Turkish Journal of Agriculture - Food Science and Technology, 13(10): 2892-2900, 2025
DOI: https://doi.org/10.24925/turjaf.v13i10.2892-2900.7735

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Nutritional Quality of Landrace and Improved Sesame (*Sesamum indicum* L.) Seed Varieties Cultivated in Uganda

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ARTICLE INFO

Research Article

Received : 04.04.2025
Accepted : 11.07.2025

Keywords:
Sesame
Landraces
Improved varieties
Fatty acid
Nutritional composition

ABSTRACT

Sesame (*Sesamum indicum* L.) seeds have been bred to boost crop yield and resistance to diseases. The impact of breeding on the nutritional value of sesame seeds in Uganda is scanty. This study evaluated the chemical composition of the improved seeds and landraces. The proximate content of the seeds was determined using the Association of Official Analytical Chemist protocols. Mineral concentrations were analysed using atomic emission spectrophotometry. Fatty acid (FA) composition was determined using gas chromatography. The protein and total lipids were in the range of 6.90 to 10.41% and 37.47 to 50.45%, respectively. Ash content ranged from 3.45 to 4.05% while crude fibre ranged from 5.38 to 9.40%. Linoleic and oleic acids were the predominant unsaturated FA with respective range values of 43.92 to 46.89% and 37.91 to 41.50%. Palmitic and stearic acids were the most abundant saturated FA with values ranging from 7.92 to 9.61% and between 3.32 and 6.24%, respectively. The Atherogenic Index, Thrombogenic Index, Hypocholesterolemic FA to hypercholesterolemic FA ratio and polysaturated FA to saturated FA ratio showed favourable nutritional effects. Mineral ratios showed a favourable mineral-mineral interaction for sodium and potassium which is desirable for use as a functional food. Seed breeding may not have caused notable effect on the chemical composition of sesame seeds.

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Introduction

Sesamum indicum L. commonly known as sesame (simsim in the East African region) is a herbaceous plant that belongs to the Pedaliaceae family and is one of the ancient oil seed crops (Ünal and Yalçın 2008). Sesame is rich in oil, proteins, carbohydrates, essential minerals, and fiber (Myint, Gilani, Kawase, & Watanabe, 2020). The oil comprises 80% unsaturated fatty acids (UFA) mostly linoleic (C18:2ω6) and oleic (C18:1ω9) acids (Dissanayake, Ranwala, & Perera, 2017; Ahmed et al., 2020a). The seed is also rich in secondary metabolites such as lignans that include sesamin, sesamolin and sesaminol. Lignans are polyphenolic compounds that can be converted into bioactive substances in the human body, potentially offering health benefits like antioxidants, anti-inflammatory, anticancer by triggering apoptosis in cancer cells and neuroprotective effects (Namiki, 2007). Sesame also contains fat-soluble vitamins, especially vitamin E, which offer stability to the oil, and phytosterols with cholesterol-lowering effects (Abbas et al., 2022). Sesame protein is rich in essential amino acids such as leucine and phenylalanine (Wei et al., 2022). According to Jáuregui-Lobera (2014) and Hojyo & Fukada (2016), sesame is also rich in macro-minerals especially calcium (Ca) and phosphorus (P) and the trace minerals iron (Fe), and zinc (Zn).

Africa contributes about 44% of the world's sesame production (Mohammed & Hamidu, 2018). According to FAOSTAT, sesame seed production in Uganda reached 138,000 tonnes in 2021, and the country was ranked 14th largest producer in the world (FAOSTAT, 2022). Sesame production in Uganda is still quite low (Lukurugu et al., 2023). Sesame is mainly grown in the districts of northern Uganda, which lie at an altitude between 1000 and 2000 m above sea level (Elepu, 2014). White sesame which is the most widely traded type globally due to its high oil yield mild flavour, and versatility in baking is the main type of sesame grown (Agidew et al., 2021).

Sesame growers desire high-yielding, pest and disease-resistant, early maturing, and drought-tolerant varieties. This has led to the development of improved sesame varieties with the desired traits and properties through controlled breeding (Lukurugu et al., 2023). Studies on sesame around the world have concentrated on elucidating the seed for its chemical composition (Hassan, 2012; Ogbonna & Ukaan, 2013; Asghar & Majeed, 2013). However, there is little information on the nutrient composition of landraces and improved sesame seeds grown in Uganda. This information would help in formulation of health policies, agricultural strategies, trade competitiveness, and combating malnutrition. Uganda's leveraging this data can improve public health outcomes, farmer incomes, and global market positioning.

Materials and Methods

Experimental Design

Stratified sampling technique was used across the four districts of Amolatar (1°39′6″N, 32°49′30″E), Gulu (2°46'54.0"N 32°17'57.0"E), Kitgum (03°13′N 32°47′E) and Lira (2°14'50.0"N 32°54'00.0"E) in Northern Uganda. In each district, five sub-counties with high sesame production were identified and from each stratum, a farmer was randomly selected.

Sampling and Sample-Treatment

Fourteen sesame seed varieties were analyzed. Two varieties were the improved type and were obtained from the National Semi-Arid Resources Research Institute (NaSARRI) while twelve were landraces and were obtained from farmers in each of the four districts. One kilogramme of sesame seeds was obtained from each farmer. The chaff and foreign matter were removed from the seeds by sieving through a fine mesh (BSS12X12). The clean seeds were sealed in airtight glass containers and kept for analysis.

