Food Agricultural Sciences and Technology (FAST)
Food Agricultural Sciences and Technology, 2025; *11*(3)

Research Article

Fatty acid composition of lipids from Ugandan green coffee beans

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Abstract - The study assessed the lipid content of green *Coffea arabica* and *Coffea canephora* var. *robusta* beans, the fatty acid (FA) composition of the lipids, and their nutritional quality to provide a basis for utilization. The green coffee beans (GCB) were obtained from the Uganda Coffee Development Authority (UCDA) and coffee dealers. Lipid was extracted in a Soxhlet apparatus using n-hexane. Fatty acids were determined as the FA methyl esters using gas chromatography with flame ionization detector (GC-FID). Differences in lipid content were analyzed using one-way analysis of variance (ANOVA). The polyunsaturated FA; PUFA/saturated fatty acid; SFA (PUFA/SFA), palmitic acid; PA/PUFA, and ω6:ω3 ratios were used to evaluate the nutritional quality of the GCB lipids. Lipid content ranged between 1.75 and 15.45%. Higher lipid content was obtained for *C. arabica* than for *C. canephora*. Unsaturated FA (UFA) predominated over SFA. Linoleic acid (LA; 18:2ω6) and oleic acid (OA; 18:1ω9) were the main UFA and accounted for 50 to 60% of the total FA. Palmitic acid (16:0) was the major SFA. The PUFA/SFA ratio was within the desired range. Fifty-eight percent of the samples had PA/PUFA ratio < 1. The ω6/ω3 ratio was higher than the recommendation of 1:1 to 4:1 for a healthy diet. Information on the FA composition of coffee lipids will provide a basis for their industrial utilization. Coffee lipid can be a source of 16:0 and 18:2ω6 that can be used in food and as an excipient in drug preparations, respectively.

Keywords: Green coffee beans, fatty acid composition, nutritional quality, *Coffea arabica*, *Coffea canephora*

Received: 4th September 2024
Revised: 29th November 2024
Accepted: 3rd December 2024

Citation: Bamuwamye, M., Mugabe, A., Nakisozi, H., Byarugaba-Bazirake, G. W., & Ogwok, P. (2025). Fatty acid composition of lipids from Ugandan green coffee beans. *Food Agricultural Sciences and Technology (FAST), 11*(3), 272-284 https://doi.org/10.14456/fast.2025.20

1. Introduction

Green coffee beans (GCB) are dry unroasted seeds obtained from ripe coffee cherries. Coffee belongs to the family *Rubiaceae* and the genus *Coffea*. The genus *Coffea* is native to tropical Africa and comprises more than 100 species of which *Coffea arabica* Linn. (Arabica coffee) and *Coffea canephora* Pierre *ex* Froehner (Robusta coffee) are of commercial significance (Ferreira et al., 2019). The coffee value chain involves a large number of stakeholders and is a major financial source for many developing countries. About 1.7 million households representing 10% of global coffee farms depend on coffee as a major source of income (Bunn et al., 2019). The world's GCB production is estimated at 10.7 million tonnes (FAO, 2022). Uganda is Africa's third largest coffee-producing country and is ranked seventh globally with coffee production of 374,760 tonnes per annum (FAO, 2022).

Coffee is a functional food whose regular consumption may have positive effects on non-communicable diseases such as cancer and diabetes, and gonad and liver function in humans (Samoggia & Riedel, 2019). The pharmacological benefits associated with the consumption of coffee include antioxidant, detoxifying, lipid-reducing, cardio-protective, and anti-inflammatory activity. Green coffee beans contain considerable amounts of lipids, sterols, vitamins, minerals, phenolic acids, polyphenols, and alkaloids that account for coffee's health benefits (Parras et al., 2007). Lipids are important reserve compounds in GCB and can make up 10 to 17% of the bean weight (Anagbogu et al., 2021). Coffee lipids are important for aroma and flavor formation, flavor retention, foam stability in the coffee beverage, and are also popular in pharmacology and cosmetology (Speer & Kölling-Speer, 2006). Fatty acid (FA) profiles have been considered as discriminant parameters for differentiating coffee quality (Martín et al., 2001). However, large variations have been observed in GCB of different origins and genetics (Anagbogu et al., 2021).

