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PHYSICO-CHEMICAL CHARACTERISTICS AND FATTY ACID PROFILE OF DESERT DATE KERNEL OIL

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ABSTRACT

The desert date (*Balanites aegyptiaca* (L.) Del.) is an indigenous fruit tree, common in the arid and semi-arid lands of Africa. Its fruits, available in the height of the dry season, contain edible pulp which is an important food for both humans and livestock. Balanites kernel is a source of highly regarded edible and medicinal oil. Both the fruits and oil are trade items in the west Nile sub-region of Uganda. Because of its growing importance as a source of food and income for dryland communities, an assessment of the physico-chemical characteristics and fatty acid profile of kernel oil in Uganda was carried out. Balanites fruit samples were collected from Katakwi, Adjumani and Moroto districts; representing the Teso, West Nile and Karamoja tree populations, respectively. Balanites kernels constituted 19.5% of the nuts, and kernel oil yield was 44.5% (v/v or w/w). The oil was light yellow with a refractive index of 1.46 at 20 ^{o}C and viscosity of 15.75 - 22.60 cSt at 40 ^{o}C. The saponification value of the oil was 186.28 mg KOH g^{-1}; while the acid value was generally low (1.33 -1.95 mg KOH g^{-1}). Iodine value ranged from 98.20 to 103.32 I_2 g 100 g^{-1}. Four major fatty acids; linoleic (39.85%), (oleic 25.74%), stearic (19.01%) and palmitic (15.40%) were found in Balanites oil. This gives a high percentage of the nutritionally beneficial unsaturated fatty acids (65.6%). Balanites kernel oil is a good source of essential unsaturated fatty acids. Attempts should be made to increase its utilisation through improved processing and packaging for the benefit of rural and peri-urban communities.

Key Words: *Balanites aegyptiaca*, fruits, nutrition, unsaturated fatty acids, Uganda

RÉSUMÉ

Le dattier du desert (*Balanites aegyptiaca* (L.) Del.) est un arbre fruitier indigène commun des milieux arides et semi-arides d'Afrique. Ses fruits, disponibles dans la saison sèche contient une pulpe comestible constituant un aliment important pour l'alimentation humaine et le bétail. Le grain de Balanites est une source reconnue d'huile comestible et médecinale. D'autre part, les fruits et l'huile ensemble sont commerciables dans la sous-région ouest du Nile en Ouganda.Du fait de sa grande importance comme source d'aliment et de revenu pour les communautés des régions arides, une évaluation des caractéristiques physico-chimiques et le taux d'acide gras dans les huiles de graines était conduite en Ouganda. Des échantillons de fruits de balanites étaient collectés dans les districts de Katakwi, Adjumani et Moroto représentant la région de Teso, la partie Ouest du Nile et les populations d'arbres de Karamoja, respectivement. Les graines de Balanites constituaient 19.5% des noix, et le rendement en huile était de 44.5% (v/v or w/w). L'huile était jaune claire avec un indice de refraction de 1.46 at 20 oC et une viscosité de 15.75 - 22.60 cSt à 40 ^{o}C. La valeur de saponification de l'huile était de 186.28 mg KOH g^{-1}; pendant que la valeur de l'acide était généralement basse (1.33 -1.95 mg KOH g^{-1}). La valeur de l'Iodine variait de 98.20 à 103.32

I2 g 100 g^{-1}. Quatre acides gras majeurs dont l'acide linoléique (39.85%), oléique (25.74%), stéarique (19.01%) et palmitique (15.40%) étaient trouvé dans l'huile de Balanites. Ceci donne un pourcentage élevé d'acides gras insaturés nutritionnellement bénéfiques (65.6%). L'huile des graines de Balanites est une bonne source d'acides gras essentiels insaturés. Plus d'efforts devront être fait pour accroître son utilisation à travers des procédvs améliorés et emballage pour le bénéfice des communautés rurales et peri-urbaines.

Mots Clés: *Balanites aegyptiaca*, iodine, huile, acides gras insaturés

INTRODUCTION

Balanites aegyptiaca (L.) Del., commonly known as Desert date, is an important food and medicinal tree found in most African countries, stretching from arid and semi-arid regions to sub-humid savannah. According to Hall and Walker (1991) and (Sands, 2001), few African species are as widely distributed as *B. aegyptiaca*, which occurs in almost every African country north of the equator and several countries in the southern hemisphere. In Uganda, *B. aegyptiaca* is common in the lowland areas of West Nile, Teso and Karamoja sub-regions (Katende *et al*., 1995; Okia, 2010). As a multipurpose tree, *B. aegyptiaca* offers food, medicines, cosmetics, fodder, fuelwood and pesticides valued for subsistence living in the arid and semi-arid areas where other options are few (NRC, 2008). Okia *et al*. (2011a and b) documented the use and management of Balanites and harvesting and processing of its products in Uganda.