Determination of Proximate Composition

The proximate composition was determined using the Association of Official Analytical Chemists (AOAC) standard methods of analysis (AOAC, 2015). Moisture was determined gravimetrically according to AOAC (2015) method 925.40. Total lipid was determined following the protocol outlined in AOAC (2015) method 948.22 using petroleum ether as extraction solvent. Total fibre was determined using AOAC (2015) method 935.53. Protein was determined using AOAC (2015) method 950.48 by measuring the total nitrogen content and converting to protein value using a factor of 6.25. The ash content was determined using AOAC (2015) method 950.49, and the total carbohydrate was determined by difference using AOAC (2015) method 986.25.

Determination of Mineral Composition

Mineral concentrations were determined by atomic emission spectroscopy (AES) after acid digestion of the sample. The powdered sample (0.5g) was digested using a 3:1 v/v mixture of HNO_3 and $HClO_4$. The digest was cooled to room temperature and 5 ml of distilled water was added. The solution was gently shaken to dissolve and then filtered on a Whatman filter paper number 1001125. The filtrate was diluted to 50 ml with deionized water and 0.5 ml was aspirated into a MP-AES 4200 Micro Plasma AES equipment (Agilent technologies). The minerals sodium (Na), potassium (K), magnesium (Mg), chromium (Cr), manganese (Mn), copper (Cu), Ca, Zn, P and Fe, were determined at a wavelength of 588.995, 766.491, 285.213, 422.673, 213.857, 214.915, 259.940, 324.754, 425.433, and 257.610 nm, respectively. A 1.00 μgL^{-1} multi element calibration standard (VHG Labs, USA) was used to prepare working standards at ten concentrations between 5 and 160 mg/L. Linear calibration curve ($R^2 > 0.999$) were used to determine the concentration (mg/kg DW) of respective elements using standard calibration method by Skoog et al. (2013). From the metal concentrations, the mineral ratios; Na:K, Na:Mg, Ca:K, Ca:P, Ca:Mg, Ca:[Ca+Mg], Fe:Cu, Fe:Zn, and Zn:Cu were computed to assess the nature of the interaction between the different elements.

Fatty acid Profiling

Fatty acids were determined as the fatty acid methyl esters (FAME), which were prepared according to International Organization for Standardization (ISO) method ISO 5509:2007 (Standard & Warsaw, 2013). Profiling was done on an Agilent 8890 GC chromatograph system (Agilent Technologies Inc., USA) equipped with flame ionisation detection (GC-FID). The GC conditions were as follows; injector temperature was 240°C, injection volume of 2μL; split ratio 50:1; column-oven temperature was programmed to remain at 240°C for a holding time of 2.61 min. and increased to 260 at a rate of 10°C/min. Nitrogen and hydrogen were used as carrier gas at an internal pressure of 4.95 psi.: detection temperature was 260°C. The FA compositions were expressed as the relative percentage of the FA calculated by internal normalisation of the chromatographic peak area. Fatty acid identification was performed by comparing the relative retention times of the FAME peaks of the samples with those of FAME standards (Sigma-Aldrich, USA).

Assessment of The Nutritional Quality of Sesame Seeds Based on Fatty Acid Composition

The nutritional quality of sesame seeds was assessed using the ratios P/S, ω6/ ω3, h/H ratios, and the FA indices of atherogenicity (AI) and thrombogenicity (TI). The P/S was determined as the ratio of the sum of polyunsaturated fatty acids (∑PUFA) to the sum of saturated fatty acids (∑SFA), ω6/ω3 as the ratio of the sum of omega (ω) 6 (∑ω6 FA) to the sum of omega 3 (∑ω3 FA). The h/H, AI and TI indices were calculated using equations (1), (2) and (3), respectively (Ulbricht & Southgate, 1991)

$$h/H = \sum \begin{pmatrix} \text{C16:1}\omega 7, \\ \text{C18:1}\omega 9, \\ \text{C18:2}\omega 6, \\ \text{C18:3}\omega 6, \\ \text{C18:3}\omega 3, \\ \text{C20:3}\omega 6, \\ \text{C20:4}\omega 6, \\ \text{C20:5}\omega 3 \end{pmatrix} / \sum(\text{C14:0 and C16:0}) \quad (1)$$

$$\text{AI} = \frac{(\text{Cl2:0} + (4 \times \text{l4:0}) + \text{C16:0})}{(\omega\text{-6 PUFA} + \omega\text{-3 PUFA} + \text{MUFA})} \quad (2)$$

$$\text{TI} = \frac{(\text{C14:0+C16:0+C18:0})}{\left[\begin{array}{c}(0.5\times\text{MUFA}) + \\ (0.5\times\omega\text{-6 PUFA}) + \\ (3\times\omega\text{-3 PUFA}) + \left(\frac{\omega\text{-3PUFA}}{\omega\text{-6 PUFA}}\right)\end{array}\right]} \quad (3)$$

Statistical Analysis

Data obtained were expressed as the mean of three replicates plus or minus the standard deviation (SD). Analysis of variance (ANOVA) was used to compare means values. Statistical analysis was performed with RStudio (Posit, 250 Northern Ave, Boston, MA 02210, USA). The values were considered significantly different at $p < 0.05$.