Quality is an important requisite for consumers in the world coffee market. Saturated FA, including arachidic (20:0), stearic (18:0) and palmitic (16:0) acids are potential discriminators of the quality of coffee that indicate better sensory properties. The unsaturated FA; elaidic (18:1ω9*t*), oleic (18:1ω9*c*), linoleic (18:2ω6) and linolenic (18:3ω3) acids are related to coffees with less intense acidity, fragrance, body and flavor (Figueiredo et al., 2015). Additionally, the duration of storage of the GCB may have a significant effect on the levels of C14:0, C17:0, and C18:0, which seem to increase as the storage period and temperature increase (Alabdalall, 2024). This research aimed to provide coffee processors with information about coffee quality in Uganda to promote innovations and boost international trade.

2. Materials and methods

2.1 Description of the study area

The study comprised 12 different coffee-growing districts of Uganda. These are Maracha in the North West, Kisoro in South West, Masaka, Luwero and Kayunga in the Central region, Iganga and Bugisu in the East, and Mbarara, Ibanda, Rukungiri, Ntungamo, and Rwenzori in the West (Figure 1). Uganda is found between 1°30'S-4°N latitude and 29º30E-34°E longitude, hence existing astride the Equator (Nsubuga & Rautenbach, 2018). Temperatures fall between 15 and 30 °C. More than two-thirds of Uganda is a plateau 800 to 2,000 m above sea level. Along the western border, in the Rwenzori Mountains, Margherita Peak reaches a height of 5,109 m, while on the eastern frontier, Mount Elgon rises to 4,321 m above sea level. Precipitation is fairly reliable, varying from 750 mm in the Karamoja region in the Northeast to 1,500 mm on the shores of Lake Victoria, in the highlands around Mt. Elgon in the east, the Rwenzori Mountains in the southwest and some parts of Masindi and Gulu (Karamage et al., 2017).

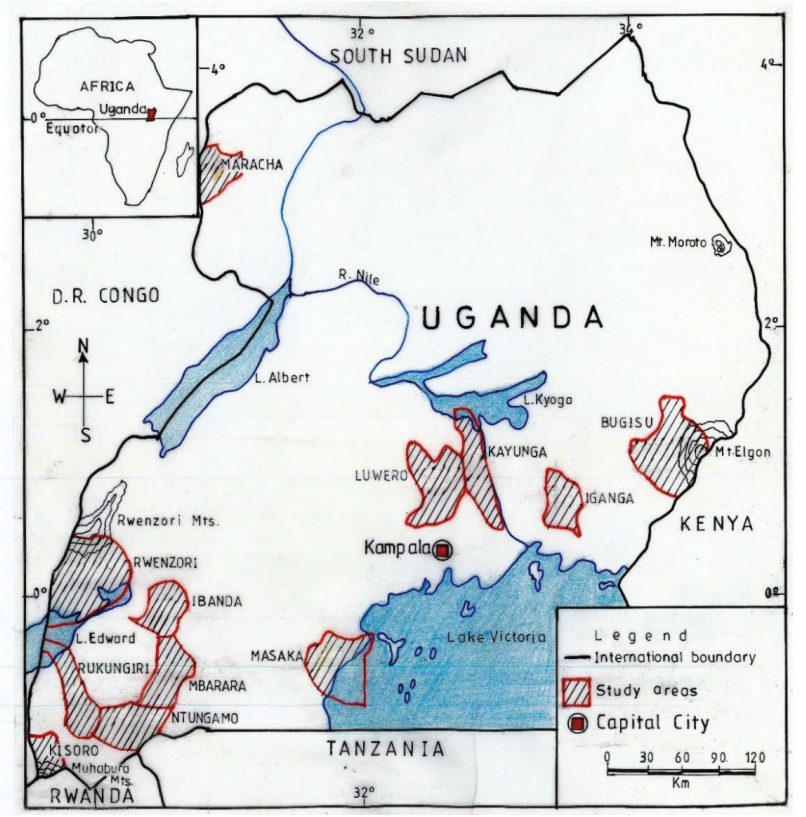

Figure 1. Map of Uganda showing the sampled areas.

