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Fatty Acid Composition of Oil from Groundnuts and Oyster Nuts Grown in Uganda

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Abstract

This study determined the fatty acid (FA) composition of oil from groundnuts and oyster nuts in Uganda. The FA composition was determined by Gas Chromatography/Mass Spectrometry with FID. Oil from groundnuts contained 39.71 to 55.89% oleic, 20.21 to 35.59% linoleic and 11.91 to 17.16% palmitic acids. Oil from Serenut cultivars contained cis 11-eicosenoic acid (C20.1), cis 11, 14 eicosadienoic acid (C20.2) and cis 11, 14, 17 eicosatrienoic acid (C20.3ω3) which were not detected in traditional cultivars. Oyster nut oil was high in linoleic acid at 41.02 to 44.86% and palmitic acid at 33.58 to 38.11% while oleic acid was low with amounts <10%. The polyunsaturated to saturated FA ratios of oil from groundnuts and oyster nuts were >0.45, the minimum recommended by FAO. The atherogenic (AI) and thrombogenic indices (TI) of <1 and the hypocholesterolemic to hypercholesterolemic index (h/H) of >4 in groundnut oil were favorable for cardiovascular health. Indices for oyster nut oil were ≤1for AI and >1for TI. The h/H was low compared to that of groundnut oil. Results showed little distinction between the FA compositions of oil from traditional and improved groundnuts suggesting that breeding may not have significant effect on major FAs. Oyster nut oil contained saturated and unsaturated FA in a ratio of 1:1. The lipid health indices for groundnut oil were within recommendations while those of oyster nuts were less desirable. Oyster nut oil should therefore be consumed with moderation.

Keywords: fatty acids, groundnut, oil, oyster nut, Uganda

1. Introduction

Nuts have been recognised as a high fat food group (Hollis & Mattes, 2007). Most nuts contain low levels of saturated and high amounts of unsaturated fatty acids (Kris-Etherton et al., 1999). Fatty acids (FA) in nuts have structural and metabolic roles in the body (Arbex et al., 2015). Groundnuts (*Arachis hypogea* L.) are the second most widely grown and consumed legumes in Uganda after common beans (*Phaseolus vulgaris*). Their production is in Northern, Eastern and Southern parts of Uganda with Eastern region being the highest producer (Okello, Biruma, & Deom, 2010). In North and Eastern Uganda, groundnuts are valued as cash crops and a valuable source of oil and protein (Mugisha, Lwasa, & Mausch, 2014; Okello et al., 2010). Groundnuts contain approximately 40 to 50% oil (Ntare, Diallo, Ndjeunga & Waliyar, 2008). Despite being an excellent source of oil, the highest proportion of groundnuts produced in Uganda is consumed as snacks, stew and paste with low value added to the crop (Okello et al., 2010; Mugisha, Lwasa, & Mausch, 2014). Vegetable oils are important sources of polyunsaturated fatty acids (PUFA), alpha linolenic and linoleic acids (Yehuda, 2003). Utilization of the oil depends on FA composition and fat soluble vitamins (Shad, Pervez, Zafar, Nawaz, & Khan, 2012; Strayer, Belcher, Fine, & Mcbrayer, 2006). Groundnut oil is considered healthier than saturated oil due to its high monounsaturated FA content and is resistant to rancidity because of the anti oxidant vitamins (Asibuo et al., 2008; Shad et al., 2012).

The groundnut research program at the National Arid and Semi-Arid Resources Research Institute (NaSARRI) in Serere, Uganda is focused on developing groundnut varieties with improved agronomic characteristics. Breeding at NaSSARI resulted in large scale production and commercialization of improved groundnut (Serenut) cultivars. These cultivars are high yielding, high quality, resistant to diseases, and quick maturing (Okello et al., 2010; Okello, Deom, Puppala, Monyo, & Bravo-Ureta, 2016).

Today's consumers are concerned about the nutritional value and safety of foods they consume. It is therefore

important to establish any nutritional and safety differences between new varieties and traditional ones. Even though modification was intended for another purpose, it may result in some unintended positive or negative changes in the product. Little information however, is available on the nutritional profile of these cultivars in comparison with their traditional counterparts.

Oyster nut, *Telfairia pedata*, is a perennial climbing vine and a member of the *Cucurbitaceae* family (Jumbe et al., 2016). It is common in Tanzania, Kenya and some parts of Uganda. Oyster nuts contain 55 to 60% oil (Ajayi et al., 2004; Hopkins & Chisholm, 1964). Oyster nuts are eaten raw or cooked are especially mentioned as source of food for women during the lactating period. The nuts have been reported to have other non-food uses ascribed to the properties of their oil. Ajayi et al. (2004) asserted that oyster nuts may stay in good condition for up to eight years despite their high concentration of oil. Oyster nut oil however, may have limited application due to lack of information regarding its chemical composition.

Despite the indiscriminate utilisation of groundnuts and their products, there is scant information on the FA composition of oil from the Serenut and traditional cultivars as well as oyster nuts in Uganda. To establish whether breeding improves the nutritional properties of the oil, this study determined the FA composition of oil from Serenut and traditional groundnut cultivars. Oyster nut oil was characterised to establish its constituent fatty acids. Determining these parameters could add to the nutritional data base for crops grown in Uganda and allow for consumption from an informed perspective.