Results and Discussion

Proximate Composition

Moisture content of sesame seeds ranged from 2.77 to 5.00% (Table 1). The values were lower than the maximum limit of 7% set by the Codex Alimentarius Commission (CODEX Stan 210, 1999). A moisture content below 7% would prevent mould growth, which affects the quality, safety, and shelf life of sesame seeds (Alemayehu et al., 2023). The lipids, fibre and ash content ranged from of 37.49 to 53.70%, 5.38 to 9.40%, and 3.45 to 4.05%, respectively. There were no statistical differences (p<0.05) in the values across all the varieties. Improvement may not affect the oil yield, ash and crude fibre of sesame seed. Ahmed et al. (2020); Ujong and Emelike (2023) and Kassaw et al. (2023a) reported similar values of lipids, fibre and ash in sesame seeds (Table 2). Protein amounts ranged from 6.90 to 10.41%. Similarly, there were no differences (p<0.05) in the protein content between the seeds of landraces and the improved sesame varieties. The observed protein content was lower than reported values by Wada *et al.* (2021); Abbas (2022); Kassaw *et al.* (2023) and Ahmed et al. (2020) but higher than that reported by Irshad et al. (2023). Carbohydrate content ranged from 20.58 to 40.35%. The carbohydrate amounts were within the values reported by Kassaw et al. (2023) for sesame. On the whole, there were no meaningful differences in the amounts of proximate components between landraces and improved sesame seeds.

Minerals Composition

Major minerals

Sesame seed had Sodium concentrations in the range of 7.14 to 7.90 mg/100 g (Table 3). Landrace` *Latino* had a higher (p<0.05) Na content than the improved varieties and the rest of the landraces. The composition of K varied from 22.29 to 39.60 mg/100 g with Arutarut having the highest and Latino with the lowest values. Potassium content was lower than reported in sesame seeds (Table 4). Sodium and K amounts were too low in the sesame seeds. Phosphorous concentration (52.05 to 64.75 mg/100 g) did not differ between landraces and improved varieties. Sesame is not a good source of P. The Mg content ranged from 52.58 to 58.75 mg/100 g with no differences (p>0.05) between landrace and improved sesame seeds. The amounts of Mg were above the values of 28.23 to 47.54 mg/100 g reported by Irshad et al. (2023).

Table 1. Proximate composition (%) of sesame landraces and improved varieties grown in Uganda.

Sesame type	Moisture	Total Lipids	Protein	Ash	Crude Fibre	Carbohydrates
Nino arema	4.89±0.26[a]	37.49±1.37[b]	8.47±0.50[abc]	3.43±0.23[a]	5.38±0.07[a]	40.35±2.03[a]
Oganik	2.93±0.07[b]	52.38±1.65[a]	9.25±0.24[ab]	3.47±0.06[a]	8.01±0.96[a]	23.96±1.13[b]
Otara	2.93±0.32[b]	50.45±2.14[a]	9.21±1.44[ab]	3.36±0.25[a]	7.44±0.25[a]	26.62±2.62[b]
Oturu tatar	3.34±0.42[ab]	52.36±3.53[a]	8.97±0.69[abc]	3.55±0.41[a]	9.40±0.82[a]	22.39±3.34[b]
Layee	3.22±0.12[b]	52.70±2.34[a]	10.41±0.17[a]	3.77±0.21[a]	8.54±1.28[a]	21.35±3.03[b]
Gure	2.77±0.19[b]	53.70±1.60[a]	8.79±1.78[abc]	3.54±0.18[a]	7.54±1.20[a]	23.66±1.55[b]
Latino	3.57±0.42[ab]	51.54±5.06[a]	7.76±0.39[bc]	3.80±0.29[a]	5.75±3.69[a]	27.59±3.99[b]
Ladoncoo	5.00±0.97[a]	50.35±2.92[a]	8.80±0.64[abc]	4.05±0.29[a]	5.81±1.68[a]	25.99±3.03[b]
Arutarut	4.22±0.56[ab]	52.33±0.78[a]	9.30±0.23[ab]	3.58±0.64[a]	8.36±0.57[a]	22.20±1.21[b]
Ajimo	3.69±0.55[ab]	49.05±2.97[a]	8.95±0.60[abc]	3.65±0.47[a]	7.31±0.69[a]	27.37±3.42[b]
Ayerayer	3.91±0.29[ab]	54.65±0.95[a]	8.34±0.17[abc]	3.61±0.16[a]	8.90±0.56[a]	20.58±1.69[b]
Adongo	3.53±0.98[ab]	52.28±2.07[a]	8.40±0.47[abc]	3.65±0.39[a]	7.59±0.75[a]	24.55±1.92[b]
Sesim 2	3.98±1.00[ab]	52.15±1.09[a]	8.00±0.61[bc]	3.47±0.15[a]	8.65±1.31[a]	23.74±2.20[b]
Sesim 3	4.91±0.72[a]	49.82±2.26[a]	6.90±0.47[c]	3.45±0.26[a]	6.73±1.89[a]	28.18±0.47[b]

Means with different superscript within the same column are significantly different (p<0.05). Landraces: Nino arema, Oganik, Otara, Oturu tatar, Layee, Gure, Latino, Ladoncoo, Arutarut, Ajimo, Ayerayer, and Adongo. Improved Varieties: Sesim 2 and Sesim 3.