The fruit of *B. aegyptiaca* has an edible mesocarp and a hard woody endocarp enclosing an edible oil-rich seed kernel. The seed kernel oil is reported to be rich in saturated fatty acids and is used as cooking oil (Hall and Walker, 1991; NRC, 2008). It also contains steroids (saponins, sapogenins, diosgenins) used as raw material for industrial production of contraceptive pills, corticoids, anabolisants and other sexual hormones (UNIDO, 1983). Reports on studies of *B. aegyptiaca* kernel oil (e.g. Hussain *et al.*, 1949; Cook *et al*., 1998 and Mohamed *et al*., 2002) indicate that the kernel oil consists of four major fatty acids; linolein, olein, stearic and palmitic acid but in varying proportions across study sites. Some studies (e.g. WIPO, 2006a&b; Deshmukh and Bhuyar, 2009 and Chapagain *et al.*, 2009) have demonstrated and recommended use of Balanites oil for biodiesel production. There is therefore a growing interest in understanding the development potential of *B. aegyptiaca* as a resource for improving livelihoods of dryland communities.

Natural vegetable oil and fats are increasingly becoming important worldwide in nutrition and commerce because they are sources of dietary energy, antioxidants, biofuels and raw material for the manufacture of industrial products. They are widely used in food, cosmetic, pharmaceutical and chemical industries. According to FAO (2007), vegetable oils account for 80% of the world's natural oils and fat supply. Nutritional information on Balanites oil will prove useful to nutritionists, policy makers, development agencies and the general public in Uganda and elsewhere where nutrition and health benefits would be most beneficial. This study was therefore, aimed at determining the nutritional composition of *B. aegyptiaca* oil so as to promote its wider use and to improve livelihoods through incomes gained. Specifically, the physico-chemical characteristics of Balanites kernel oil in terms of colour, refractive index, viscosity, iodine value, acid value, and saponification value were determined and the fatty acid profile of the kernel oil assessed.

MATERIALS AND METHODS

Samples, for laboratory analyses, were collected from three sub regions in Uganda; all located in the semi-arid belt where *B. aegyptiaca* is naturally growing. In each sub region, one district was selected and in each of these districts, study samples were collected from two villages or localities.

Sample collection and preparation. Balanites fruit samples were collected from all the three study sub regions. In each locality, ripe fruits were collected from under 10 randomly selected

healthy trees after fruit fall. These were mixed and a sub sample of about 3 kg obtained and tagged. Locally processed Balanites oil was collected from Adjumani district where it was processed and utilised at the time of the study. About 300 ml samples of locally processed Balanites oil were bought from three farmers and placed in appropriate plastic containers. Both the fruit and local oil samples were transported to the laboratory in cooler boxes and stored in freezers. Later, the epicarp was removed by hand and the mesocarp was removed by maceration in water. The resulting nuts were oven-dried at 60°C for seven days. Dried nuts were decorticated manually between a stone and mallet to extract the oil rich seed kernels. The kernels were oven-dried at 60°C for three days, ground into powder using a mortar and pestle and stored in airtight containers in a freezer (-20°C) to prevent deterioration.

Oil extraction and yield determination. The total weight (M_1) of each kernel powder sample was determined using an electronic balance. Oil was extracted by leaching in soxhlet apparatus using *n*-hexane (analytical grade) as a solvent. The sample was then placed in a thimble and loaded into a soxhlet. Six runs of the condensing solvent (lasting 6-8 hours) were sufficient to extract oil from each sample. The process was stopped when the condensing solvent passing through the sample turned colourless. The solvent/oil mixture was separated using a rotary vapourator (Buchi Rotavapor R-210, USA, Pump: Vacuubrand MZ 2C, Cooler: Huber Miniciller Ref 466.0010). The resulting Balanites oil was weighed (M_2) and oil content determined gravimetrically and expressed as percentage of the kernel powder weight using the formula; Oil yield = (M_2/ M_1) x 100%. The oil was stored in a freezer (-20 °C) until it was required for analysis.

Analysis of the physico-chemical properties of Balanites oil. The physical and chemical parameters of Balanites oil were analysed using standard methods described by AOAC (1984). Physical parameters analysed included colour, refractive index and viscosity and the chemical parameters investigated were acid, saponification and iodine values. Colour was determined using lovibond apparatus (Model E Tintometer L322/ 92E, UK), viscosity using a viscometer (Brookfield DV-11+Pro) at 40°C and the refractive index using a refractometer (Bellingham + Stanley, No. A86006). Briefly, analytical procedures carried out were as follows;

Colour. Balanites oil sample (10 ml) was melted in a water bath placed in a cuvet and analysed using lovibond. The red, yellow and blue colour units were adjusted until a perfect colour match was obtained. The value of the colour with the lowest unit was subtracted from the rest of colours leaving two units which were then, used to describe the colour of the sample. Colour was described using the colour nomenclature namely, red, orange (combination of red and yellow), yellow, green (combination of yellow and blue), blue and violet (combination of red and blue). In addition, the terms "bright" and "dull" were used to further describe a particular oil sample.

