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# Fat content and fatty acid profiles of shea tree (*Vitellaria paradoxa* subspecies *nilotica*) ethno-varieties in Uganda

Samson Gwali[a,b]*, Grace Nakabonge[a], John Bosco Lamoris Okullo[a], Gerald Eilu[a], Nelly Forestier-Chiron[c], Georges Piombo[d] and Fabrice Davrieux[c]

[a]*School of Forestry, Environment and Geographical Sciences, College of Agricultural Sciences, Makerere University, P.O. Box 7062, Kampala, Uganda;* [b]*National Forestry Resources Research Institute (NaFORRI), P.O. Box 1752, Kampala, Uganda;* [c]*CIRAD, Persyst, UMR Qualisud, TA B-95/16, 73, Rue Jean François Breton, 34398 Montpellier Cedex 5, France;* [d]*CIRAD, UMR IATE, Laboratoire de Lipotechnie TA B-62/16, 73 rue Jean François Breton, 34398 Montpellier Cedex 5, France*

Fat content and fatty acid composition are important nutritional properties of shea fruits. Farmers in Uganda report the presence of local shea tree ethno-varieties, but it is necessary to investigate their relative fat content and fatty acid composition to evaluate the economic importance of these ethno-varieties. Near infrared spectrophotometry (NIRS) was used to determine the fat content as well as the fatty acid composition of 44 ethno-varieties. Wet chemistry (soxtec petroleum – ether fat extraction and gas chromatography) methods were used to validate the results from NIRS. Fat content ranged from 43.9% to 58.4% while fatty acid composition was dominated by oleic (47–62%) and stearic acid (25–38%). Other fatty acids present were palmitic, vaccenic, linoleic, linolenic and arachidic acids. There was no significant difference in stearic, palmitic and oleic acid composition between ethno-varieties. However, significant variation of fat content, vaccenic and linoleic acids was observed between some ethno-varieties, perhaps due to locality, climatic and tree-to-tree differences. These findings can be utilized for the selection of ethno-varieties that are suitable for commercial production of shea oil in Uganda.

**Keywords:** shea tree; *Vitellaria paradoxa*; *nilotica*; fatty acids; near infrared spectrophotometry; Teso; West Nile

## Introduction

The shea tree (*Vitellaria paradoxa* C. F. Gaertn. – Family Sapotaceae) is a small- to medium-sized tree that is distributed over a large swathe of territory in sub-Saharan Africa (Hall et al. 1996). Its distribution extends from Senegal in West Africa to Uganda and Ethiopia in the eastern part of Africa. Taxonomically, *Vitellaria* C.F. Gertn is a monospecific genus with two subspecies: *paradoxa* and *nilotica* (Hemsley 1968; Hall et al. 1996). Studies of lipid composition of *V. paradoxa* suggest that stearic acid dominates in subspecies *paradoxa* while oleic acid dominates in subspecies *nilotica* (Maranz et al. 2004; Davrieux et al. 2010). According to Hemsley (1968), subspecies *nilotica* can be distinguished from the subspecies *paradoxa* by the possession of larger flowers whose pedicels and outer sepals are densely indumented. More recent research, however, indicates that there is no clear morphological distinction based on leaves, inflorescences and fruits between those two subspecies (Bouvet et al. 2004; Sanou et al. 2006). Genetic evidence suggests that some subspecies *paradoxa* populations, especially in central Africa and Cameroon, share common evolutionary origins with subspecies *nilotica* populations

*Corresponding author. Email: gwalis@yahoo.co.uk

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in eastern Africa (Allal et al. 2011). However, there is general agreement that the populations in eastern Africa belong to the subspecies *nilotica*, while the subspecies composition of the populations in West and Central Africa (including Chad) are still the subject of ongoing research (Bouvet et al. 2004; Allal et al. 2011).