2. Materials and Methods

2.1 Sample Collection and Preparation

Fourteen improved cultivars (Serenuts 1 to 14) and six traditional groundnut cultivars (Acholi white, *Igola*, *Egoromoit*, *Rudu* white, *Rudu* red and Red beauty) were studied. Serenut 1 to 14 were collected from National Arid and Semi-Arid Research Resources Institute (NaSARRI) in Serere. Traditional cultivars were purchased from markets in Soroti, Arapai, and Achorimongin markets in Teso sub-region, Eastern Uganda. Groundnuts were shelled, sorted, hulled and finely crushed to obtain groundnut flour. Oyster nuts were obtained from Kamuli district in Eastern, Dokolo district in Northern, and Luwero district in central Uganda and transported to the laboratory. Nuts were cleaned and sorted according to gender, the flat nuts were classified as female and the creased nuts as male. A total of 18 samples comprising of 9 male and 9 female were peeled to remove the fibrous shell. Splitting of the inner shell was done using a knife to release the oil-bearing cotyledon. Oyster nut cotyledons were pounded using a mortar and pestle to obtain a paste. Groundnut flours and oyster nut paste were stored in the refrigerator (4^oC) prior to oil extraction. All assays were done in triplicate.

2.2 Oil Extraction

Oil extraction was done according to Bligh and Dyer (1959). Groundnut flour and oyster nut paste were separately weighed (10 g) into a 250 ml flat bottomed flask then chloroform was added (100 ml). Flask contents were mixed using an ultraturax homogenizer (IKA T18, Bergkirchen, Germany) for 2 min. The mixture was transferred into a 40 ml dionex vial and centrifuged at 2000 rpm for 5 min. The chloroform layer was filtered through a filter paper (Macherey-nagel, 125 mm) containing anhydrous sodium sulphate. Twenty milliliters of the filtrate was concentrated under a stream of nitrogen at 40 ^0C.

2.3 Fatty Acid Composition

2.3.1 Preparation of Fatty Acid Methyl Esters

Fatty acid methyl esters (FAME) were prepared according to AOAC (2000) method number 969.33. Fat was weighed (0.5 g) in a 40 ml glass vial and diethyl ether added (2 ml). The mixture was then vortexed until oil was dissolved. Methanolic potassium hydroxide was added (0.5 ml) and the mixture allowed to react for 15 min. during which the solution became cloudy due to soap formation.

2.3.2 Extraction of the Fatty Acids from the Soap Solution

Distilled water was added (2 ml) to the FAME solution followed by 10 ml of hexane. The mixture was vortexed to allow phase separation. The organic layer was transferred to a clean test tube then distilled water was added (2 ml). The mixture was allowed to stand to allow phase separation. This was repeated until the water used to wash the organic layer showed no color change with phenolphthalein. The organic layer was transferred (1 ml) to a 1.5 ml GC vial and injected (1 µl) onto a 30 m x 0.32 mm x 0.5 µm solgel wax column with polyethylene-glycol as the stationary phase and helium gas at 20 psi as the mobile phase. The column was mounted in a GC/FID (Varian chrompack CP-3800, USA). The injector temperature was 260 ℃. The temperature of the column was kept at 50 ℃ for 5 min. after injection and thereafter increased to 180 ℃ at a rate of 20 ℃/min., followed by an increase of

2 ℃/min to 200 ℃, held for 11 min. and then finally ramped to 250 ℃ at 2 ℃/min. and held for 2.5 min. Fatty acids were identified by analyzing a reference standard mixture (Supelco 47885-U, Sigma Aldrich, Belgium) under the same conditions as the test portion. The retention distances of the standard were compared with those of the test portion. The esters appeared in order of increasing number of carbon atoms and of increasing level of unsaturation for the same number of carbon atoms. Calculation of the peaks was by normalization which assumes all components of test portion represented on the chromatograms so that the sum of the peaks represents 100% of the constituents.

2.4 Iodine Value

Iodine value was calculated from the fatty acid composition using the method of Hashim et al.(1993).

$$\text{IV} = (\%\ \text{Oleic acid X } 0.8601) + (\%\text{Linoleic acid X } 1.7321) + (\text{Eicosanopentanoic acid X } 0.7854) \quad (1)$$

2.5 Lipid Health Indices

2.5.1 Atherogenic Index and Thrombogenic Indices

Atherogenic index (AI) and thrombogenic index (TI) were calculated according to the following equations by Ulbricht and Southgate (1991).

$$\text{Atherogenic index} = (\text{C14.0x4} + \text{C16.0} + \text{C18.0})/(\sum\text{MUFA} + \sum\omega\text{6PUFA} + \sum\omega\text{3PUFA}) \quad (2)$$

$$\text{Thrombogenic index} = (\text{C14.0} + \text{C16.0} + \text{C18.0})/(0.5\text{xMUFA} + 0.5\text{x}\omega\text{6PUFA} + 3\text{x}\omega\text{3PUFA}) + \frac{\omega 3}{\omega 6} \quad (3)$$

2.5.2 Hypocholesterolemic/Hypercholesterolemic Index

This index indicates potential of a lipid to balance between the good and bad cholesterol. It was calculated from the equation by Santos-Silva, Bessa, and Santos-Silva (2002).

$$\frac{h}{H} = (C18.1\omega 9 + C18.2\omega 6 + C20.4\omega 6 + C18.3\omega 3 + C20.5\omega 3 + C22.6\omega 3)/(C14 + C16) \quad (4)$$

h: Hypocholesterolemic

H: Hypercholesterolemic

2.6 Statistical Analysis

Samples were analysed in triplicate and data presented as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) with a Turkey's least significant difference (LSD) test was used in SPSS version 17.0 (SPSS, Chicago, IL, USA) to evaluate the differences in fatty acids. Differences were considered statistically significant at $p<0.05$.

3. Results and Discussion

The percent FA composition of oil from groundnuts and oyster nuts are presented in Tables 1 and 2, respectively. Oils were found to contain variable levels of FA as discussed below.