Refractive index. Balanites oil sample (0.5 g) was melted at 25°C in water bath and analysed using Bellingham + Stanley refractometer, (Model No. A86006, UK).

Viscosity. Balanites oil sample (300 ml) melted at 40°C was placed in 600 ml beaker and the viscosity was determined using Brookfield DV-11+Pro programmable viscometer, USA, S.No. TR P6514911, model LVDV-11+P by inserting the spindle down to a depth of 1cm into the oil sample. Analysis was carried out with a spin code 61, RPM: 30 and temperature of 40 °C. The viscometer was standardised using viscosity standard fluid from Brookfield. The values were read in centistokes (cst).

Acid value. Diethyl ether (25 ml), ethanol (25 ml) and 1% phenolphthalein (1 ml) were mixed and neutralised with 0.1M sodium hydroxide. Two grams of Balanites oil was dissolved in the neutral diethyl ether, ethanol and phenolphthalein solution. The solution was titrated with 0.1 M sodium hydroxide until a pink colour that persisted for at least 10 seconds was obtained. Acid value was calculated using the equation:
Acid value (AV) = 56.1 x Mv/w

Where; M = molarity of KOH (0.1), v = volume of KOH solution (ml), and w = weight of the oil sample (2 g).

Saponification value. Two grams (2 g) of each of the Balanites oil samples were weighed into the different conical flasks and 25 ml of ethanolic potash was added. To another flask was added the same quality of the ethanolic potash but omitting the oil sample that was used as a blank. All the flasks were boiled in a water bath for 30 minutes and shaken frequently. Two drops of phenolphthalein indicator was added to each flask and titrated with 0.5M HCl with vigorous shaking to get the end point. The saponification value was derived from the equation:

$$SV = 56.1M (x - v)/w$$

Where; x = volume of HCl used in the blank titration, v = volume of the HCl used in the test titration, M = molarity of HCL and w = weight of the oil sample (2 g).

Iodine value **(Hanus method).** The hanus iodine reagent was prepared by dissolving iodine (13.2 gm) in glacial acetic acid (1litre) under heat and 3 ml of bromine added. The hanus iodine reagent was then kept in a bottle until the analysis was complete. Two grams of Balanites oil was weighed into a 500 ml conical flask and 10 ml of chloroform added. Using a pipette, 25 ml of Hanus iodine was added and left to stand in the dark for 30 minutes with occasional shaking. Fifteen percent potassium iodine was added and shaken thoroughly. One hundred millilitres of distilled water was added to rinse any iodine on the stopper. The solution was then titrated with 0.1N sodium thiosulphate until a yellow solution turned almost colourless (S ml). Three drops of starch indicator (1%) was added towards the end point and titration continued until the blue colour turned colourless. A blank determination was done and recorded (B ml). The iodine value was calculated using the equation:

$$\text{Iodine value (IV)} = (B - S) \times M \times 12.69/w$$

where; B = volume of $Na_2S_2O_3$ used for blank titration, S = volume of $Na_2S_2O_3$ used for oil sample, M = molarity of $Na_2S_2O_3$ (0.1), and 12.69 = constant (meq weight of iodine).

Analysis of fatty acids in Balanites oil. Five steps were followed to determine the fatty acid content in Balanites oil, namely; (i) *Preparation of acidified anhydrous methanol:* Dry hydrogen chloride (HCl) gas was bubbled into methanol placed in a bottle and immersed in an ice bath. Increase in mass of the methanol was checked periodically to monitor the concentration of hydrochloric acid. The hydrogen chloride gas was prepared by adding drops of conc. H_2SO_4 to conc. HCl in a stoppered round-bottomed flask using a dropping funnel. The ensuing hydrogen chloride gas (7.2 g) was dried by passing it through conc. H_2SO_4 and bubbled into methanol (100 ml) to make methanol/2MHCl solution. *(ii) Esterification of the fatty acids in the oil:* About 10 mg of each oil sample was placed in 15 ml thick-walled glass tubes with teflon-lined screw caps to which acidified anhydrous methanol (1 cm^3) was added. The test tubes were securely capped and placed in an oven at 90°C for two hours, removed and allowed to cool to room temperature. During the heating process, free and bound fatty acids reacted with the methanol and were converted to the corresponding fatty acid methyl esters (FAME). *(iii) Extraction of the fatty acid methyl esters (FAME):* The resulting FAMEs were separated from the mixture by solvent extraction using a water-hexane solvent system (Grahl-Nielsen and Barnung, 1985). To achieve this, hexane (1 cm^3) and water (0.5 cm^3) were added to the resulting FAME mixture and after shaking for three minutes, the mixture was centrifuged at 1500 rpm for a further three minutes. The FAMEs were then obtained from the upper hexane phase of the partition by siphoning. A second extraction was performed after addition of hexane (1 cm^3) to the residual mixture and repeating the same procedure. The extracts were then pooled and stored under refrigeration until GC-MS analyses were performed. *(iv) GC-MS determination of fatty acid composition:* Analyses of FAMEs was performed with Gas Chromatography-Mass Spectrometry (GC-MS) using an Agilent 6890N GC model equipped with a 7683B series auto-sampler, fitted with an electronic pressure control and mass selective detection ionisating energy