The shea tree produces fruits whose kernels are rich in oil (Hall et al. 1996). Shea oil is one of a few sources of fat in the diets of the local farming communities of the savanna parklands of Africa (Maranz et al. 2004). Apart from its use in cooking (Lamien et al. 1996), shea oil is utilized in various social and cultural rituals such as traditional initiation, marriages, births, rainmaking, traditional worship, funerals and coronation rituals (Goreja, 2004). Shea oil is also used in traditional medicine, for example, in the treatment of wounds (Egunyomi et al. 2009), and its importance to local communities is further manifested by its use in local poetry, song and dance (Fardon 1990; Kuwabong 2004).

Shea oil is an important source of tocopherols (or vitamin E) and vitamin F (Wiesman et al. 2003). However, shea oil attracts attention for industrial and commercial uses mainly on account of the dominant fatty acids it contains. Shea oil is principally composed of palmitic, stearic, oleic, linoleic and arachidic acids (Maranz et al. 2004). Stearic and oleic acids are the two dominant fatty acids, accounting for 85–90% of the total fatty acid composition. Stearic acid is specifically ideal for use as an industrial base for confectionary and food products (Ming 2008; Talbot & Slager 2008), whereas oleic acid is specifically ideal as a raw material for cosmetic and personal care applications (Ferris et al. 2004; Maranz et al. 2004).

Fat content and fatty acid composition, therefore, provide a good opportunity to characterize particular shea trees with desirable traits for possible production linked to particular markets. However, while recent studies suggest variable fat content and fatty acid composition in shea oil (Maranz et al. 2004; Akihisa et al. 2010), little is known about such variation in shea tree phenotypes which farmers identify as distinct ethno-varieties. Most studies have often treated shea trees in Uganda as an entity without segregation into ethno-varieties. Identification of ethno-varieties with high fat content and desired fatty acid profiles would, therefore, transform the shea oil industry in Uganda to a lucrative venture or enterprise.

The concept of ethno-variety was defined by Rivera et al. (2006) as the infra-specific diversity, especially in crop plants, as understood and managed by farmers. The prefix "ethno" is used in this paper to refer to the cognition and traditional knowledge that discerns different phenotypes as distinct. In the context of this paper, therefore, an ethno-variety refers to a grouping of shea trees that are identified by farmers under a single name within a particular ethnic group. It is important to point out that ethno-varieties are conceptual entities (mainly classified according to folk nomenclature) in contrast to landraces that are a result of anthropogenic and natural selection over time. However, farmers point to the stability of the important traits upon which they base to classify these ethno-varieties. Understanding the variation in fat content and fatty acid composition of shea tree ethno-varieties is important, as this knowledge can be useful in shea tree improvement programmes. The objectives of this study were, therefore, to describe the fat content and fatty acid composition and investigate the variation in fat content and fatty acid composition content of shea tree ethno-varieties in Uganda.

## Materials and methods

Shea trees in Uganda have been reported by Gwali et al. (2011) to comprise 44 ethno-varieties. According to the authors (Gwali et al. 2011), shea tree folk classification is based

on fruit organoleptic (taste and colour) and morphological (size and shape) properties, and can be categorized under 13 broad descriptors (Table 1). In this study, the 44 ethno-varieties were assessed for fat content as well as fatty acid composition.

### *Sample collection and preparation*

A total of 40–50 ripe fruits per tree were collected from 180 trees in the northern, Teso and West Nile farming systems of Uganda. These farming systems form the distributional range of shea trees in Uganda. The vegetation in these farming systems is classified as *Combetrum/Vitellaria* and grass savannas (Langdale-Brown et al. 1964). Each fruit was de-pulped and the nuts were oven-dried at 55°C for 2–3 days. The oven-dried nuts were ground for 8 sec to a coarse powder in a Verwoerk grinder. The powder was then finely ground in a SEB Moulin Prepline 850 coffee grinder to produce a consistent fine powder. Samples that were not satisfactorily ground by the coffee grinder were subjected to finer grinding under liquid nitrogen. Samples were then stored at − 20°C until required for analysis.