3.1 Groundnut Oil

The dominant fatty acids (FA) in groundnut oil were oleic (C18.1), linoleic (C18.2) and palmitic (C16.0) acids with amounts more than 10% (Table 1). Approximately 80% of FA in oil from all cultivars were unsaturated (Table 3). Oleic (C18.1) as the major unsaturated FA varied from 39.71 to 55.89%. This finding is close to the data reported by Khetarpaul, Jood, & Goyal (2007) and Dorni, Paras, Gunendra, & Longvah (2018) who reported 48.90% and 53.77% oleic acid (C18.1), respectively. Linoleic acid (C18.2) ranged from 20.21 to 35.59%. Levels of linoleic acid (C18.2) were in agreement with the findings of Achola et al. (2017) who reported 26.79 to 33.44% while Dorni, Paras, Gunendra, & Longvah (2018) reported 26.96% linoleic acid (C18.2) in groundnut oil. Similarly, Gulluoglu, Bakal, Onat, Sabagh, & Arioglu (2016) reported 2 to 43% linoleic acid (C18.2) in groundnut oil. Palmitic acid (C16.0) concentration varied from 11.91 to 17.16%. Findings were consistent with data by Achola et al. (2017) who reported a range of 14.61 to 18.6% palmitic acid (C16.0) in Serenuts 5 to 10. Shahidi (2005) and Özcan (2010) presented slightly lower ranges of 8 to14% and 7.63 to 11.41% palmitic acid (C16.0), respectively, in groundnut oil. Stearic acid (C18.0) ranged from not detected (nd) to 4.93%. Berry (1982) reported 3.17 to 3.68% stearic acid (C18.0) while Achola et al. (2017) obtained 2.19 to 3.46% stearic acid (C18.0) in Serenuts 5 to 10. Levels of oleic (C18.1), linoleic, (C16.0) and stearic acid (C18.0) varied significantly ($p<0.05$) indicating composition differences among the cultivars. Similarly, behenic acid (C22.0) levels were higher in the traditional cultivars compared to the Serenuts. Oil from red beauty (RB) had the highest amount of behenic acid. Other FAs such as gamma linolenic (C18.3ω6), alpha

linolenic (C18.3ω3), arachidic (C20.0), eicosenoic (C20.1) and eicosadienoic (C20.2) occurred in amounts less than 2% in all cultivars. Levels of these FA were more pronounced in oils from traditional than Serenut cultivars. Arachidic acid (C20.0) is a characteristic FA in groundnuts and their products. The level of arachidic acid (C20.0) should not exceed 4.8% in groundnut oil (Codex, 2001). Dorni, Paras, Gunendra, & Longvah (2018) and Özcan (2010) reported 1.44 to 2.36% and 1.42% arachidic acid (C20.0), respectively, in groundnut oil. The levels of arachidic acid in this study agreed with reports of the aforementioned scholars. Cis 11-eicosenoic acid (C20.1), cis 11, 14 eicosadienoic acid (C20.2) and cis 11, 14, 17 eicosatrienoic acid (C20.3ω3) were detected in oil from Serenut cultivars and not in the other cultivars. The presence of these FA in oil from the Serenut cultivars may be attributed to breeding or growth environment.