of 70eV; source temperature was 300°C and a column of 25 m x 0.25 mm fused silica capillary with polyethylene glycol (PEG) as a stationary phase with a thickness of 0.2µm (CP-WAX 52CB) from chrompack. The temperature of the injector pot was maintained at 260^{0}C. The oven temperature was maintained at 90°C for four minutes, increased to 165 °C at 30°C per minute, and then increased to 225^{0}C at 3^{0}C per minute, and maintained at 225°C for 10 minutes. Helium gas was used as the carrier at 1.7 ml per minute at 40^{0}C. The fatty acids in the samples were identified by a standard FAME mixture, GLC-68D from Nu-Chek-Prep (Elysian, Minn., USA) and mass spectrometry. The combination of all the instruments above was operated by the Chemstation software to produce Agilent 6890N, gas chromatographs. *(v) Qualitative identification of the fatty acids:* The chromatographic peaks of a reference standard mixture of FAME (GLC-68D from Nu-Chek-Prep (Elysian, Minn., USA), were identified by interpretation of their mass spectra, and by matching the spectra with an in-built library of spectra. Component chromatographic peaks of analytes were identified by correlating with individual peak retention times with the reference standard mixture of FAME. Matching the mass spectra with in-built CHEM PREP mass spectra libraries confirmed the identity of the components.

Data analysis. Data were entered in MS Excel and later transferred to SPSS Version 16 to generate means and standard errors. A one-way analysis of variance (ANOVA) was applied to compare means of oil characteristics between the study sites with significance levels determined at $P< 0.05$. Where the null hypothesis was rejected in favour of the alternative, Scheffe's test (due to unequal sample size) was used to identify homogeneous subsets of means (Kleinbaum and Kupper, 1978).

RESULTS

Oil yield and physico-chemical properties of *B. aegyptiaca* kernel oil. Up to 60% of the fruit was made up of nut (endocarp and kernel). The kernel constituted 18.1 - 23.2% of the nut with a mean of 19.57% while the rest was endocarp/stone (Table 1). The mean oil yield from *B. aegyptiaca* seed kernels was 44.5%. The highest oil yield was from Katakwi district (50.56%), followed by Adjumani district (44.37%) and Moroto district (38.53%) (Fig. 1).

The physico-chemical characteristics of *B. aegyptiaca* oil are presented in Table 1. The oil obtained from Katakwi and Adjumani districts was light yellow while the oil from Moroto district was yellowish-orange.

Saponification value was highest in Katawi oil (192.80 mg KOH g^{-1}) followed by Adjumani oil (185.55 mg KOH g^{-1}) and Moroto oil (180.50 mg KOH g^{-1}). Acid value was highest in the Moroto population (1.954 mg KOH g^{-1}) followed by Katakwi (1.41 mg KOH g^{-1}) and Adjumani (1.33 mg KOH g^{-1}). Viscosity was highest in Moroto oil (23.04 cSt) followed by Katakwi oil (22.60 cSt) and Adjumani oil (18.94 cSt). The oil's refractive index was similar (1.46) in the samples from the three sites. The amount of Iodine ranged from 98.20 to 103.32 (I_2 g 100 g^{-1}).

Fatty acid profile of *B. aegyptiaca* kernel oil. *Balanites aegyptiaca* oil had four major fatty acids in the range of C_{16} to C_{18} namely, palmitic (15.5%), stearic (19.01%), oleic (25.74%) and linoleic (39.85%) acids (Table 3; Fig. 2). Small amount of α-linolenic acid (< 0.7%) was detected in some samples. The amount of unsaturated fats (oleic + linoleic) was higher (65.59%) than that saturated fats (palmitic + stearic) (34.41%) giving unsaturated to saturated ratio of 1.9.