### *Analytical procedures*

Fat content and fatty acid composition were determined using non-solvent [near infrared spectrophotometry (NIRS)], solvent (Soxtec petroleum-ether and gas chromatography) and gravimetric methods.

NIRS, the main analytical procedure in this study, is a non-solvent, rapid, non-destructive and quantitative method that is increasingly being employed in the analysis of fat content and fatty acid composition in food and forage samples (Dempsey et al. 1996). Approximately 3–8 g of fine shea nut powder was loaded into 50-mm-diameter cells and analysed for reflectance using a FOSS NIRSystems 6500 spectrophotometer (Foss NIRSystems, Silver Spring, MD, USA) running WINISI version 3.1 software (InfraSoft International, Port Matilda, PA, USA). Fat content and fatty acid composition values were determined by scanning each sample at a wavelength 400–2500 nm. Data were saved as spreadsheets and analysed using the Statistical Package for Social Scientists (SPSS) version 16.0.

Table 1. List of the 44 ethno-varieties (including their corresponding descriptors) documented by Gwali et al. (2011).

| Trait | Descriptor | Ethno-variety |
|---|---|---|
| Pulp taste | Astringent pulp | *Egeget, Etria, Menacwot, Nyangili-Macwot, Udanyo-Macwot* |
| | Sweet pulp | *Abono, Ewiny, Limi, Mbilimbili* |
| | Tasteless pulp | *Asa, Epiana* |
| Pulp quantity | Little pulp | *Ajiki, Upende-Aboro* |
| | Much pulp | *Amoo, Mudaa* |
| Fruit/nut size | Big fruits/nuts | *Enyii, Mbele* |
| | Small fruits/nuts | *Abor, Alindiri, Ciria, Nyiri, Yao-Matino* |
| Fruit/nut shape | Oval/elliptical fruits/nuts | *Acula, Aloto, Coloa, Julu, Nasomel* |
| | Round fruits/nuts | *Alulung, Gburua, Mangulungulu, Mulunge, Nalungur, Ngulu* |
| Pulp hardness | Hard pulp | *Acogo, Ngorokwa, Nyangili-Acogo, Yao-Atega* |
| | Soft pulp | *Apocopoco, Mayom, Upende-Appi* |
| Fruit hairiness | Hairy fruit | *Ajayer, Layer, Nacekum, Nyangili-Ayir* |

Data obtained through NIRS were validated by analysing a subset of 29 randomly selected samples representing 29 trees using gravimetric and wet chemistry methods. Fat extraction by petroleum ether was conducted in a semi-automatic Soxtec 2050 extractor (FOSS Analytical, Denmark). Approximately 4 g of sample was weighed and placed in 33 mm × 80 mm Whatman extraction thimbles (Carlo Erba Reactifs, SA). Fat extraction was conducted in three cycles at 100°C: extraction (60 min), rinsing (30 min), evaporation (25 min) and drying (5 min). Extracted fat was collected in pre-weighed aluminium cups, and the fat content was determined using the following formula:

$$MG = \frac{w_i - w_{ii}}{m} \times 100,$$

where $w_i$ is the initial weight (in g) of cup and sample, $w_{ii}$ is the final weight (in g) of cup and sample after Soxtec extraction and $m$ is the weight of sample (in g).

The fat was then placed in vials and stored at −20°C until its use in gas chromatography.

Fatty acids were extracted by esterification of the triacylglycerols in shea oil using sodium methylate ($CH_3NaO$) under hexane ($C_6H_{14}$) to produce fatty acid methyl esters (FAME). Up to 3 ml of $CH_3NaO$ was added to a flask containing two to three drops of phenolphthalein, and the mixture was refluxed for about 10 min. Approximately 3 ml of hydrochloric methanol (Hcl-MeOH) was then added to the mixture until saponification of phenolphthalein. The mixture was again refluxed for 10 min and allowed to cool. The FAME was then concentrated by adding 8 ml of hexane and 10 ml of distilled water. One microlitre of the hexane–FAME mixture was then analysed with a Thermo Focus Gas Chromatograph (Thermo Fisher Scientific, Inc., MA, USA) fitted with a Flame Ionization Detector (FID) on a non-bonded CP SIL 88 column (Varian, Inc., CA, USA). The injector and detector temperatures were set at 250°C and 270°C, respectively. The oven temperature was allowed to build from 150°C to 225°C at a rate of 5°C/min. The temperature was then held at 225°C for 2 min before cooling for the next run. The chromatographic peaks were identified by comparison with a coco-test standard and captured using Chrom-Card data system.