Table 1. Fatty acid composition (%) of oil from groundnuts

GNC	C16.0	C18.0	C18.1	C18.2	C18.3ω3	C18.3ω6	C20.0	C20.1	C20.2	C20.3ω3	C22
S1R	15.73 ± 0.11^{e}	2.13 ± 0.10^{a}	50.28 ± 0.61^{fghi}	26.06 ± 0.49^{cd}	1.09 ± 0.07^{i}	0.34 ± 0.03^{cde}	1.02 ± 0.07^{ab}	nd	1.42 ± 0.14^{bcde}	0.52 ± 0.36^{bc}	1.09 ± 0.16^{bcdefg}
S2T	14.84 ± 0.14^{cde}	nd	52.28 ± 0.88^{j}	25.96 ± 0.79^{cd}	1.05 ± 0.04^{i}	0.36 ± 0.02^{cde}	nd	1.24 ± 0.02^{de}	1.05 ± 0.06^{b}	1.40 ± 0.08^{e}	1.48 ± 0.00^{fg}
S3R	14.51 ± 0.27^{cde}	2.89 ± 0.21^{cde}	54.85 ± 0.14^{k}	21.68 ± 0.21^{ab}	0.08 ± 0.01^{bc}	0.28 ± 0.00^{abcde}	nd	1.10 ± 0.03^{c}	1.41 ± 0.28^{bcde}	1.45 ± 0.07^{e}	1.41 ± 0.01^{efg}
S4T	13.62 ± 0.64^{bc}	4.15 ± 0.10^{f}	55.05 ± 0.70^{k}	21.94 ± 0.53^{b}	0.08 ± 0.01^{bc}	0.34 ± 0.02^{cde}	nd	0.68 ± 0.03^{b}	1.57 ± 0.03^{de}	1.60 ± 0.13^{e}	0.85 ± 0.07^{bcd}
S5R	14.84 ± 0.50^{cde}	2.76 ± 0.08^{cd}	48.71 ± 0.65^{fg}	27.16 ± 0.99^{de}	0.05 ± 0.00^{ab}	0.57 ± 0.05^{de}	nd	1.32 ± 0.10^{ef}	1.06 ± 0.03^{bc}	1.66 ± 0.12^{e}	1.59 ± 0.17^{g}
S6T	15.88 ± 0.16^{ef}	3.40 ± 0.18^{e}	50.29 ± 0.13^{ghi}	25.78 ± 0.22^{cd}	0.07 ± 0.01^{abc}	0.51 ± 0.02^{de}	nd	0.70 ± 0.01^{b}	1.08 ± 0.01^{bc}	1.06 ± 0.15^{d}	1.07 ± 0.02^{bcdef}
S7T	14.61 ± 1.26^{cde}	3.15 ± 0.27^{de}	46.31 ± 0.54^{cd}	30.79 ± 0.86^{i}	0.06 ± 0.02^{abc}	0.02 ± 0.00^{ab}	0.12 ± 0.00^{a}	1.20 ± 0.01^{d}	1.48 ± 0.02^{cde}	0.65 ± 0.05^{e}	1.46 ± 0.03^{defg}
S8R	13.78 ± 0.18^{bcd}	3.14 ± 0.05^{de}	48.63 ± 0.52^{ef}	29.25 ± 0.22^{gh}	0.23 ± 0.01^{e}	0.24 ± 0.03^{abcd}	0.06 ± 0.00^{a}	1.15 ± 0.07^{cd}	1.75 ± 0.45^{e}	0.23 ± 0.01^{ab}	1.33 ± 0.04^{cdefg}
S9T	14.56 ± 0.63^{cde}	2.08 ± 0.06^{a}	45.92 ± 0.30^{bcd}	31.91 ± 0.56^{ij}	0.27 ± 0.01^{e}	0.28 ± 0.01^{abcd}	nd	1.33 ± 0.04^{ef}	1.41 ± 0.21^{bcde}	0.26 ± 0.04^{ab}	nd
S10R	15.09 ± 0.05^{de}	2.44 ± 0.22^{ab}	51.85 ± 0.70^{ij}	24.67 ± 0.45^{c}	nd	0.19 ± 0.01^{abcd}	nd	1.36 ± 0.03^{f}	1.26 ± 0.18^{bcd}	1.63 ± 0.10^{e}	1.36 ± 0.02^{defg}
S11T	13.79 ± 0.07^{bcd}	2.36 ± 0.20^{ab}	46.45 ± 1.03^{cd}	34.02 ± 0.39^{k}	0.97 ± 0.01^{h}	0.31 ± 0.15^{abc}	0.92 ± 0.07^{ab}	nd	nd	nd	0.95 ± 0.07^{bcde}
S12R	15.41 ± 0.34^{e}	2.64 ± 0.19^{abc}	52.11 ± 0.09^{j}	27.57 ± 0.26^{ef}	nd	0.37 ± 0.03^{bcde}	1.02 ± 0.04^{ab}	nd	nd	nd	0.98 ± 0.15^{bcdef}
S13T	14.63 ± 0.38^{cde}	2.36 ± 0.15^{ab}	50.30 ± 0.49^{ghi}	30.61 ± 0.12^{hi}	nd	0.97 ± 0.07^{cde}	0.69 ± 0.02^{ab}	nd	nd	nd	0.76 ± 0.58^{b}
S14R	14.86 ± 0.83^{cde}	2.65 ± 0.04^{abc}	49.73 ± 0.39^{fgh}	28.93 ± 0.63^{fg}	nd	0.97 ± 0.07^{f}	1.03 ± 0.06^{b}	nd	nd	nd	1.33 ± 0.27^{cdefg}
AW	17.16 ± 0.11^{f}	4.88 ± 0.12^{h}	39.71 ± 0.65^{a}	35.59 ± 0.39^{l}	nd	0.35 ± 0.31^{cde}	0.55 ± 0.47^{ab}	nd	nd	nd	0.83 ± 0.08^{bc}
IGO	14.83 ± 0.25^{cde}	2.63 ± 0.00^{abc}	50.86 ± 0.45^{hij}	28.87 ± 0.22^{fg}	nd	0.13 ± 0.01^{g}	2.70 ± 0.21^{c}	nd	nd	nd	0.78 ± 0.09^{b}
RR	12.78 ± 0.24^{ab}	4.21 ± 0.48^{ff}	44.74 ± 0.18^{bc}	30.86 ± 0.66^{i}	0.14 ± 0.01^{cd}	nd	nd	nd	nd	nd	3.27 ± 0.12^{h}
RW	12.68 ± 0.17^{ab}	4.80 ± 0.38^{gh}	44.28 ± 0.08^{b}	33.08 ± 0.18^{jk}	0.21 ± 0.02^{de}	nd	nd	nd	nd	nd	3.28 ± 0.05^{h}
EGT	13.75 ± 0.34^{bcd}	4.93 ± 0.23^{h}	55.89 ± 0.12^{k}	20.21 ± 0.18^{a}	0.67 ± 0.02^{g}	nd	nd	nd	nd	nd	3.49 ± 0.09^{hi}
RB	11.91 ± 0.14^{a}	4.74 ± 0.20^{fgh}	46.90 ± 0.49^{de}	30.76 ± 0.11^{hi}	0.59 ± 0.02^{f}	nd	nd	nd	nd	nd	3.86 ± 0.15^{i}

Data are expressed as percentages of total fatty acid methyl esters; Values are means of triplicate determinations, values followed by the same letter within each column are not significantly different ($p>0.05$) nd: not detected; GNC: Groundnut cultivar; S: Serenut; R: red;T: Tan; AW: Acholi White; IGO: *Igola*; RR: *Rudu* Red; RW: *Rudu* White; EGT: *Egoromoit*; RB: Red Beauty.

3.2 Oyster Nut Oil

Oyster nut oil had high amounts of palmitic acid (C16.0) and linoleic acid (C18.2) but had low amount of oleic acid (C18.0). Palmitic acid (C16.0) ranged from 33.58 to 38.11% (Table 2). This concurs with the concentrations obtained by Hopkins and Chisholm (1964) and Nyagah (2016) who reported 35% and 32.03% palmitic acid (C16.0) in oyster nut oil from South Africa and Kenya, respectively. Minzangi, Mpiana, Samvura, Kaaya, Bertrand, & Kadima, 2015 examined nuts from DR Congo and obtained a lower level of Palmitic acid (C16.0) at 14.06%. Palmitic acid (C16.0) has been positively associated with high serum cholesterol and hence cardiovascular risk (Galli and Calder, 2009; Fattore and Fanelli, 2013; Mancini et al., 2015 and Carta et al., 2017).