Table 2. Proximate composition (%) of sesame seeds compared with data from other studies

	Moisture	Total lipids	Protein	Ash	Crude fibre	Carbohydrates
1	2.77-5.00	37.49-53.70	6.90-10.41	3.36-4.05	5.38-8.90	20.58-40.35
2	5.48	39.08	19.31	6.20	11.82	18.11
3	4.53	41.20	22.41	4.27	3.42	__
4	6.40	44.00	17.10	6.50	4.60	21.60
5	3.25-3.68	44.70-48.40	11.90-13.90	3.08-4.60	4.05-4.80	26.00-30.70
6	1.1	58.3	6.37	4.55	7.59	22.05
7	4.70	51.9	19.8	5.2	3.1	15.3
8	4.15	40.82	2.81	3.89	3.76	22.97
9	4.75	49.40	20.13	4.85	5.60	15.28
10	5.00	52.60	22.50	4.10	2.00	8.20

Source: 1. This study; 2. (Wada et al., (2021); 3. Abbas (2022); 4. (Bamigboye & Adepoju, 2010); 5. Kassaw *et al.* (2023); 6. Nweke et al., 2014: 7. Namiki Mitsuo (2013); 8. Irshad et al (2023); 9. (Ujong & Emelike, 2023); 10. (Sá et al., 2022).

Table 3. Mineral composition (mg/100g) of sesame seeds compared with the RDI (mg/day)

Varieties	Na	K	Mg	Ca	P
1	7.46 ± 0.05^{def}	35.1.7 ± 0.12^{d}	53.51 ± 5.34^{a}	42.79 ± 0.25^{b}	60.28 ± 2.51^{ab}
2	7.44 ± 0.09^{def}	31.44 ± 0.18^{f}	52.58 ± 1.69^{a}	42.76 ± 0.17b	64.75 ± 3.39^{a}
3	7.88 ± 0.09^{ab}	31.38 ± 0.08^{f}	58.23 ± 0.89^{a}	42.74 ± 0.09b	60.43 ± 4.56^{ab}
4	7.35 ± 0.10^{efg}	36.69 ± 0.17^{bc}	57.28 ± 1.21^{a}	42.85 ± 0.13b	57.68 ± 4.63^{ab}
5	7.14 ± 0.13^{g}	33.54 ± 0.14^{e}	53.44 ± 1.31^{a}	42.58 ±0. 29b	54.96 ± 2.10^{b}
6	7.36 ± 0.06^{efg}	23.71 ±0.16^{g}	54.05±1.43^{a}	42.71±0.27b	58.05±3.70^{ab}
7	7.90 ± 0.08^{a}	22.29 ±1.23^{h}	52.63±3.25^{a}	42.69 ±0.30b	59.63 ± 4.27^{ab}
8	7.64 ±0.12^{abcd}	37.02 ±0.05^{b}	57.91 ±0.51^{a}	42.51 ±0.34b	55.71±2.60^{b}
9	7.24 ±0.13^{fg}	39.60 ±0.13^{a}	58.75 ±0.61^{a}	43.90 ±1.07b	52.05 ±0.90^{b}
10	7.60 ±0.07^{cde}	33.78 ±0.38^{e}	52.85 ±1.06^{a}	42.46 ±0.55b	53.40 ±1.17^{b}
11	7.85±0.08^{abc}	38.58±0.04^{a}	53.63±0.17^{a}	43.85±0.10b	54.66±0.11^{b}
12	7.57 ± 0.12^{de}	35.42 ±0.93^{cd}	54.63 ±3.56^{a}	43.53 ±3.70^{b}	52.59 ±1.07^{b}
13	7.52 ±0.07^{de}	36. 45± 0.77^{bcd}	53.76 ±3.74^{a}	47.21 ±2.14^{a}	55.96 ±1.50^{b}
14	7.62 ±0.15b^{cde}	36.66 ±0.99^{bc}	55.67 ±4.27^{a}	44.31 ±1.54^{ab}	53.47 ±4.20^{b}
RDI	2400	4000	320 - 420	1000 - 1200	1000 - 1200
UI(mg)			350	1500	3500
%RDI	0.31	0.84	17.16-13.08	4.34-3.61	5.57-4.72
Varieties	**Zn**	**Fe**	**Cu**	**Mn**	**Cr**
1	1.47 ± 0.37^{a}	0.85 ± 0.04^{a}	0.35 ± 0.04^{a}	0.14 ± 0.006^{b}	0.01 ± 0.003^{b}
2	1.09 ± 0.16^{a}	0.86 ± 0.02^{a}	0.37 ± 0.01^{a}	0.13 ± 0.022^{b}	0.009 ± 0.003^{b}
3	1.43 ± 0.47^{a}	0.85 ± 0.02^{a}	0.33 ± 0.01^{a}	0.17 ± 0.004^{ab}	0.010 ± 0.006^{b}
4	1.14 ± 0.09^{a}	0.84 ± 0.01^{a}	0.36 ± 0.03^{a}	0.16 ± 0.030^{ab}	0.011 ± 0.003^{b}
5	1.78 ± 0.46^{a}	0.86 ± 0.04^{a}	0.37 ± 0.03^{a}	0.22 ± 0.055^{a}	0.006 ± 0.003^{b}
6	1.31 ± 0.16^{a}	0.85 ±0.04^{a}	0.35 ± 0.04^{a}	0.16 ± 0.013^{ab}	0.008 ± 0.003^{b}
7	1.27 ±0.04^{a}	0.85 ± 0.04^{a}	0.34 ± 0.04^{a}	0.18 ± 0.021^{ab}	0.008 ± 0.002^{b}
8	1.20 ± 0.06^{a}	0.86 ±0.01^{a}	0.31 ±0.01^{a}	0.15 ±0.004^{ab}	0.016 ±0.011^{ab}
9	1.28 ±0.05^{a}	0.82 ±0.02^{a}	0.35 ±0.05^{a}	0.18 ±0.018^{ab}	0.008 ±0.002^{b}
10	1.20 ±0.10^{a}	0.86 ±0.05^{a}	0.34 ±0.03^{a}	0.17 ±0.036^{ab}	0.006 ±0.001^{b}
11	1.10±0.04^{a}	0.75±0.01^{b}	0.38±0.06^{a}	0.13 ±0.002^{b}	0.007±0.0 1^{b}
12	1.42 ±0.34^{a}	0.88 ±0.03^{a}	0.34 ±0.04^{a}	0.15 ±0.013^{ab}	0.043 ±0.031^{a}
13	1.58 ±0.42^{a}	0.84 ±0.03^{a}	0.31 ±0.02	0.17 ±0.025^{ab}	0.030 ±0.031ab
14	1.63 ±0.29^{a}	0.87 ±0.02^{a}	0.32 ±0.02^{a}	0.13 ±0.014^{b}	0.047 ±0.018^{a}
RDI	8 -11	8 - 18	0.9	1.8 -2.3	0.025 – 0.035
UI(mg)	40-50	45	10	11	1
%RDI	16.85-12.26	10.56-7.88	38.37	8.94 – 7.00	64.00 – 45.71