### *Data analysis*

Pearson's bivariate correlations were computed to determine the relationship between fatty acid composition and fat content. One-way analysis of variance (ANOVA) was used to test for differences between mean values of fatty acids and fat content within ethno-varieties. Equality of variances was tested by the Levene's (Levene 1960) and Welch test (Welch 1951). Due to differences in sample sizes and variances, differences in mean values ($p = 0.05$) between ethno-varieties were analysed using the Games–Howell multiple comparison *post hoc* test (Games & Howell 1976). This test is useful in instances of unequal variances and also takes into account unequal group sizes (Tamhane 1979). All data were analysed using the SPSS version 16.0.

## Results

A comparison of the NIRS and wet chemistry data gave satisfactory accuracy. For example, regression of NIRS values of fat content against those from Soxtec extraction gave a standard deviation of 4.18 and a coefficient of determination ($R^2$) of 85.96%. Fat content values ranged between 43.9% and 58.4% with an average value of 53.5% (Table 2).

Table 2. Mean, minimum and maximum fat content and fatty acid composition of shea tree ethno-varieties ($n = 180$ trees) in Uganda.

| Variable | Minimum | Maximum | Mean | SD | Coef Var |
|---|---|---|---|---|---|
| Fat content | 43.88 | 58.40 | 53.46 | 2.22 | 4.14 |
| Palmitic acid | 3.55 | 5.31 | 4.44 | 0.29 | 6.46 |
| Stearic acid | 25.31 | 38.48 | 32.49 | 1.99 | 6.13 |
| Oleic acid | 47.35 | 62.04 | 54.06 | 1.99 | 3.68 |
| Vaccenic acid | 0.29 | 0.62 | 0.42 | 0.07 | 15.52 |
| Linoleic acid | 4.72 | 8.97 | 6.21 | 0.54 | 8.65 |
| Linolenic acid | 0.13 | 0.37 | 0.25 | 0.05 | 19.08 |
| Arachidic acid | 0.76 | 1.12 | 0.98 | 0.07 | 7.26 |
| Sat/unsat acid ratio | 0.43 | 0.81 | 0.62 | 0.06 | 8.91 |

The highest fat content was observed in *Ajayer* (58.4% ± 2.2) and *Aloto* (58.4% ± 2.9). *Yao-atega* (43.9% ± 5.2) and *Egeget* (43.9% ± 2.2) had the lowest fat content. Fat content did not differ significantly among the ethno-varieties assessed ($F_{40,\ 136} = 1.306$; $p = 0.132$). However, *post hoc* analysis indicated that fat content varied significantly between *Ajiki* and nine other ethno-varieties, namely, *Limi, Mayom, Mbele, Ngulu, Nyangili-Acogo, Nyangili-Ayir, Nyangili-Macwot, Nyiri* and *Udanyo-Macwot*. Fat content was significantly higher in *Ajiki* compared to any of the listed ethno-varieties. Similarly, fat content was significantly ($p < 0.05$) higher in *Acula* and *Menacwot* compared to *Nyangili-Macwot*.