The high amount of palmitic acid (C16.0) in this study suggests that oyster nut oil may not favour cardiovascular health. In addition, high levels of palmitic acid (C16.0) may enhance metabolic complications such as insulin resistance and decreased oxidation of FA and glucose in muscles hence their accumulation in tissues (Iggman & Risérus, 2017). However, moderate consumption of oils rich in palmitic acid (C16.0) could provide health benefits as it forms a significant part of cell membrane phospholipids (Calder, 2015). Stearic acid in oil ranged from 9.47 to 13.60%. Hopkins and Chisholm (1964) reported 14% and Nyagah (2016), 10.31% stearic acid (C18.0). Contrary to our findings, Minzangi et al. (2015) obtained 9.3 % stearic acid (C18.0). In the body, stearic acid is converted to oleic acid. This conversion may help to lower plasma cholesterol (Bonanome & Grundy, 1988; Strayer et al., 2006; Mente et al., 2017). It is, therefore, implied that diet containing more stearic than palmitic acid may improve plasma lipid profile. Saturated FA that were detected in amounts less than1.0% included; butyric acid (C4.0) caproic (C9.0), undecanoic (C11.0), lauric (C12.0), tridecanoic (C13.0), myristic (C14.0), heptadecanoic (C17.0), arachidic (C20.0), heneicosanoic (C20.1), tricosanoic (C23.0) and nervonic acid (C24.0). There were no significant differences ($p>0.05$) in the levels of different FA based on location or gender. Linoleic acid (C18.2) was the major unsaturated FA detected and it ranged from 41.02 to 44.86%. This result is

close to that obtained by Hopkins & Chisholm (1964) at 44% though slightly lower than that of Nyagah (2016) at 53.66%. The levels of linoleic acid (C18.2) in this study doubled the 22.03% obtained by Minzangi et al. (2015). Linoleic acid (C18.2) has been reported to lower total serum cholesterol, a positive attribute in reducing cardiovascular risk (Ristić-Medić, Vučić, Takić, & Karadžić, Ivana and Glibetić, 2013). Oleic acid (C18.1) ranged from 5.69 to 8.10% (Table 2). While other scholars reported low levels of oleic acid (C18.1) at <10%, Minzangi et al. (2015) presented 41.77%. Levels of Alpha linolenic acid (C18.3ω3) in oil were less than 2%. Literature sources, (Hopkins & Chisholm, 1964; Jumbe et al., 2016) indicate that alpha linolenic acid (C18.3ω3) levels were either too low or undetected.

Table 2. Fatty acids (%) in oyster nut oil

Location	C16.0	C18.0	C18:1	C18:2	18.3ω3	18.3ω6	C20.1	C20.2	C22.1ω9	C23.0	C24.0
Dokolo											
Male	38.11±0.96[a]	13.60±0.21[a]	5.93±0.26[a]	41.02±1.02[a]	nd	nd	nd	nd	nd	0.03±0.00[a]	nd
Female	36.39±3.99[a]	11.49±3.07[a]	8.08±2.05[a]	44.86±2.44[a]	0.03±0.00[a]	0.06±0.01[a]	nd	0.02±0.00[a]	nd	0.13±0.00[a]	nd
Kamuli											
Male	38.72±3.37[a]	10.47±0.56[a]	5.69±2.09[a]	42.88±3.77[a]	nd	nd	nd	nd	nd	0.16±0.00[a]	nd
Female	37.21±3.19[a]	10.29±1.29[a]	7.16±1.70[a]	43.64±3.51[a]	nd	nd	nd	nd	nd	nd	0.03±0.00[a]
Luwero											
Male	35.32±5.01[a]	9.47±2.88[a]	8.10±4.15[a]	44.62±1.22[a]	nd	0.23±0.00[a]	0.22±0.01a	0.01±0.00[a]	0.12±0.00[a]	nd	nd
Female	33.58±3.02[a]	13.56±2.76[a]	6.85±1.58[a]	43.44±2.06[a]	0.01±0.00[a]	0.30±0.01[a]	0.20±0.00a	0.13±0.00[a]	0.14±0.00[a]	nd	nd

Data are expressed as percentages of total fatty acid methyl esters, Values are means of triplicate determinations; values followed by the same letter within each column are not significantly different (p>0.05) nd: not detected.

3.3 Lipid Health Indices for Groundnut Oil

The polyunsaturated to saturated FA ratio (P/S) measures the tendency of the diet to influence the incidence of coronary heart disease (SˇimaT, Bogdanovic´, Poljak, & Petricˇevic´, 2015). This ratio is also important in determining the cholesterolemic effect of dietary lipids. Foods with P/S ratio above 0.45 (FAO, 2010) are considered beneficial due to their potential to lower serum cholesterol (Kostik, Memeti, & Bauer, 2013). The beneficial effect is even more significant when the P/S ratios are >1. The P/S of groundnut oil ranged from 0.99 to 2.15 (Table 3). Nile and Park (2013) and Johnson, Saikia, Mathur, & Agarwal (2009) obtained P/S ratios of 1.8 and 2.28 for groundnut oil. The high P/S ratios in this study suggests that consumption of diet rich in groundnut oil is beneficial for human health. Oils with high P/S ratios have higher nutritional value than ones with less (Kostik et al., 2013). Ramprasath, Jones, Buckley, Woollett, & Heubi (2012) reported that serum cholesterol concentrations are hiked with diets rich in SFA while the opposite effect is provided by diets containing high levels of PUFA. Consumption of diets with a high P/S ratio reduces plasma total and LDL-cholesterol concentrations. Similarly Wen and Chao (1998), suggested that high ratio of P/S is crucial in keeping serum and liver cholesterol low. Experimental data by Iggman and Risérus (2017) suggests that partial replacement of SFA by PUFA hence increasing the P/S ratio may reduce cardiovascular risk. This is in agreement with report from expert consultation of FAO in 2010 on fats and FA in human nutrition (FAO, 2010).