TABLE 1. Proportion of Balanites kernel powder in the nut

District	Village/locality	Kernel powder (%)
Adjumani	Egge	19.67
	Adropi	19.52
Katakwi	Aputon	19.92
	Abela	16.97
Moroto	Moroto town	18.10
	Moroto prison farm	23.24
Mean	Combined	19.57

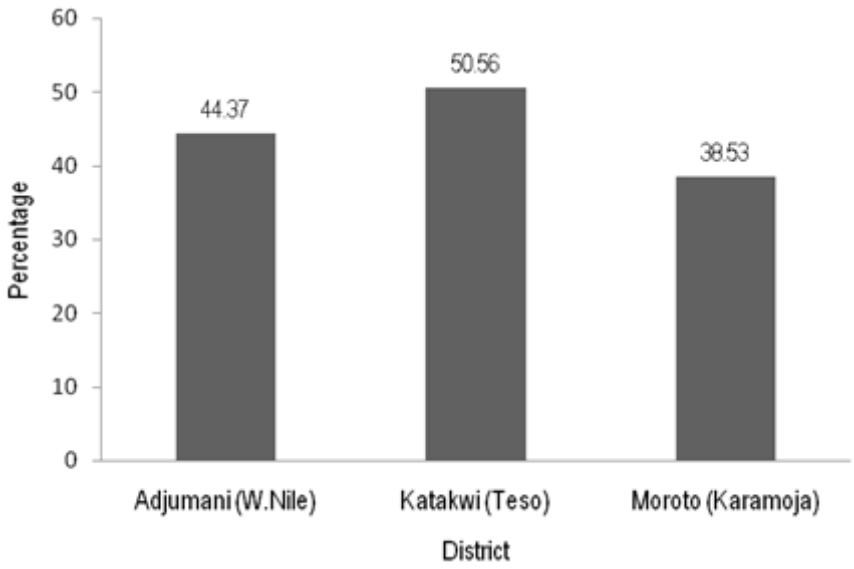

Figure 1. Balanites kernel oil yield from different districts/sub-regions in Uganda.

TABLE 2. Physico-chemical characteristics of *B. aegyptiaca* oil

Property	Katakwi district	Adjumani district	Moroto district	Mean
Physical				
Colour (degree of colour mixtures)*	Yel-Gr+9.9Y	Yel-Gr+9.3Y	Yel-Or+13.3Y	Yel-Gr+10.8Y
Refractive Index [25°C]	1.461	1.460	1.464	1.46
Viscosity [40°C] (cSt)	22.60	18.94	23.04	21.53
Chemical				
Saponification Value (mgKOH g^{-1})	192.80	185.55	180.50	186.28
Acid Value (mg KOH g^{-1})	1.41	1.33	1.954	1.56
Iodine Value (I_2g 100 g^{-1})	98.20	100.04	103.32	100.52

* Yel-Gr a" Yellow-Green, Yel-Or a" Yellow-Orange

Variation in *B. aegyptiaca* oil from Adjumani, Katakwi and Moroto districts. Comparison of means (one-way ANOVA) showed significant ($P<0.05$) difference in the amounts of oleic acid only (Table 4). Separation of means revealed that *B. aegpytiaca* oil from Katakwi had significantly lower oleic acid content than oil samples from Adjumani and Moroto districts. There were no differences in the fatty acid contents of oil locally processed from Adjumani district and the hexane-extracted oil.

DISCUSSION

Oil yield and physico-chemical characteristics of *B. aegyptiaca* oil. Balanites kernels constituted 18.1 - 23.2% of the nut weight with a mean of 19.5%. These values are close to those reported in the Borno State, Nigeria where Aviara *et al.* (2005) found *B. aegyptiaca* kernels to constitute 22.6 - 24% of the nuts. Oil yield from the kernels varied from 38.53 - 50.56% with a mean of 44.5%. This yield is within the range reported

TABLE 3. Fatty acid profile of *B. aegyptiaca* kernel oil (n=42)

Fatty acid	Weight % ± SE
Palmitic	15.40±0.26
Stearic	19.01±0.29
Oleic	25.74±0.35
Linoleic	39.85±0.48
Saturated	34.41±1.80
Unsaturated	65.59±6.92
Unsaturated/saturated acid ratio	1.91

elsewhere. For example, Chapagain and Wiesman (2005) reported oil yield of 46.12, 44.17 and 39.20% from Israel, Africa and India populations of *B. aegyptiaca* respectively. It has also been reported that oil yield is positively correlated with level of diosgenin in Balanites kernels. Since these parameters are desirable characteristics, the relationship may play a vital role in germplasm selection for future domestication of *B. aegyptiaca* (Chapagain and Wiesman, 2005).