Means with different superscript within a column are significantly different ($p<0.05$). 1: Nino arema, 2: Oganik, 3: Otara, 4: Oturu tatar, 5: Layee, 6: Gure, 7: Latino, 8: Ladoncoo, 9: Arutarut, 10: Ajimo, 11: Ayerayer, 12: Adongo. 13: Sesim 2: 14: Sesim 3.

Table 4. Mineral composition (mg/100g) of sesame seeds compared with data from other studies.

	1	2	3	4	5
Na	7.14-7.90	2.31	32.4	41.8-84	-
K	22.29-39.60	468	1263	308-344	-
Mg	52.58-58.75	324	340	214-217	52.5
Ca	42.46-47.21	962	947	326-352	45.3
P	52.05-64.75	605	59.4	342-641	-
Zn	1.09-1.78	5.74	7.56	8.2-9.74	1.46
Fe	0.75-0.88	14.6	14.1	12.3-13.1	3.78
Cu	0.31-0.38	1.5	3.9	4.9-5.02	0.73
Mn	0.13-0.22	1.24	2.37	-	0.23
Cr	0.006-0.047	-	-	-	-
	6	**7**	**8**	**9**	**10**
Na	76.3	7.64	2.00	0.80-1.11	121.43
K	549.91	385	400	630-741	157.97
Mg	-	212	-	445-466	118.13
Ca	1146.25	421	1200	985-2017	166.70
P	-	445	540	626-663	254.54
Zn	5.62	2.27	-	8.18-11.01	12.87
Fe	9.45	6.19	9.60	9.83-11.20	-
Cu	-	0.98	-	1.96-2.23	124.13
Mn	-	1.57	-	4.90-5.69	112.14
Cr	-	-		-	3.32

Source: 1. This study; 2. Tanwar & Goyal, (2020); 3. Kassaw et al. (2023); 4. Beshaw et al. (2022); 5. Seid & Mehari, (2022); 6. Abbas et al. (2022); 7. Hahm *et al* (2009); 8. (Namiki, 1995); 9 Tenyang et al. (2017); 10. Karaye et al. (2022).

A serving of 100 g of sesame seed would meet the RDI for Mg. The amount of Ca varied between landraces and improved varieties. Sesim 2 had a higher ($p<0.05$) Ca content than landraces and Sesim 3. There was no difference ($p>0.05$) in the amounts of Ca among landraces. The Ca content of the sesame seeds was within the values reported by (Seid & Mehari, 2022) (Table 4) but lower than that reported by Tanwar and Goyal (2021); Beshaw et al. (2022) and Kassaw et al. (2023). The low amount of Ca in sesame in this study could be attributed to environmental conditions especially water stress due to drought which is a common occurrence in Northern Uganda (Ozkan & Kulak, 2013).

Trace minerals

The concentrations of trace minerals ranged from 1.09 to 1.78, 0.75 to 0.88, 0.31 to 0.38, 0.13 to 0.22 and 0.006 to 0.047 mg/100 g for Zn, Fe, Cu, Mn and Cr, respectively. There were no differences ($p>0.05$) in the concentrations of Zn, Fe and Cu between landraces and improved seeds. The Zn content observed in the seeds of this study was higher than 4.46 mg/100 g and 7.56 mg/100 g reported by Bamigboye et al. (2010) and Kassaw et al. (2023), respectively. The amounts of Cu and Fe were below values reported for by Kassaw et al. (2023). Therefore, this study showed that sesame is a good source of Zn and Fe and rich sources of Cu and Cr based on classification by Codex Alimentarius Commission, (1991).

Mineral ratios

Mineral to mineral interactions is more crucial than individual mineral levels. This is because they determine nutritional interactions that may affect the development and progression of certain conditions such as diseases, psychological and developmental factors (Watts, 2010; Soetan et al., 2010). The Na/K ratio ranged from 0.18 to 0.35 (Table 5). The recommended value of Na/K for a healthy diet is <1. This implies that sesame seeds were within range. A Na/K ratio below 1 is associated with reduced blood pressure and the risk of stroke (Jacob et al., 2015). The Na/K ratio observed in this study suggests that sesame seeds may be used as a functional food in the prevention of hypertension. The Na/Mg ratio (0.12 to 0.15) were below 1. Na/Mg ratio < 1.0 is considered optimal for cardiovascular health (Vulin et al., 2022). These findings show that the consumption of sesame seeds may promote cardiovascular health.