The polyunsaturated to monounsaturated FA (P/M) ratio of oil ranged from 0.39 to 0.91. Polyunsaturated and monounsaturated FAs are linked to reduction of atherosclerosis and cardiovascular disease (Kris-Etherton, 1999; Harlioğlu and Yilmaz, 2011). Diets rich in monounsaturated FA are neutral while polyunsaturated FA lower plasma lipids (Wen and Chao, 1998; Bos et al., 2010). No clear recommendations are available for P/M ratio however, Wen & Chao (1998), experimented with different P/M ratios and reported that high ratios lowered plasma and liver cholesterol and triglycerides. Findings of their experiments suggested that diets containing oil with a P/M ratio of 2.5 reduce the plasma and liver cholesterol of human subjects. Our results were far below the threshold given by the above scholars.

The monounsaturated to saturated FA ratio (M/S) of groundnut oil varied from 1.65 to 3.25 (Table 3). Nile and Park (2013) obtained M/S ratio of 1.06 for groundnut oil. The M/S ratio of this study is slightly higher. Diets with high M/S ratio of >1 decrease plasma HDL-C and triacylglycerides (Yang, Lin, Chang, & Chien, 2017). Sinanoglou, Batrinou, Mantis, Bizelis, & Miniadis-meimaroglou (2013) and Calder (2015) suggested that MUFA are heart protective while SFA may increase risk of cardiovascular disease. The high M/S ratio in this research suggests a healthy balance of FA in groundnuts.

The ratio of omega-6 to omega-3 (ω6/ω3) of groundnut oil varied from not detected (nd) to 228.55. where omega -3 FAs were detected, all the ratios exceeded the optimal range (4:1) suggested by Simopoulos (2010). This is attributed to the very low levels of omega 3 FA in the oil and higher levels of omega-6. Johnson et al.

(2009) obtained ω6/ω3 of 7.5 for groundnut oil while Nile and Park, (2013), reported ω6/ω3 value of 25.0. Literature reports on this ratio are highly variable. Some scholars did not report any ALA in groundnut oi1 while others reported very low amounts hence the high ratios. Omega-3 and omega-6 produce eicosanoids with conflicting effects in the body, omega-3 being anti-inflammatory while omega-6 eicosanoids support formation of thrombus, atheromas and obesity (Simopoulos, 2008, 2016; Alabdulkarim, Bakeet, & Arzoo, 2012) . The oleic to linoleic (O/L) acid ratio of groundnut oil varied from 1.12 to 2.77. Shad et al. (2012) obtained an O/L ratio of 3.53 to 19.79 and suggested that high O/L ratio is stable to oxidation (Shad et al., 2012). Among studied oil, *Egoromoit* exhibited the highest O/L ratio implying that its oil have better oxidative stability than the other oils.

Atherogenic and thrombogenic indices are used to assess nutritional quality of lipids (S˘imaT et al., 2015). The atherogenic Index (AI) of groundnut oil ranged from 0.18 to 0.29 while the thrombogenic index (TI) ranged from 0.31 to 0.58 (Table 3). These ranges were close to the range for some vegetable oils as reported by Turan (2007). Different recommendations have been suggested for AI and TI. According to Hernández-martínez, Gallardo-velázquez, Osorio-, Castañeda-pérez, & Uribe-hernández (2016) levels of <1 are favourable while Ulbricht & Southgate (1991) recommended an upper limit of 0.5 for both AI and TI.. The AI and TI of groundnut oil is comparable to the respective indices; 0.17 to 0.19 and 0.30 to 0.34 reported by Kou, Sabolová, Hor, & Rys, (2018) for oats. Similarly, Attia, Al-harthi, Korish, & Shiboob, (2015; 2017) reported a TI range of 0.38 to 0.78 for eggs. The TI and AI indices of groundnut oil were within recommended levels for good cardiovascular health.

Hypocholesterolemic to hypercholesterolemic index (h/H) indicates potential of a lipid to balance between the good and bad cholesterol. Hernández-martínez et al. (2016) and Osmari, Cecato, Macedo, & Souza (2011) suggested that high h/H of >1 may be beneficial to human health. The Hypocholesterolemic to hypercholesterolemic index for groundnut oil ranged from 4.41 to 6.53. The h/H observed for groundnut oil was close to that (6.14) reported for olive oil (Hashempour-Baltork, Torbati, Azadmard-Damirchi, & Savage, 2018). The high h/H observed in this work implies that consumption of groundnut oil may result in reduced cardiovascular risk.

3.4 Iodine Values for Groundnut Oil

The iodine values (IV) groundnut oil were all in accordance to the recommended range of 86 to 106 except *Egoromoit*, with the lowest IV at 83.08 (Table 3). The highest IV in the Serenuts were observed for Serenut 11T and 13T were 98.88 and 96.27, respectively. Among traditional cultivars, Acholi white and *Rudu* white had the highest IV of 95.79 and 95.38. the iodine values in this study were in agreement with the range reported by Asibuo, (2008) at 85.77 to 98.43 for groundnuts.