TABLE 4. Percentage composition of fatty acids in Balanites kernel oil from different study districts

Sample	N	Percentage fatty acid (Mean ± SEM)			
		Palmitic (16:0)	Stearic (18:0)	Oleic (18:1n9)	Linoleic (18:2n6)
Adjumani	16	15.73±0.29[a]	18.94±0.32[a]	26.22±0.63[a]	39.12±0.63[a]
Adjumani-local	6	16.23±0.21[a]	17.76±0.18[a]	26.61±0.12[a]	39.40±0.27[a]
Katakwi	11	14.89±0.66[a]	19.30±0.19[a]	23.99±0.78[b]	41.82±1.44[a]
Moroto	9	14.90±0.75[a]	19.61±1.20[a]	26.46±0.12[a]	39.03±0.37[a]
Mean		15.40±0.26	19.01±0.29	25.74±0.35	39.85±0.48

Values with the same superscript letter within a column are not statistically different (P<0.05)
SEM = Standard error of the mean

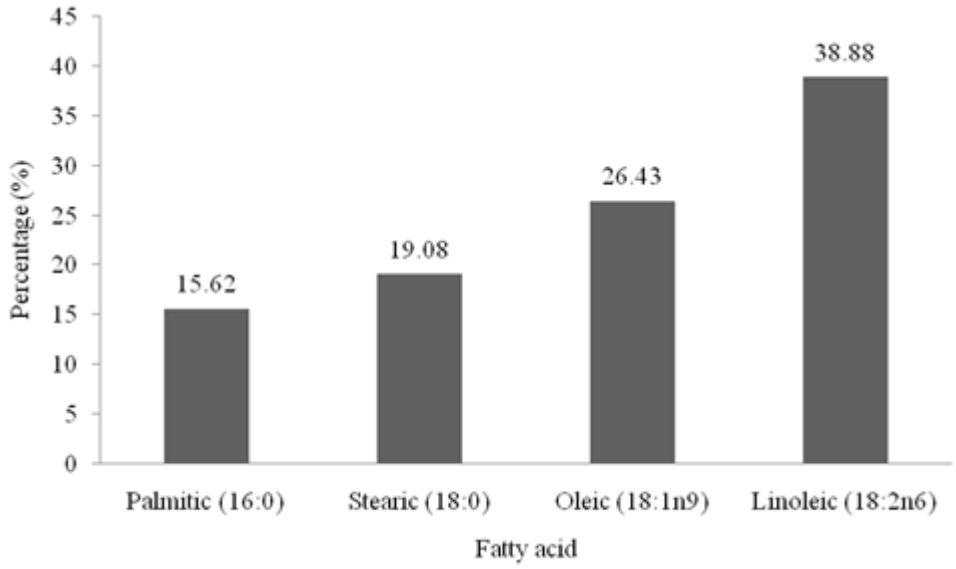

Figure 2. Average fatty acid content of *B. aegyptiaca* kernel oil in Ugandan populations.

that are lipid and are precursors for vitamin A (WHO, 2004). The light yellow colour of the oil also makes it visually attractive thus, along with other good attributes; this could make Balanites oil a viable and competitive market commodity.

The refractive index of 1.46 at 20°C is similar to that reported for shea butter oil in Uganda (Okullo *et al.*, 2010) and is in agreement with that reported for Balanites (Hussain *et al.*, 1949; Abdel-Rahim *et al.*, 1986). However, Chapagain *et al.* (2009) reported a slightly higher value (1.51) for samples from Israel. Other kernel oils have been reported to have similar refractive indices, for instance, 1.46 for Jojoba in Jordan and India (Kaul *et al*., 2008) and 1.48 for shea butter in Uganda (Omujal, 2008). Refractive index is an important attribute of oil quality (Omujal, 2008).

At the same temperature (40°C) Eromosele and Paschal (2003) in Nigeria and Deshmurkh and Bhuyar (2009) in India reported higher viscosities, 46.8 and 38.60 cSt, respectively. Similarly, Chapagain *et al.* (2009) though without specifying the temperature reported higher viscosity (49 cP). Eromosele and Paschal (2003) also found the viscosity of *Balanites* oil showing a negative dependence on temperature increase; thus, suggesting potential application as lubricating oil base stock. According to Chapagain *et al.* (2009), viscosity is one of the quality parameters of oil. Other qualities of Balanites oil such as refractive index and specific gravity were very similar to those of soy oil; thus, making it suitable and potential resource for biodiesel production.