2.2 Methods

2.2.1 Sampling and sample treatment

Twelve areas were considered for sampling and these included: Kisoro, Maracha, Bugisu and Rwenzori for Arabica coffee and Mbarara, Kayunga, Ntungamo, Luwero, Masaka, Ibanda, Rukungiri and Iganga for Robusta coffee. Green coffee beans from Bugisu, Rwenzori, Mbarara, Kayunga, Ntungamo, Masaka, Ibanda and Rukungiri were obtained from Uganda Coffee Development Authority (UCDA) in Kampala. Luwero, Iganga, Maracha and Kisoro samples were obtained from coffee dealers in the respective areas. The GCB were transported in sample bags to the Natural Chemotherapeutics Research Institute (NCRI) chemistry laboratory for lipid extraction.

2.2.2 Extraction of lipids

The GCB was dried for 4½ h in a DSO-D/DSO DF series hot air oven (Taiwan) at 105 °C. The dry GCB was ground to a fine powder and 10 g of the powder was placed in a Whatman High-Performance Cellulose Extraction Thimble of internal diameter 33 mm and a height of 80 mm. Extraction was carried out for 6 h in a Soxhlet extractor using pro-analysis grade n-hexane (62-68 °C) manufactured by Sharlab S. L. Spain. The n-hexane was rotary evaporated at a temperature of 50 °C and condensed at 10 °C. The lipid fraction was placed in an oven at 70 °C for 1½ h. The oily residue that remained was weighed to determine the percentage of lipid in each sample. Lipid yield was computed based on the GCB weight used for extraction. The green coffee bean lipid was packaged

in amber glass bottles and kept in a deep freezer until analysis. Fatty acid analysis was performed at Chemiphar (Uganda) Limited, an internationally accredited analytical laboratory (accreditation no: 167-TEST/INSP).

2.2.3 Determination of fatty acid composition of lipids

Fatty acids were determined as fatty acid methyl ester (FAME) according to the American Oil Chemists Society Official Method Ce 1j-07 (AOCS, 2020) on a Varian CP-3800 GC equipped with flame ionization detection (GC-FID) manufactured by Varian Chromatography System (Varian Inc., USA). The GC conditions were: injector temperature, 240 °C; injection volume, 2.0 μL; split ratio, 1:100; column temperature, the column-oven temperature was programmed to remain at 190 °C for 15 min and then raised to 240 °C at a rate of 20 °C/min and maintained at this temperature for a further 6.5 min; carrier gas, helium at the flow rate of 1.5 mL/min; detector temperature, 285 °C. One hundred microliters of lipid extract was saponified with 1 mL of 0.5 M sodium hydroxide (prepared in analytical grade methanol) for 10 min at 90 °C. The free fatty acids (FFA) were esterified with 1 mL of boron trifluoride (BF_3) in 20% methanol for 40 min at 80 °C. Two successive extractions were carried out with 1 mL of hexane. Quantification of FA was carried out by normalization and identification by comparison of the relative retention times of FAME peaks from the samples with pure standards of FAME (Supelco 37 component FAME MIX) from Supelco/ Sigma-Aldrich (USA).

2.3 Data analysis

All experiments were performed in triplicate and the results were expressed as the mean. Analysis of variance (ANOVA) using *R* statistical *software* was used to determine differences in lipid content. The means were statistically significant at $p < 0.05$.

3. Results and Discussion

3.1 Lipid content of green coffee beans

The lipid content of GCB ranged from 1.75 to 15.45% (Table 1). The findings of the study show a higher content of lipid in Arabica than in Robusta coffee. The highest content was obtained for Arabica coffee from Bugisu and the lowest for Robusta coffee from Ntungamo. Within varieties, Arabica coffee from Bugisu showed a significantly ($P < 0.05$) higher lipid content than the Arabica from the other areas. There was no difference ($P > 0.05$) in the lipid content of the Robusta coffee from the different areas. Wagemaker et al. (2011) and Dong et al. (2015) correspondingly reported lipid content of 6.90 to 32.40% and 8.60 to 12.03% for Robusta coffee. Wagemaker et al. (2011) and Nogaim et al. (2013) reported the lipid content of Arabica coffee to be between 2.49 and 13.13%, and 11.53 and 14.95%, respectively. Lipid composition is influenced by coffee varieties, soil, climate, and handling practices (Cheng et al., 2016). High temperatures have the effect of reducing the amount of accumulated lipids. Among varieties, Arabica coffee is reported to have a higher lipid content than Robusta coffee because the former starts to store oil earlier and in higher amounts than the latter (Cheng et al., 2016). Moreover, Arabica coffee grows at a high altitude which favors lipid accumulation (Cheng et al., 2016).