Fatty acid profiles were dominated by two unsaturated fatty acids (oleic and linoleic acids), and two saturated fatty acids (palmitic and stearic acids) (Figure 1, Tables 2 and 3). Over 87% of the fatty acid composition consisted of stearic acid (25–38%) and oleic acid (47–62%). Linoleic and palmitic acids were present in an average proportion of 6% and 4%, respectively. The lowest values of linoleic (4.72%) and palmitic (3.55%) acids were

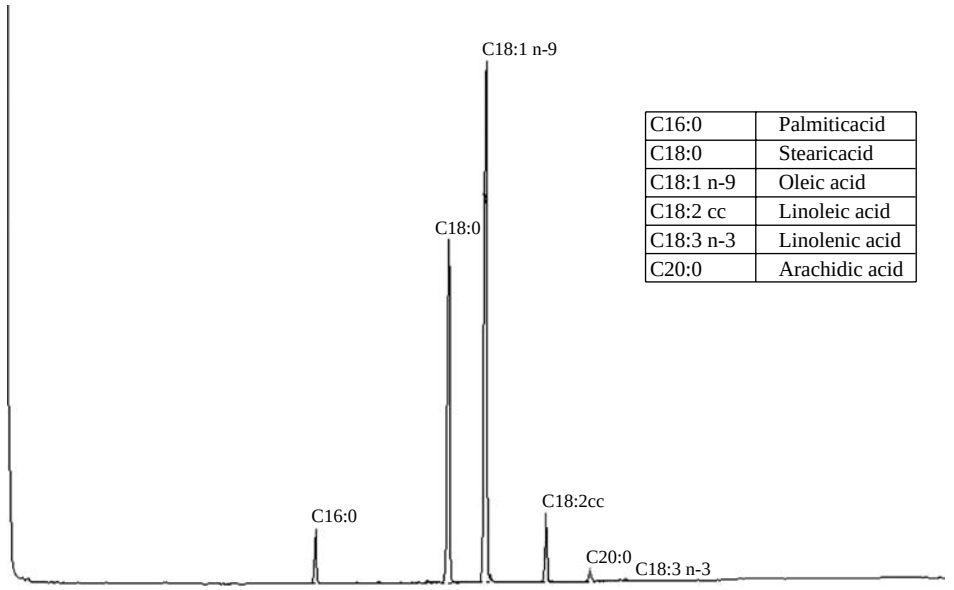



Figure 1. Typical gas chromatogram of the fatty acid profile of an ethno-variety sample from Uganda.

Table 3. Average composition (in per cent) of fatty acid and fat content of shea tree ethno-varieties in Uganda ($n = 176$ trees).