The Ca/K ratio ranged from 1.1 to 1.92. The optimum Ca/K ratio for good health ranges from 1:2 to 1:5. A low Ca/K ratio may lead to muscle weakness and fatigue, and the disruption of heart rhythm. A Ca/K ratio < 4 plays a crucial role in controlling thyroid activity (Olagbemide et al., 2016). The Ca/P ratio ranged from 0.66 for Oganik to 0.84 for Arutarut and Sesim 2. A Ca/P ratio of 1 has been recommended as most desirable for optimal health (Kemi et al., 2010). The Ca/P ratio above the recommended value of 1 in the diet may favour Ca absorption in the intestine which is crucial for bone formation and mineralization (Adeyeye et al., 2012). The Ca/Mg ratio ranged from 0.73 to 0.82 for landraces and 0.80 to 0.88 for improved varieties. A Ca/Mg ratio of 1.7 has been recommended for optimal health. The Ca/P and Ca/Mg ratios in sesame were below recommendations

The Fe/Cu ratio was lowest for Ayerayer and highest for Ladoncoo. Values were above the recommendations. Maintaining a balanced Fe/Cu ratio in the diet is important for optimal health because very high ratios have been linked to oxidative stress, cardiovascular and cancer risks. Lower Fe/Cu ratios have been implicated in neurological and immune dysfunction (Gaetke & Chow, 2003). The Fe/Zn ratio ranged from 0.48 to 0.8. A Fe/Zn ratio of 2.5 to 4 has been suggested to be beneficial for immune function and antioxidant balance. Fe/Zn ratio less than 1 as observed in this study may result in Fe deficiency, anemia, and impaired cognitive function (Knez & Stangoulis, 2023).

The Zn/Cu ratio was in the range of 2.90 to 5.07. These values were below recommendations. Improved varieties had higher Zn/Cu ratio than landraces. The optimum dietary Zn/Cu ratio for proper immune function and antioxidant activity balance ranges from 8 to 12. A Zn/Cu ratio < 6 shows Cu imbalance that may result in zinc deficiency, and subsequently impaired immune function and increased oxidative stress (Chebieb et al., 2024).

Table 5. Mineral ratios of sesame landraces and varieties grown in Uganda.

Varieties	Na/K	Na/Mg	Ca/K	Ca/P	Ca/Mg	Ca/[Ca+Mg]	Fe/Cu	Fe/Zn	Zn/Cu
Nino arema	0.21	0.14	1.22	0.71	0.80	0.44	2.43	0.58	4.21
Oganik	0.24	0.14	1.36	0.66	0.81	0.45	2.31	0.80	2.90
Otara	0.25	0.14	1.36	0.71	0.73	0.42	2.62	0.60	4.37
Oturu tatar	0.20	0.13	1.17	0.74	0.75	0.43	2.33	0.74	3.16
Layee	0.21	0.13	1.27	0.77	0.80	0.44	2.30	0.48	4.76
Gure	0.31	0.14	1.80	0.74	0.79	0.44	2.43	0.64	3.78
Latino	0.35	0.15	1.92	0.72	0.81	0.45	2.50	0.67	3.73
Ladoncoo	0.21	0.13	1.15	0.76	0.73	0.42	2.78	0.72	3.88
Arutarut	0.18	0.12	1.11	0.84	0.75	0.43	2.32	0.65	3.60
Ajimo	0.22	0.14	1.26	0.80	0.80	0.45	2.50	0.72	3.49
Ayerayer	0.20	0.15	1.14	0.80	0.82	0.45	1.98	0.68	2.90
Adongo	0.21	0.14	1.23	0.83	0.80	0.44	2.55	0.62	4.12
Sesim 2	0.21	0.14	1.30	0.84	0.88	0.47	2.69	0.53	5.02
Sesim 3	0.21	0.14	1.21	0.83	0.80	0.44	2.70	0.53	5.07
Recommended	<1[a]	<1	<4	1[b]	1.7-2.6[cd]	2.2	1[e]	2.5[f], 4[g]	<16[h]

a: Mirmiran et al. (2021); b: Kemi et al. (2010); c: DeLuccia et al. (2019); d: Costello, Rosanoff, Dai, Saldanha, & Potischman (2021); e: Arredondo, Martnez, Nez, Ruz, & Olivares (2006); f: Sandström, Davidsson, Cederblad, & Lönnerdal, (1985); g: Godoy, Rebelatto, Borin-Nogueira, & Lima-Pallone (2014); h: Ma & Betts (2000). Landraces: Nino arema, Oganik, Otara, Oturu tatar, Layee, Gure, Latino, Ladoncoo, Arutarut, Ajimo, Ayerayer and Adongo. Improved Varieties: Sesim 2 and Sesim 3.

Table 6. Fatty acid composition (%) of landrace and improved sesame seeds.