Table 3. Total fatty acids (%) and lipid health indices of oil from groundnuts

GNC	SFA	MUFA	PUFA	TUFA	IV	O/L	ω6/ω3	M/S	P/S	P/M	AI	TI	h/H
S1R	20.10±0.16d^{efg}	50.39±0.58^{fg}	29.37±0.42^{cde}	79.76±0.16^{cde}	88.28±0.84^{cd}	1.93	16.97	2.51	1.46	0.58	0.23	0.41	4.87
S2T	16.47±0.13^{b}	53.58±0.88^{i}	29.82±0.85^{de}	83.41±0.13^{gh}	89.94±0.62^{de}	2.01	10.74	3.25	1.81	0.56	0.18	0.31	5.30
S3R	18.94±0.07^{def}	56.05±0.14^{j}	24.93±0.19^{b}	80.99±0.06^{def}	84.73±0.39^{a}	2.53	14.03	2.96	1.32	0.44	0.22	0.40	5.30
S4T	18.68±0.66^{de}	55.82±0.67^{j}	25.53±0.56^{b}	81.35±0.68^{def}	85.36±0.99^{ab}	2.51	13.32	2.99	1.37	0.46	0.22	0.40	5.69
S5R	19.39±0.39^{defg}	50.13±0.67^{fg}	30.50±0.99^{efg}	80.63±0.37^{cdef}	88.93±1.15^{cd}	1.80	16.27	2.59	1.57	0.61	0.22	0.40	5.15
S6T	20.46±0.17^{efgh}	51.09±0.14^{gh}	28.49±0.29^{cd}	79.58±0.21^{bcd}	87.89±0.35^{bcd}	1.95	23.47	2.50	1.39	0.58	0.25	0.46	4.82
S7T	19.48±1.18^{defg}	47.61±0.54^{cd}	33.01±0.91^{i}	80.62±1.25^{cdef}	93.17±1.75^{fgh}	1.50	43.45	2.45	1.70	0.69	0.22	0.43	5.31
S8R	18.45±0.13^{cd}	49.28±0.52^{efg}	31.71±0.61^{fghi}	81.60±0.14^{efg}	92.49±0.25^{fg}	1.66	63.84	2.70	1.72	0.63	0.21	0.41	5.67
S9T	18.77±0.63^{bc}	49.13±0.41^{def}	35.99±0.68^{i}	85.13±0.62^{h}	94.76±0.89^{ghij}	1.44	61.14	2.93	2.15	0.73	0.20	0.39	5.37
S10R	19.63±0.26^{defg}	53.21±0.72^{i}	27.79±0.42^{c}	81.01±0.30^{def}	87.33±0.31^{bc}	2.10	15.14	2.70	1.46	0.52	0.22	0.40	5.09
S11T	17.09±0.81^{c}	46.58±0.84^{bc}	35.46±0.20^{i}	82.03±0.19^{fg}	98.88±0.36^{l}	1.37	15.35	-	-	0.76	0.20	0.37	5.85
S12R	20.03±0.31^{defg}	52.11±0.17^{hi}	27.88±0.27^{c}	79.98±0.31^{cde}	92.57±0.52^{fg}	1.89	35.56	2.60	1.39	0.53	0.23	0.45	5.19
S13T	18.67±0.52^{de}	50.30±0.49^{fg}	31.08±0.04^{ef}gh	81.37±0.50^{def}	96.27±0.50^{k}	1.64	-	2.70	1.67	0.62	0.21	0.42	5.56
S14R	20.26±0.93^{efg}	49.73±0.40^{efg}	30.05±0.66^{def}	79.78±0.89^{cde}	92.88±1.31^{fgh}	1.72	-	2.46	1.48	0.60	0.22	0.44	5.37
AW	24.26±1.41^{i}	39.80±0.75^{a}	36.03±0.77^{i}	75.83±1.51^{a}	95.79±1.21^{ij}	1.11	-	1.65	1.50	0.91	0.29	0.58	4.41
IGO	18.96±0.45^{def}	50.86±0.45^{gh}	30.18±0.03^{def}	81.04±0.45^{def}	93.76±0.77^{fghij}	1.76	-	2.68	1.59	0.59	0.22	0.43	5.46
RR	23.14±0.64^{gh}	45.87±0.34^{b}	32.03±0.68^{hij}	77.80±0.67^{b}	92.02±1.08^{ef}	1.45	228.54	1.98	1.38	0.70	0.22	0.44	5.93
RW	20.76±0.29^{fgh}	45.94±0.24^{b}	34.95±0.20^{i}	80.89±0.43^{def}	95.38±0.36^{hij}	1.34	158.78	2.21	1.68	0.76	0.22	0.44	6.10
EGT	22.18±0.11^{hi}	57.01±0.08^{j}	22.00±0.24^{a}	79.01±0.17^{ab}	83.08±0.23^{a}	2.76	29.98	2.57	0.99	0.39	0.24	0.46	5.54
RB	20.51±0.45^{fgh}	48.38±0.41^{de}	32.71±0.16^{h}	80.17±0.37^{def}	93.72±0.36^{fghi}	1.53	52.32	2.35	1.59	0.68	0.21	0.40	6.53

Data are expressed as percentages of total fatty acid methyl esters; Values are means of triplicate determinations, values followed by the same letter within each column are not significantly different (p>0.05) nd: not detected; GNC: Groundnut cultivar; S: Serenut; R: red; T: Tan; AW: Acholi White; IGO: *Igola*; RR: *Rudu* Red; RW: *Rudu* White; EGT: *Egoromoit*; RB: Red Beauty. S: saturated fatty acid; M: monounsaturated fatty acid; P: polyunsaturated fatty acid; TUFA: total unsaturated fatty acid; O/L: oleic/linoleic ratio; AI: Atherogenic index; TI: thrombogenic index; h/H: hypocholesterolemic to hypercholesterolemic index; IV: Iodine value.

3.5 Lipid Health Indices for Oyster Nut Oil

The ratio of polyunsaturated to saturated fatty acids (P/S) is important in determining the cholesterolemic effect of dietary lipids. High P/S ratios of >1 have a hypo-cholesterolemic effect and higher nutritional value than ones with less (Kostik et al., 2013). The P/S index of oyster nut oil ranged from 0.79 to 1.01 (Table 4). Nutritional guidelines show preference for P/S >0.45 (FAO, 2010). The P/S ratio of oyster nut oil was within recommendations. The MUFA to SFA ratio (M/S) varied from 0.12 to 0.19. Saturated FA have been suggested to increase cardiovascular risk while the converse is reported for MUFA (Grundy, 1997; De Souza et al., 2015; Iggman & Risérus, 2017). Pacheco et al. (2006) studied the effect of different ratios of M/S and indicated that a low ratio resulted in pro-thrombic effect compared to a high ratio.