| Ethno-variety | Fat content | Palmitic acid | Stearic acid | Oleic acid | Vaccenic acid | Linoleic acid | Linolenic acid | Arachidic acid | Saturated/unsaturated |
|---|---|---|---|---|---|---|---|---|---|
| *Abor* | 54.22 | 4.58 | 33.23 | 53.34 | 0.46 | 6.29 | 0.29 | 0.97 | 0.64 |
| *Acogo* | 53.62 | 4.62 | 32.07 | 54.49 | 0.51 | 5.95 | 0.30 | 0.94 | 0.62 |
| *Acula* | 55.27 | 4.38 | 32.66 | 54.48 | 0.45 | 5.83 | 0.23 | 0.95 | 0.62 |
| *Ajayer* | 55.22 | 4.33 | 34.09 | 52.99 | 0.45 | 5.85 | 0.26 | 0.97 | 0.66 |
| *Ajiki* | 56.37 | 4.31 | 33.85 | 53.87 | 0.50 | 5.42 | 0.30 | 0.95 | 0.65 |
| *Alindiri* | 52.58 | 4.67 | 32.80 | 53.62 | 0.46 | 6.30 | 0.29 | 0.96 | 0.63 |
| *Aloto* | 54.36 | 4.48 | 31.65 | 54.94 | 0.46 | 6.23 | 0.26 | 0.93 | 0.60 |
| *Alulung* | 52.79 | 4.56 | 32.10 | 54.18 | 0.45 | 6.28 | 0.29 | 0.99 | 0.62 |
| *Amoo* | 53.64 | 4.31 | 30.23 | 56.80 | 0.45 | 6.30 | 0.30 | 0.93 | 0.56 |
| *Apocopoco* | 54.29 | 4.40 | 34.10 | 53.04 | 0.46 | 5.77 | 0.24 | 0.96 | 0.67 |
| *Asa* | 54.15 | 4.33 | 32.77 | 53.73 | 0.39 | 6.24 | 0.23 | 0.94 | 0.63 |
| *Ciria* | 53.64 | 4.60 | 30.85 | 55.72 | 0.48 | 6.35 | 0.24 | 0.94 | 0.58 |
| *Coloa* | 53.20 | 4.53 | 32.32 | 54.34 | 0.43 | 6.24 | 0.24 | 0.99 | 0.62 |
| *Egeget* | 51.43 | 4.30 | 30.65 | 55.36 | 0.41 | 6.82 | 0.29 | 0.97 | 0.57 |
| *Enyii* | 54.86 | 4.25 | 32.66 | 54.30 | 0.39 | 6.01 | 0.24 | 1.00 | 0.63 |
| *Epiana* | 52.34 | 4.16 | 32.19 | 53.98 | 0.35 | 6.88 | 0.24 | 1.05 | 0.61 |
| *Ewiny* | 52.96 | 4.16 | 31.30 | 55.36 | 0.40 | 6.42 | 0.25 | 1.02 | 0.59 |
| *Gburua* | 54.82 | 4.48 | 31.82 | 55.18 | 0.45 | 6.02 | 0.24 | 0.97 | 0.60 |
| *Julu* | 53.76 | 4.50 | 33.40 | 53.01 | 0.43 | 6.16 | 0.21 | 0.94 | 0.65 |
| *Layer* | 53.21 | 4.43 | 33.04 | 53.23 | 0.43 | 6.37 | 0.29 | 0.97 | 0.64 |
| *Limi* | 52.86 | 4.49 | 31.65 | 55.17 | 0.42 | 6.05 | 0.23 | 0.97 | 0.60 |
| *Mangulungulu* | 52.43 | 4.47 | 32.56 | 53.75 | 0.35 | 6.29 | 0.19 | 0.97 | 0.63 |
| *Mayom* | 53.67 | 4.54 | 33.27 | 53.55 | 0.42 | 6.03 | 0.24 | 1.00 | 0.64 |
| *Mbele* | 53.36 | 4.29 | 34.87 | 51.40 | 0.38 | 6.30 | 0.22 | 1.04 | 0.69 |
| *Mbilimbili* | 54.12 | 4.34 | 33.09 | 53.74 | 0.47 | 5.98 | 0.22 | 0.98 | 0.64 |
| *Menacwot* | 55.89 | 4.48 | 32.51 | 54.87 | 0.41 | 5.50 | 0.22 | 0.93 | 0.62 |
| *Mudaa* | 53.50 | 4.36 | 31.56 | 55.12 | 0.41 | 6.31 | 0.23 | 0.98 | 0.59 |
| *Mulunge* | 54.95 | 4.52 | 32.46 | 54.12 | 0.47 | 5.92 | 0.25 | 0.96 | 0.63 |
| *Nacekum* | 51.29 | 4.46 | 32.08 | 53.61 | 0.39 | 6.92 | 0.27 | 1.02 | 0.61 |
| *Nalungur* | 52.60 | 4.46 | 31.34 | 54.80 | 0.39 | 6.56 | 0.26 | 0.98 | 0.59 |
| *Nasomel* | 52.09 | 4.38 | 30.61 | 55.41 | 0.40 | 6.82 | 0.25 | 0.95 | 0.57 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Ngorokwa* | 53.03 | 4.41 | 31.69 | 55.04 | 0.36 | 6.22 | 0.21 | 1.00 | 0.60 |
| *Ngulu* | 53.41 | 4.49 | 34.17 | 52.45 | 0.44 | 5.96 | 0.22 | 0.98 | 0.67 |
| *Nyangili-Acogo* | 52.03 | 4.52 | 33.50 | 52.70 | 0.42 | 6.25 | 0.26 | 1.06 | 0.66 |
| *Nyangili-Ayir* | 53.11 | 4.28 | 32.51 | 53.97 | 0.40 | 6.47 | 0.24 | 1.02 | 0.62 |
| *Nyangili-Mac-wot* | 51.96 | 4.57 | 32.93 | 53.28 | 0.39 | 6.35 | 0.23 | 1.04 | 0.64 |
| *Nyiri* | 52.89 | 4.51 | 32.31 | 53.93 | 0.42 | 6.12 | 0.25 | 0.96 | 0.62 |
| *Udanyo-Mac-wot* | 52.87 | 4.64 | 31.38 | 55.51 | 0.39 | 5.70 | 0.19 | 0.92 | 0.60 |
| *Upende-Aboro* | 53.35 | 4.28 | 35.10 | 51.38 | 0.36 | 6.08 | 0.20 | 1.06 | 0.70 |
| *Yao-Atega* | 51.25 | 4.49 | 31.39 | 54.10 | 0.45 | 7.02 | 0.32 | 0.94 | 0.60 |
| *Yao-Matino* | 53.69 | 4.62 | 31.54 | 54.57 | 0.48 | 6.20 | 0.30 | 0.92 | 0.60 |