Fatty acid	1	2	3	4	5	6	7
C10:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C12:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C14:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C16:0	8.38	7.97	8.10	8.12	8.39	8.48	8.43
C18:0	5.63	5.56	5.73	5.66	5.40	5.46	5.47
C22:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C24:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
SFA TOTAL	14.01	13.53	13.83	13.78	13.79	13.94	13.9
C16:1ω7	0.13	0.10	0.11	0.10	0.11	0.12	0.12
C18:1ω9	38.91	40.62	39.29	39.35	40.19	38.53	38.5
C20:1ω9	0.16	0.19	0.21	0.20	0.20	0.19	0.18
MUFA TOTAL	39.2	40.91	39.61	39.65	40.5	38.84	38.8
C18:2ω6	45.36	44.32	45.2	45.3	44.26	45.88	46.07
GLA; C18:3ω6	0.40	0.38	0.40	0.38	0.38	0.38	0.41
ALA; C18:3ω3)	0.63	0.57	0.62	0.61	0.64	0.59	0.62
C20:4ω6)	0.15	0.13	0.13	0.13	0.15	0.13	<0.05
EPA; C20:5ω3)	0.09	0.09	0.09	0.09	0.11	0.10	<0.05
PUFA TOTAL	46.63	45.49	46.44	46.51	45.54	47.08	47.1
Fatty acid	8	9	10	11	12	13	14
C10:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C12:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C14:0	<0.05	0.14	<0.05	<0.05	<0.05	<0.05	<0.05
C16:0	9.44	9.61	7.92	8.00	8.12	8.73	8.73
C18:0	3.32	6.24	5.58	5.87	5.84	4.20	3.81
C22:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C24:0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
SFA TOTAL	12.76	15.85	13.5	13.87	13.96	12.93	12.54
C16:1ω7	0.08	0.14	0.10	0.09	0.10	0.10	0.13
C18:1ω9	39.01	37.91	39.61	39.08	39.61	41.5	40.06
C20:1ω9	<0.05	0.18	0.14	0.20	0.19	<0.05	<0.05
MUFA TOTAL	39.09	38.23	39.85	39.37	39.9	41.6	40.19
C18:2ω6	46.89	43.92	44.86	45.4	44.34	44.04	44.92
GLA; C18:3ω6	0.29	0.39	0.40	0.44	0.38	0.23	0.28
ALA; C18:3ω3)	0.21	0.62	0.62	0.64	0.61	0.22	0.25
C20:4ω6)	<0.05	0.15	0.130	0.14	0.14	<0.05	<0.05
EPA; C20:5ω3)	<0.05	0.11	0.09	0.10	0.08	<0.05	<0.05
PUFA TOTAL	47.39	45.19	46.1	46.72	45.55	44.49	45.45

Key:<0.05% means "below the detection limit" for the parameter and was not included in the summation. Landraces: 1: Nino arema, 2: Oganik, 3: Otara, 4: Oturu tatar, 5: Layee, 6: Gure, 7: Latino, 8: Ladoncoo, 9: Arutarut, 10: Ajimo, 11: Ayerayer, 12: Adongo, 13: Sesim 2 and 14: Sesim 3

Fatty Acid Composition

Total saturated fatty acid (SFA) composition ranged from 12.54 to 15.85%. Palmitic acid (C16:0) and stearic acid (C18:0) were the predominant SFA. The amounts of C16:0 ranged from 7.92 to 9.61% while that of C18:0 varied from 3.32 to 6.24%. Ahmed et al. (2020) reported C16:0 content of sesame in the range of 7.93 to 9.55%, similar to the findings of this study. Capric acid (C10:0), lauric acid (C12:0), behenic acid (C22:0) and lignoceric acid (C24:0) were below the detection limits. Landraces and improved sesame did not present any differences in the amounts of SFA. The SFA especially C12:0, myristic acid (C14:0) and C16:0 have been shown to increase the LDL cholesterol levels and promote prothrombogenic tendencies (Zhao et al., 2024).

Monounsaturated fatty acid (MUFA) levels ranged from 38.23 to 41.6% (Table 6). Oleic acid (OA; C18:1ω9) was the dominant MUFA. The amount of oleic acid ranged from 37.91 to 41.5%. Asghar & Majeed (2013) reported that C18:1ω9 to be the main MUFA in sesame oil. Oleic acid reduces total cholesterol and LDL cholesterol thereby lowering the risk of heart disease (Arsic et al., 2019). Patients with Alzheimer's disease have been reported to have low OA levels in the brain implying that OA may also have neuroprotective effects (Santa Mara et al., 2023). In addition, OA can improve insulin sensitivity and help regulate blood sugar levels (López-Gómez et al., 2020).

The content of polyunsaturated fatty acids (PUFA) varied between 44.49 and 47.39%. Variations in PUFA amounts between landraces and improved varieties did not show differences. Linoleic acid (C18:2ω6) was the main PUFA in sesame oil ranging from 43.92 to 46.89%. The α-linolenic acid (ALA; 18:3ω3), γ-linolenic acid (GLA; 18:3ω6), arachidonic acid (AA; 20:4ω6) and eicosapentaenoic acid (EPA; C20:5ω3) were present in low amounts (< 2%).

Fatty Acid Ratios and Indices

The P/S ratio ranged from 2.85 to 3.62 and the values showed that sesame oils have a good balance of fatty acids (Table 7). The P/S. A P/S ratio ≥0.45 is considered optimal for a healthy diet (Kang et al., 2005). High P/S ratios have been shown to lower the levels of low-density lipoprotein (LDL) cholesterol in the body and thus reduce the risk of cardiovascular disease.

Table 7. Nutritional quality of sesame seed based on fatty acid composition (ratios and indices).