Table 1. Lipid content (%w/w) of the *Coffea arabica* and *Coffea canephora* var. Robusta green beans.

Area	Altitude (m)	Coffee type	Min	Max	Mean	SD
Kisoro	1900	Arabica	3.21	5.2	4.42[a]	1.06
Maracha	1250	Arabica	3.92	4.7	4.31[a]	0.39
Bugisu	1300-2600	Arabica	10.4	15.45	12.78[b]	2.56
Rwenzori	1500-2300	Arabica	4.83	6.36	5.51[a]	0.78
Mbarara	1800	Robusta	3.96	4.44	4.21[a]	0.24
Kayunga	1070	Robusta	1.75	4.02	3.18[a]	1.24
Ntungamo	1400	Robusta	2.53	3.33	2.81[a]	0.45
Luwero	1100	Robusta	2.87	3.92	3.38[a]	0.53
Masaka	1115	Robusta	2.74	3.27	3.05[a]	0.27
Ibanda	1400	Robusta	3.97	5.56	4.57[a]	0.87
Rukungiri	1640	Robusta	4.68	6.98	5.71[a]	1.17
Iganga	1082	Robusta	4.38	6.25	5.09[a]	1.01

Note: Means with different superscripts within the same column are significantly different ($P < 0.05$).

3.2 Fatty acid composition of lipids of green coffee bean

Nineteen FA were detected in lipids from *C. arabica* and *C. canephora* var. Robusta. Palmitic acid, 18:2ω6, 18:1ω9 were in high proportions while α-linolenic acid (ALA, 18:3ω3), C20:0 and behenic acid (22:0) were in low quantities (Table 2). Palmitic acid was the most predominant SFA and its proportion ranged from 30.48 to 47.4%. Linoleic acid was the major UFA with a proportion ranging from 33.23 to 42.11%. The concentration of 16:0 and 18:2ω6 is similar to that of Ethiopian coffee (Tsegay et al., 2020). However, 18:0 and 18:1ω9 were lower than reported by the authors. Saturated and UFA of C20, C22, and C24 series are present in low amounts. Gamma (γ)-linolenic acid (GLA; γ-18:3ω6) was detected in Arabica coffee from Maracha and Bugisu districts, and Robusta coffee from Kayunga, Ntungamo, Luwero, Ibanda, and Rukungiri districts. Erucic acid (22:1ω9) also known as *cis*-13-docosenoic acid and eicosatrienoic acid (ETE; 20:3ω3) were detected in small amounts in lipids from the Arabica green coffee bean from Kisoro and Maracha districts. Eicosatrienoic acid is thought to result from the elongation and desaturation of 18:3ω3. Arachidonic acid (AA; 20:4ω6), 22:1ω9, and 18:1ω9 were present in Robusta lipid from Mbarara, Kayunga, Ntungamo, Luwero and Masaka. Stearic acid (18:0) was absent in lipids from GCB obtained from Masaka and Rukungiri. Variation in the amounts of FA in green coffee bean lipid from different areas implies that the FA composition of the GCB is affected more by geographical source than coffee variety (Tsegay et al., 2020). Differences between Arabica and Robusta coffee FA compositions become visible only when their 18:1ω9 content is compared. Similar observations were made by Speer and Kölling-Speer (2006).

Table 2. Fatty acid profile (g/100g) of *Coffea arabica* and *Coffea canephora*.