The saponification value was 186.28 mg KOH g^{-1} on average. Jain and Kenerjee (1988) and Chapagain *et al* (2009) reported slightly lower saponification values, 175.91 and 172.7 mg NaOH g^{-1}, respectively. Other earlier reports by Abu-Al-Futu (1983), Nour *et al.* (1985) and Abdel-Rahim *et al* (1986) indicated variable saponification values ranging from 177 to 204. Whereas some of the variations could be explained by differences in environmental conditions, improvements in the methods of analysis could explain some of the variance. The total acidity of the oil expressed as acid value was generally low (1.33 - 1.95 mg KOH g^{-1}) and agrees with that reported by Deshmurkh and Bhuyar (2009) and Abdel-Rahim *et al* (1986)

Other studies have reported variable oil yield from Balanites kernels, such as, 46% in Sudan (Hussain *et al*., 1949); 45.0 - 46.1% in Sudan (Nour, *et al.*,1985); 40-46% in Sudan (Abdel-Rahim *et al*., 1986); 45% in India (Jain and Banerje, 1988); 38.2% in Nigeria (Eromosele *et al.*, 1994); 48% in Cameroon (Kapseu *et al.*,1997); 49% in Sudan (Mohamed *et al.*, 2002); 39 – 46.7% in Israel (Chapagain *et al.*, 2009); and 45 – 47% in India (Deshmukh and Bhuyar, 2009).

It can be inferred that *B. aegyptiaca* kernels yield oil in the range of 40 - 50%. Oil yield obtained from Katakwi population therefore seems to be on a higher side than that reported in literature. However, the average oil yield of 44.5% reported in this study for Uganda compares well with that reported from other countries where *B. aegyptiaca* is found. Balanites oil content for Moroto population was relatively lower than that from Katakwi and Adjumani populations. These differences in oil yield could be explained by differences in environmental conditions between the sub-regions as well as genetic variation. Kapseu *et al.* (1997) and Omujal (2008) reported similar variations in shea oil yield, another dryland fruit tree found in Uganda. The good oil yield from Uganda coupled with high density of trees along the River Nile in West Nile sub-region (Madrama, 2006; Okia, 2010) and Teso and Karamoja sub-regions (Katende *et al.*, 1995) make the drylands of Uganda a potential niche for Balanites oil production for both local and external markets.

Physico-chemical characteristics of any oil are important for determining its nutritional quality and commercial value (Omujal, 2008; Chapagain *et al*., 2009). Colour of hexane-extracted oil was light yellow; refractive index was 1.46 at 20°C while viscosity of the oil varied between 15.75 - 22.60 cSt at 40°C. Deshmurkh and Bhuyar (2009) described Balanites oil as golden yellow and Hussain *et al.* (1949) attributed the yellow colour in Balanites oil to presence of á-carotene. According to FAO/WHO (1994) and WHO (2004), carotenoids and their derivatives are responsible for the yellow colour of fruits, vegetables, cereals and some crude oils. The presence of carotene makes Balanites oil nutritionally important because carotenoids are highly unsaturated polyisoprene hydrocarbons

although higher than that reported by Eromosele *et al.* (1994), and Nour *et al*. (1985) who found acid values of 0.11 – 0.5 mg KOH g^{-1}. Omujal (2008) reported a higher acid value of 3.18-6.92 mg KOH kg^{-1} for shea butter in Uganda. Iodine value ranged from 98.20 to 103.32 I_2 g $100g^{-1}$, which is within the ranges reported by Abu-Al-Futu (1983) and Chapagain *et al.* (2009). Eromosele *et al.* (1994) and Jain and Kenerjee (1988) reported lower values (76.2 and 56.5 I_2g 100 g^{-1}, respectively). Acid, saponification and iodine values reported in this study are generally within the range of most edible oils that are suitable for food and cosmetics. The high saponification value suggests that Balanites oil is suitable for soap making. Since the physico-chemical characteristics of Balanites oil obtained in this study are more or less similar to those reported in other countries, it is possible to develop regional standards for Balanites oil before it is commercialised or widely traded like shea butter which has standards (RCT, 2006).

Fatty acid composition of *B. aegyptiaca* kernel oil. The fatty acid profile is important for determining the nutritional value of oils (WHO, 2004; NAS, 2005; Ajayi *et al*., 2006). The fatty acid composition of Balanites oil revealed linoleic acid as the predominant fatty acid. Four major fatty acids in the order linoleic>oleic> stearic>palmitic were found in oils from the three study sub-regions, with small quantities of α-linolenic acid in some of the samples. The mean fatty acid contents in this study were; palmitic 15.40%, stearic 19.01%, oleic 25.74%, and linoleic 39.85%. Cook *et al.* (1998) also reported the same four fatty acids in fruit pulp though in smaller proportions of 0.5 - 1.31 mg g^{-1} dry weight. The four major fatty acids in Balanites oil constituted 99.2 – 100% of the total fatty acids. Chapagain *et al* (2009) found the same four major fatty acids to constitute 98 – 100% of total fatty acids for cultivated and irrigated *B. aegyptiaca* plants in Israel. They also found significantly higher levels of linoleic acid (31 - 51%) and correspondingly lower quantities of oleic and stearic acids than reported here. They further found the fatty acid profile of *B. aegyptiaca* oil to be very similar to soybean oil profile. When compared to the Uganda shea oil (Omujal, 2008), Balanites oil in this and other studies is about six times higher in the essential omega 6 linoleic acid. This also explains why Balanites oil remains liquid while shea oil turns solid at room temperature.