Varieties	P/S	ω-6/ω-3	AI	TI	h/H
Nino arema	3.33	63.76	0.10	0.56	5.56
Oganik	3.36	67.92	0.09	0.55	5.71
Otara	3.36	64.41	0.09	0.55	5.73
Oturu tatar	3.38	65.44	0.09	0.55	5.73
Layee	3.30	59.72	0.10	0.56	5.43
Gure	3.38	67.23	0.10	0.55	5.55
Latino	3.39	74.97	0.10	0.55	5.59
Ladoncoo	3.71	224.67	0.11	0.53	5.02
Arutarut	2.85	60.90	0.12	0.65	10.17
Ajimo	3.41	63.93	0.09	0.54	5.82
Ayerayer	3.37	62.14	0.09	0.55	5.84
Adongo	3.26	65.01	0.10	0.57	5.61
Sesim 2	3.44	201.23	0.10	0.57	5.10
Sesim 3	3.62	180.8	0.10	0.54	5.21
Recommended	≥ 0.45	5:1-10:1	<0.5	<0.5	>2.0

Key: Landraces: Nino arema, Oganik, Otara, Oturu tatar, Layee, Gure, Latino, Ladoncoo, Arutarut, Ajimo, Ayerayer and Adongo. Improved Varieties: Sesim 2 and Sesim 3. AI: Atherogenic Index, TI: Thrombogenic Index, h/H: ratio of hypocholesterolemic FA to hypercholesterolemic FA, and P/S: ratio of polyunsaturated FA to saturated FA.

In addition, PUFA have anti-inflammatory effects meaning that the consumption of sesame seeds may be beneficial in reducing inflammation responses in the body (Balić et al., 2020).

The ω6/ω3 PUFA ratio varied from 59.72 to 224.67. The World Health Organization recommends a ω6/ω3 FA ratio of 5:1 to 10:1 for a healthy diet (WHO, 1995). This means that the balance between ω6 and ω3 PUFA in sesame was far from optimal. High ω6/ω3 ratios in the diet have been shown to promote the pathogenesis of cardiovascular diseases, cancer, inflammation and autoimmune diseases whereas low ratios suppress the proliferation of these diseases (Simopoulos, 2002). Unbalanced ω6/ω3 ratios in favour of ω6 PUFA are highly prothrombotic and proinflammatory, hence contributing to the prevalence of atherosclerosis, obesity and diabetes (Gómez Candela et al., 2011).

The (AI) was lowest (0.09) in Oganik, Otara, Oturu tatar, Ajimo and Ayerayer, and highest (0.12) in Arutarut. Atherogenic index is an indicator of the risk of atherosclerosis and heart disease. The consumption of oils or foods with low AI can reduce total cholesterol and LDL-C in human plasma (Chen & Liu, 2020a). An AI of <0.5 is considered optimal for healthy oils (Khalili Tilami & Kouřimská, 2022). Sesame oils were found to be generally favourable on basis of low AI values.

Lauric acid, C14:0 and C16:0 are considered to be prothrombogenic due to their tendency to form blood clots. The MUFA and the ω6 and ω3 PUFA families have antithrombogenic properties (Reis Lima et al., 2020; Dal Bosco et al., 2024). The thrombogenic index (TI) ranged from 0.54 to 0.57. Sesame seeds had TI indices higher than 0.5 which is recommended for good health. Based on the observed low values of TI, sesame oil would not promote prothrombogenic tendencies.

The h/H ratio ranged from 5.02 to 10.17. The h/H ratio of edible oils refers to the relationship between the hypocholesterolemic C18:1ω9 and PUFA and the hypercholesterolemic C14:0 and C16:0. The ratio considers the impact of FA on cholesterol metabolism and the higher the value of h/H, the more nutritionally balanced the food (Chen & Liu, 2020b). The recommended value of h/H for a nutritionally favoured food is greater than 2 and the higher the value above the better (Kostik et al., 2013). The h/H ratios observed for the sesame seeds mean that consumption of sesame may not promote cholesterol accumulation in the blood.

Conclusion

Seed breeding may not be seen to affect the nutritional components of sesame seeds. Sesame seeds are high in minerals especially phosphorous, magnesium, and calcium. Sesame is a good source of zinc and iron and rich sources of copper and chromium. Therefore, sesame can be blended with other foods to enhance the mineral contents of such a food. High values of monounsaturated fatty acid and polyunsaturated fatty acid coupled with low values of saturated fatty acid suggest that sesame oil may be beneficial for cardiovascular health. The ratios of polyunsaturated to saturated fatty acids and hypocholesterolemic FA to hypercholesterolemic FA values showed that consumption of sesame seeds may reduce cholesterol and inflammation in the body. However, the high ω-6/ω-3 ratio implied that sesame seeds must be blended with other seeds rich in ω-3 FA to improve the nutritional value.

Declarations

Ethical Approval Certificate

This research did not involved human or animal studies therefore, no ethical approval was required

Author Contribution Statement

Denis Ocen: Data collection, investigation, formal analysis, and writing the original draft.

Patrick Ogwok: Supervision, conceptualization, review and editing

Michael Bamuwamye: Supervision, conceptualization, review and editing

Fund Statement

This work was funded by Kyambogo University.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

This work was funded by Kyambogo University. We are grateful to Dr. Walter Okello Onyanga of National Semi-Arid Resources Research Institute (NaSARRI), Mr. Chris Okwang and Mr. Fred Doi for the supply of sesame seeds. We also acknowledge the technical support of Mr. Yusuf Mukasa of National Agricultural Research Organisation (NARO) Kawanda and staff of Uganda National Bureau of standards (UNBS) for the technical support

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