Table 4. Correlation of the most important fatty acids in shea tree ethno-varieties in Uganda ($n = 180$ trees).

| Variable | Fat | Palmitic acid | Stearic acid | Oleic acid | Vaccenic acid | Linoleic acid | Linolenic acid | Arachidic acid |
|---|---|---|---|---|---|---|---|---|
| Palmitic acid | −0.008 | | | | | | | |
| Stearic acid | .280** | 0.127 | | | | | | |
| Oleic acid | −0.061 | −.199** | −.944** | | | | | |
| Vaccenic acid | .369** | .455** | 0.01 | 0.09 | | | | |
| Linoleic acid | −.690** | −.166* | −.461** | .205** | −.382** | | | |
| Linolenic acid | −.150* | .192** | −0.094 | 0.001 | .316** | .274** | | |
| Arachidic acid | −.406** | −.379** | .308** | −.356** | −.494** | .168* | −.176* | |
| Sat/unsat acid ratio | .234** | .227** | .991** | −.962** | 0.018 | −.441** | −0.076 | .291** |

*Correlation is significant at the 0.05 level (two tailed).
**Correlation is significant at the 0.01 level (two tailed).

observed in *Ajiki* and *Enyii*, while the highest values of linoleic (8.97%) and palmitic (5.31%) acids were observed in *Yao-atega*. Vaccenic, linolenic and arachidic acids were present in percentages lower than 1%. Stearic and oleic acid composition were very strongly negatively correlated ($r = -0.944$, $p < 0.01$) while fat content was strongly correlated with linoleic acid content ($r = -0.690$, $p < 0.01$) (Table 4).

There was no significant difference ($p > 0.05$) in stearic, oleic and palmitic acid compositions between ethno-varieties. Similarly, the saturated to unsaturated acid ratio was not significantly different among the different ethno-varieties. Vaccenic acid was significantly more important in *Yao-matino* than in *Nacekum, Ngorokwa, Nyangili-Macwot, Mangulungulu* or *Nyiri.*

The ethno-variety *Ajiki* contained significantly more vaccenic acid than *Mangulungulu*. Linoleic acid content was significantly less in *Menacwot* than in *Asa, Alindiri, Nacekum, Nyangili-Ayir* or *Nyangili-Macwot*. Similarly, the linoleic acid content in *Acula* was significantly less than that in *Nacekum* or *Nyangili-Macwot*. The ratios of saturated to unsaturated fatty acids for all the ethno-varieties were all below 1.0 due to the dominance of stearic and oleic acids. The lowest saturated to unsaturated acid ratios were observed in *Amoo* ($0.56 \pm 0.09$), *Egeget* ($0.57 \pm 0.08$) and *Yao-atega* ($0.60 \pm 0.08$). The highest saturated to unsaturated acid ratio was recorded in *Upende-Aboro* ($0.70 \pm 0.07$).