Fatty acid	Arabica coffee					Robusta coffee						
	Kisoro	Maracha	Bugisu	Rwenzori	Mbarara	Kayunga	Ntungamo	Luwero	Masaka	Ibanda	Rukungiri	Iganga
14:0	ND	ND	0.12	0.11	ND	ND	ND	ND	ND	0.16	0.16	0.15
15:0	ND	ND	0.08	ND	ND	ND	ND	ND	ND	ND	ND	ND
16:0	35.47	30.48	47.4	46.19	37.04	33.89	36.49	33.85	33.92	43.39	47.72	40.67
17:0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18:0	0.11	0.14	0.11	0.11	0.09	0.09	0.09	0.12	ND	3.65	ND	0.1
20:0	2.82	1.82	1.21	ND	0.84	0.74	0.49	1.28	0.99	1.4	1.26	1.0
21:0	0.46	1.57	ND	ND	0.2	ND	ND	0.2	ND	ND	ND	ND
22:0	1.15	0.88	0.07	0.08	0.35	0.31	0.22	0.52	0.48	0.04	0.06	0.04
14:1ω5	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.09	ND	0.05
18:1ω9*c*	14.44	16.53	12.61	13.13	19.35	20.88	20.03	20.13	21.45	16.18	16.47	20.21
18:1ω9*t*	1.39	1.57	0.07	0.98	0.69	0.73	0.72	0.7	0.75	ND	ND	0.65
20:1ω9	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.12	ND	0.16
22:1ω9	0.74	1.09	ND	ND	0.15	0.11	0.05	0.21	0.15	ND	ND	ND
18:2ω6	41.51	41.71	37.1	34.61	39.43	41.2	39.9	40.86	42.1	34.24	33.23	35.03
18:3ω6	ND	0.04	0.08	ND	ND	0.02	0.04	0.02	ND	0.08	0.5	ND
20:4ω6	0.35	0.39	ND	ND	0.26	0.2	0.12	0.35	0.16	ND	ND	ND
18:3ω3	1.33	3.09	1.09	2	1.6	1.82	1.83	1.74	ND	0.62	0.55	1.94
20:3ω3	0.18	0.47	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note: ND: not detected. C14:0-Myristic acid; 14:1ω5-myristoleic acid; C15:0-Pentadecanoic; C16:0-palmitic acid; C17:0-heptadecanoic acid; C18:0-stearic acid; C18:1ω9c-oleic acid; C18:1ω9t-elaidic acid; C18:2ω6-linoleic acid; C18:3ω3-α-linolenic acid; 18:3ω6-γ-linolenic acid; C20:0-arachidic acid; C20:1ω9-gondoic acid; 20:3ω3-eicosatrienoic acid; 20:4ω6-arachidonic acid; C21:0-Heneicosanoic acid; 22:1ω9-erucic acid; C22:0-behenic acid.

Linoleic, 16:0, 18:1ω9 and 18:0 acids have been reported as the major FA in green coffee bean lipid (Dong et al., 2015; Hung et al., 2018; Tsegay et al., 2020). Lipids from seven cultivars of *C. robusta* contained high amounts of 18:2ω6, 16:0, 18:1ω9, and 20:0 and low amounts of 18:3ω3, 22:0, 24:0, 20:1, myristic acid (14:0) and 23:0. Wagemaker et al. (2011) and Hung et al. (2018) also reported low levels of 18:3ω3, 22:0, 24:0, 20:1, 14:0 and 23:0 in coffee lipids. Arabica coffee has been reported to have high amounts of 16:0, 20:0, 18:0, and 18:3ω3, but low amounts of 18:1ω9 when compared to *C. canephora* (Anagbogu et al., 2021). The relative amounts of C18:1ω9 and C18:2ω6 are always negatively correlated because of the precursor-product relationship of the two FA. Linoleic acid and 16:0 are the most dominant FA in plants (Marsilani et al., 2020). Coffee lipids are generally poor in short and medium-chain FA (Table 3). The green coffee bean lipids of this study are comparable to those reported in other studies (Wagemaker et al., 2011; Hung et al., 2018).

Table 3. Fatty acid composition of green coffee bean lipids compared with data from other studies.

