft white yellow). The colour variations in the kernels could have been determined by genetic factors, since seeds are usually formed through meiotic processes coupled with mutations or gene recombination's (Abasse *et al*, 2011; Aimasaun *et al.*, 2019).

Factors such as human selection over time and gene flow could also be some of the causative agents for the kernel colour variations (Tremblay *et al.*, 2010). On the other hand, variations in fruit pulp and oil colour could be due to environmental and other stress factors, which are not genetic such as variations in soil nutrient status, rainfall intensity, incident and the length of sun light duration, coupled with altitudinal ranges where the trees grow. According to Huang *et al.* (2013), these factors are very important in shaping the pulp and oil colour, depending upon how the different chemicals react with the factors.

The oils that exhibit clear yellowish colours are most preferred by the consumers with a belief that they are more natural and fresher than the rest. Such variation in oil colour can attract more prices from buyers when oils are graded (Aimasaun *et al.*, 2019).

Kernel oil content and response to selection. The results of this study have revealed high variations in oil content at tree level; and low variations when the trees are clumped at ethnovariety and location level (Tables 3 and 4). At location level, Moyo district emerged with the highest percentage oil content; followed by Otuke district. The oil content in these districts was greater than that reported by other researchers in the region (Okullo *et al.*, 2010; Gwali *et al.*, 2012; Animasaun *et al.,* 2019), but lower than those reported by Chibor *et al.* (2017). Samples from Amuru district recoded the lowest oil content compared to those from all other districts. Also, Moyo district registered the smallest average kernel weight among the five districts of study. This is a clear indication that larger kernel size is not a good determinant for high oil content in the Shea tree. Additionally, the variation in oil yield between locations point to the differences in the mineralogical makeup of the soil types that determine the soil mineral bonding and their availability for plant use (Barkley and Fisher, 2019).

Other factors could also be responsible for higher oil yield in the Shea tree than fruit or larger seed sizes. This is undoubtedly evidenced in figure 6, where percentage Shea kernel oil content decreases with increasing kernel sizes ($R^2 = 0.2116$). This finding is contrary to the reports by some farmers who reported a positive relationship between both traits (Odoi *et al.,* 2020a).

In the present study, Tinny seeded and round fruited ethnovarieties had the higher oil content than the rest of the ethnovarieties (Table 3). and yet these also had the smallest kernels compared to the other ethnovarieties in Uganda (Odoi *et al.,* 2020b). The fact that is not in agreement with Huang *et al.* (2013), is a pointer that variations between ethnovarieties and locations could have been caused by the interaction between genetic and environmental factors.

It should also be noted that oil yield is genetic and greatly varies from tree to tree given availability of genes that encode for high oil yield due to recombination. While Gwali *et al.* (2012), percentage Shea oil yield range of between 43.88% - 58.4% at tree level which was also higher than (Okullo *et al.*, 2010), the findings of this study revealed a higher range of 37.41% - 69.77% in kernel percentage oil yield than all the earlier researchers (Okullo *et al.*, 2010; Gwali *et al.*, 2012; Chibor *et al.*, 2017; Animasaun *et al.,* 2019). This kind of variation where there are some individuals with very high and others with very low oil contents is good for top selection in tree breeding to enhance fruit yields and income.

Given the selection intensity of 10%, forty top oil yielding genotypes were selected ranging from 59.1 - 69.77%. This resulted in oil content of the selected parent of the offspring of 62.1%, far higher than the base parental average of 52.52%. The results prove the fact that farmers know and can easily select high oil yielding Shea trees within their localities. Even then, such selections can only be successful if the traits of interest have higher heritability to the narrow sense. With higher heritability, such selection can offer higher response to selection and therefore higher genetic gain which could greatly improve on oil yield in the species (Ersullo *et al.,* 2016).

CONCLUSION

The study has highlighted yield and phenotypic properties of Shea oil in Uganda and the need for grading the nuts before processing both nuts and oil in order to attract better competitive prices with products from other regions. Tinny seeded and round fruited ethnovarieties with smaller kernel sizes had the highest oil content can therefore, be promoted for planting to increase oil yield in Uganda.

This study offers new insights for improving Shea kernel oil yield and production in Uganda. This will go a long way in enhancing Shea production for improving food and nutritional security among the communities in the Shea parkland of Uganda.

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