## Discussion

Fat content values were significantly different among some (but not all) ethno-varieties. The highest fat content was recorded in *Ajiki*, *Menacwot* and *Acula* whose distribution is separated only by about 100 km from ethno-varieties such as *Nacekum* and *Egeget*, which had the lowest fat content. These observations imply that fat content may be responsive to local site differences. With regard to fatty acid composition, all ethno-varieties exhibited a pattern similar to what has been reported in earlier investigations (Maranz et al. 2004; Akihisa et al. 2010; Okullo et al. 2010). The dominant fatty acids were oleic and stearic acids, and their content was not significantly different among ethno-varieties. All ethno-varieties had proportionally higher oleic acid than any other fatty acid present. Since the stearin and olein fractions determine the usefulness of oil for either cosmetic or pharmaceutical use, all these ethno-varieties can be considered to have similar potential for these uses.

The mean saturated to unsaturated fatty acids ratio ranged from 0.43 to 0.81, implying that unsaturated fatty acids are predominant in all these ethno-varieties. It is known that oils with a high proportion of unsaturated fatty acids can be heated to high temperatures without smoking, which leads to faster cooking time and utilization of less oil (Miller et al. 1987). In addition, since unsaturated fatty acids are particularly required for normal body functioning (Williams 2000) due to their high stability (Cunnane et al. 1993), ethno-varieties with considerable quantities of these acids possess high commercial potential. This implies that ethno-varieties with low saturated to unsaturated ratios, such as *Amoo*, would be very ideal for industrial production that aims for more stable as well as long storing oil.

Variation in saturated to unsaturated acid ratio, fat content and fatty acid composition influences the marketability, including the nutritional value and shelf life of shea tree nuts and oil. This is because human consumption of certain fatty acids, such as oleic acid, is associated with health benefits such as the lowering of blood cholesterol levels (Williams 2000). Many food industries, therefore, undertake expensive hydrogenation processes to alter fatty acid composition of various foods to suit consumer requirements (Ursin 2003).

In the case of *V. paradoxa* subspecies *nilotica*, it is known that its oil has a lower melting point and contains less unsaponifiable matter than that of subspecies. *paradoxa* (Hall et al. 1996). This advantage is, however, seriously hampered by low nut production and long distance to the European and American markets (Ferris et al. 2004). The West African hard butters, therefore, provide much cheaper and efficient alternatives for the markets in Europe and America, thereby offering stiff competition for subspecies *nilotica* oil.

In addition, development of subspecies *nilotica* as a nutritional and economic resource only began in northern Uganda in the 1990s, in spite of consistent oleic composition being a key demand for highly regulated cosmetic markets (Ferris et al. 2004). The formation and work of the Northern Uganda Shea Producer's Association (NUSPA) have resulted in more visibility of *nilotica* shea oil, and in new prospects for the sale of shea oil to a cosmetics-based "niche" market (Ferris et al. 2004; Groenewald & Dalrymple 2007). In the current context of an increasing need for certification of tradable products, the characterization of East African shea oils is an important step towards a better international promotion of this locally important economic resource.

## Conclusion

This study shows that the mean fat content of shea tree ethno-varieties in Uganda ranged from 43.9% to 58.4%. However, fatty acid composition was dominated by oleic (47–62%) and stearic acids (25–38%). Other fatty acids found included palmitic, vaccenic, linoleic, linolenic and arachidic acids. Pairwise comparisons showed no significant variation in stearic, palmitic and oleic acid composition. In contrast, significant variation in fat, vaccenic and linoleic acid contents was observed between some (but not all) ethno-varieties. The possible cause of this variation could be local site, climatic and tree-to-tree differences. Given the importance of fatty acid composition and saturated-to-unsaturated acid ratio, these data could be useful in the selection of ethno-varieties that are suitable for commercial production of shea nut oil in Uganda.

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