The ω6/ω3 is an important indicator for decreasing the risk for coronary heart disease (CHD) and hypertension (Simopoulos, 2010). The total omega-3 FA content was <0.5% while omega-6 FA proportions in oil which varied from 39.57 to 47.67% was several folds higher. Accordingly, the ω6/ω3 of >100 was very high compared to the recommended ratio of < 4:1 (Simopoulos, 2002; 2004; Codex, 2005; Rustan and Drevon, 2005 and Patterson, Wall, Fitzgerald, Ross, & Stanton, 2012). Oleic to linoleic acid ratio (O/L) is regarded as a measure of oil stability (Asibuo, 2008). Low O/L hence indicates low oxidative stability (Yanishlieva and Marinova, 2001). On the other hand a high ratio is desirable to enhance oxidative stability and nutritional value (Flagella, Rotunno, Tarantino, Di Caterina, & De Caro, 2002; Mukri et al., 2012). Oyster nut oil had low O/L value of <1 (Table 4). The low O/L ratio in oyster nut oil observed in this study implies that oyster nut oil is susceptible to oxidation.

Atherogenic index (AI) of oyster nut oil ranged from 0.57 to 1.09 while thrombogenic index (TI) ranged from 1.31 to 2.27. Antherogenic index values <1 are desirable for cardiovascular health (Hernández-martínez et al., 2016). The AI for oyster nut oil was close to the recommended level however, the TI exceeded the desirable range of <1. This is attributed to almost balanced levels of SFA of 45.37 to 52.17% compared to the unsaturated FA range of 47.33 to 53.64% in the oil. The AI and TI observed for oyster nut oil were higher than those of bogue obtained from farmed fish reported by SˇimaT et al., (2015). The above indices varied from 0.53 to 0.61 and 0.29 to 0.35 for AI and TI, respectively for bogue. Thrombogenic index shows the tendency to form clots in the blood vessels (Ulbricht & Southgate, 1991). This result implies that despite its vegetable origin, oyster nut oil may have potential to increase cardio vascular risk. The hypocholesterolemic to hypercholesterolemic index (h/H) indicates the influence of fatty acids on cholesterol metabolism (Hashempour-Baltork et al., 2018). The h/H ranged from 0.06 to 1.57. There is no clear criterion for h/H and health however, Osmari et al. (2011) and Hashempour-Baltork et al. (2018), suggested that higher values are beneficial to human health.

3.6 Iodine Values of Oyster Nut Oil

The iodine values (IV) of oil from oyster nuts ranged from 82.76 to 87.59. The highest and lowest values were observed among nuts from Dokolo. The IV of oil from oyster nut is close to the 83.2 reported by (Hopkins & Chisholm, 1964) for oyster nut oil. On the contrary, (Nyagah, 2016) obtained a higher value of 109 for oyster nut oil. Although the IV of oyster nut oil was not included in the codex standard for oils, the value is close to that of safflower and high oleic sun flower which range from 80 to 100 and 78 to 90, respectively. This confirms earlier reports which describe oyster nut oil as a drying oil (Ajayi, Dulloo, Vodouhe, Berjak, & Kioko, 2004).

Table 4. Total fatty acids (%) and lipid health indices of oil from oyster nuts

Source	Gender	SFA	MUFA	PUFA	TUFA	IV	P/S	P/M	M/S	ω6/ω3	O/L	AI	TI	h/H
Dokolo	Male	52.17±1.50^a	6.23±0.30^a	41.10±0.98^a	47.33±1.18^a	82.76±1.58^a	0.79	6.6	0.12	-	0.15	1.09	2.19	0.06
Dokolo	Female	48.89±6.66^a	8.42±2.10^a	45.22±2.36^a	53.64±2.18^a	87.59±4.90^a	0.94	5.6	0.18	3,938.98	0.18	0.19	1.8	1.48
Kamuli	Male	49.17±2.71^a	7.26±1.29^a	43.25±3.99^a	50.51±2.71^a	83.28±6.98^a	0.88	6.17	0.15	-	0.16	1.01	2.01	1.57
Kamuli	Female	49.58±3.19^a	7.17±1.54^a	43.64±2.99^a	50.81±2.28^a	84.45±7.04^a	0.89	6.33	0.23	-	0.16	0.94	1.87	1.38
Luwero	Male	45.37±6.05^a	8.34±4.19^a	45.25±1.82^a	53.59±5.58^a	85.83±3.51^a	1.01	6.2	0.19	271.65	0.18	0.85	1.77	1.56
Luwero	Female	46.77±3.84^a	7.12±1.65^a	44.33±2.63^a	51.45±2.85^a	86.91±4.77^a	0.95	6.47	0.16	262.54	0.16	0.57	1.79	1.57

Values followed by the same letter within each row are not significantly different (p>0.05) nd: not detected; SFA: saturated fatty Acid; MUFA: Monounsaturated fatty acid; PUFA: Polyunsaturated fatty acid; TUFA: Total Unsaturated fatty acid; ω6/ω3: Omega-6 to Omega-3 ratio; O/L oleic to linoleic acid ratio; AI: Atherogenic index; TI: Thrombogenic index; h/H: Hypocholesterolemic to hypercholesterolemic index; IV: Iodine value.

4. Conclusion

Breeding may not affect major FA considering the similar levels of oleic acid, linoleic acid, palmitic and stearic acids. Oil from Serenut cultivars contained cis 11-eicosenoic acid (C20.1), cis 11, 14 eicosadienoic acid (C20.2) and cis 11, 14, 17 eicosatrienoic acid (C20.3ω3) but were not detected in that from traditional. This could imply

that breeding enhanced the levels of these fatty acids in improved cultivars. Lipid health indices indicated that oil from groundnut cultivars were favourable for health. Oyster nut oil was abundant in linoleic and palmitic acid. Consequently, the ratio of total saturated FA to unsaturated FA was 1:1. The lipid health indices showed that consumption of oyster nut oil has potential to increase cardiovascular risk; however, the effect of individual SFA needs to be further examined.

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