The values obtained in this study for the respective fatty acids are within those reported elsewhere by Hussain *et al*.(1949), Giffard (1974), Abu-Al-Futuh (1983), Jain and Banerjee, 1988, Muhamed *et al.* (2002), Deshmurk and Bhuyar (2009) and Chapagain *et al.* (2009). Minute quantities of α-linolenic acid <0.7% were detected in this study and in consonance with findings by Muhamed *et al.* (2002) and Deshmurkh and Bhuyar (2009) who reported higher levels of 1.7 and 7.2%, respectively. It appears that the difference in method of extraction used (hand press as opposed to solvent extraction) and improvement in the scientific equipment could have enabled detection of increased amounts of alpha linolenic acid in these studies. The presence of an omega 3, α-linolenic acid in some populations of *B. aegyptiaca* presents further opportunities for selection of superior races for propagation trials. Chapagain *et al.* (2009) also reported several other fatty acids but in smaller quantities. Deshmurkh and Bhuyar (2009) detected presence of palmitoleic acid (4.3%) in the Indian population which appears not to have been reported in the literature so far available. It appears that Deshmurkh and Bhuyar (2009) were able to detect additional fatty acids in Balanites kernels due to the more detailed analyses employed because they were interested in the fuel properties of this oil. Environment and tree genetic variations could also account for differences in fatty acid profiles in *B. aegyptiaca* oil.

Only oleic acid content was significantly lower in the Katakwi population, 23.99% than the overall mean of 25.74%. However, the oil also had slightly higher content of the omega-6 linoleic acid (41.82%) than the overall mean (39.85%) of fatty acids recorded. Since linoleic is an essential fatty acid [EFA] (Uauy, 2009), its quantity could be used as one of the qualities for germplasm selection. Linoleic, undoubtedly one of the most important polyunsaturated fatty acids in human food because of its prevention of distinct heart vascular diseases (Omode *et al*., 1995) was predominantly in the oil from all the three study

sub-regions. It is well known that dietary fat rich in linoleic acid, apart from preventing cardiovascular disorders such as coronary heart diseases and atherosclerosis, also prevents high blood pressure (Ajayi *et al*., 2006). Furthermore, linoleic acid derivatives serve as structural components of the plasma membrane and as precursors of some metabolic regulatory compounds (Vles and Gottenbos, 1989). The presence of one of the three essential fatty acids in Balanites oil makes it nutritionally valuable and highly recommended for human consumption.

Monounsaturated oleic acid was the second most prominent fatty acid in Balanites oil. This gives higher percentage of unsaturated fatty acids [UFA] (65.59%) than saturated fatty acids [SFA] (33.41%) with UFA:SFA ratio of 1.91. Results by Deshmurkh and Bhuyar (2009) indicated UFA/SFA ratio of 3.03 and is of great nutritional significance. The polyunsaturated fatty acid (PUFA) content (linoleic) was also higher (39.85%) than that of other nonconventional oilseeds: avocado (15.5%), *Canarium schweinfurthii* (28.8%), *Dacryodes edulis* (25.2%) (Chalon, 2001; Dhellot *et al.,* 2006) and shea butter (6.9%) (Omujal, 2008). The UFA:SFA ratio makes it possible to classify Balanites oil as potentially linoleic/oleic oil having good nutritional properties. Thus, Balanites kernel oil could be a good source of essential polyunsaturated fatty acids. There are also traces of omega 3 alpha linolenic fatty acid with immensely positive nutritional and health properties.

Similarities between the locally processed and solvent extracted Balanites oil suggests that the traditional processing method does not have any detrimental effect on the fatty acid profile. However, the locally processed oil had a darker colour than solvent extracted oil**.** It is possible that there are differences in the physico-chemical characteristics of the oils extracted by the two methods, though it was not possible to perform most of the physico-chemical analyses on the locally processed oil simply because of this rather dull colour. In order to capture the urban market and make the oil visually attractive to younger persons, there is a need to improve the processing method by the introduction of a hand press as already being done for shea butter in the drylands of Uganda. The same technology could be adopted for Balanites oil processing in Uganda.

CONCLUSION

The results indicate that Balanites oil yield is high (44.5%) with good physico-chemical properties and rich in polyunsaturated omega 6 linoleic acid which is an essential fatty acid. The order of fatty acids is linolenic>oleic>stearic>palmitic. Unsaturated fatty acids constituted 65.6% of the oil making it nutritionally beneficial. The physico-chemical characteristics and fatty acid profile of Desert date oil from Uganda presented here make it a potential raw material for cosmetics, soap and food processing (as edible vegetable oil). Equipping rural communities with appropriate tools and techniques for increasing oil production hygienically could improve their livelihoods through incomes generated.

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