Fatty acid	Arabica coffee							Robusta coffee						
	1	2	3	4	5	6	7	1	2	3	5	8	9	10
C14:0	ND- 0.12	trace	0.1	-	-	-	-	ND - 0.16	trace	0.1	-	0.082	trace	0.15-0.60
C15:0	ND- 0.08	trace	-	-	-	-	-	-	trace	-	-	0.03	-	-
C16:0	30.48 - 47.4	26.6 -27.8	33	32.4	30.2	34.51	38.3	33.85 - 47.72	27.2-32.1	32.5	31.3	36.4	34	29.68-35.46
C17:0	-	trace	-	-	-	-	-	ND - 0.01	trace	-	-	0.03	-	-
C18:0	0.11 - 0.14	5.6-6.3	7.3	9.7	8	9.19	7.89	ND- 3.65	5.8-7.2	7.5	5.9	6.69	7	6.60-7.47
C20:0	ND- 2.82	2.6-2.8	2.5	4.6	2.3	3.01	3.24	0.49 - 1.4	2.7-4.3	2.9	2.4	2.65	3	3.36-4.34
C21:0	ND- 1.57	trace	-	-	-	-	-	ND- 0.2	Trace	-	-	0.06	-	-
C22:0	0.07 - 1.15	0.5-0.6	0.6	0.8	-	-	-	0.04 - 0.52	0.3-0.8	0.6	-	0.41	0.7	0.76-0.97
C23:0	ND- 0.2	trace	-	-	-	-	-	ND - 0.03	Trace	-	-	-	-	0.14-0.34
C24:0	ND - 0.04	0.2-0.4	-	-	-	-	-	ND - 0.04	0.3-0.4	-	-	0.273	-	0.32-0.78
C14:1ω5	ND	-	-	-	-	-	-	ND- 0.09	-	-	-	-	-	-
C16:1ω7	ND	trace	0.2	-	-	-	-	ND- 0.04	trace	0.2	-	-	trace	-
C20:1ω9	ND	trace - 0.3	0.3	-	-	-	-	ND - 0.16	0.2-0.3	0.5	-	0.4	0.3	0.33-0.43
C18:1ω9	12.61 - 16.53	6.7-8.2	8.7	12.8	10.6	8.69	9.34	1 - 21.45	9.7-14.2	12.3	12.5	11.94	9	7.73-10.4
C18:1ω9*t*	0.07 - 1.57	-	-	-	-	1.18	-	ND - 0.75	-	-	-	-	-	-
C22:1ω9	ND - 1.09	-	-	-	-	-	-	ND - 0.21	-	-	-	-	-	-
C18:2ω6	34.61 - 41.71	52.2-54.3	45.8	38.3	46.3	39.46	39.9	33.23 - 42.1	43.9-49.3	42.6	44	38.47	44	40.51-46.57
C18:3ω6	ND- 0.08	2.2-2.6	-	-	-	-	-	0.02 - 0.5	0.9-1.4	-	-	-	-	-
C20:4ω6	ND - 0.39	-	-	-	-	-	-	0.12 - 0.35	-	-	-	-	-	-
C18:3ω3	1.09 - 3.09	-	1.5	1.4	1.6	1.55	1.25	0.55 - 1.94	-	0.9	1.5	0.67	1.5	0.68-1.15
C20:3ω3	ND - 0.47	-	-	-	-	-	-	-	-	-	-	-	0.3	-

Source: *1. This study; 2.* Speer and Kölling-Speer (2006); 3. Cossignani et al. (2016); 4. Oliveira et al. (2014); 5. Wagemaker et al. (2011); 6. Figueiredo et al. (2015); 7. Raba et al. (2018); 8. Romano et al. (2014); 9. Oliveira et al. (2006); 10. Dong et al. (2015).
Note: ND: not detected. Means on the measure of FA composition. C14:0-Myristic acid; 14:1*ω*7-myristoleic acid; C15:0-Pentadecanoic; C16:0-palmitic acid; C16:1*ω*7palmitoleic acid; C17:0-heptadecanoic acid; C18:0-stearic acid; C18:1*ω*9*c*-oleic acid; C18:1*ω*9*t*-elaidic acid; C18:2*ω*6-linoleic acid; C18:3*ω*3-*α*-linolenic acid; 18:3*ω*6-*γ*-linolenic acid; C20:0-arachidic acid; C20:1*ω*9-gondoic acid; 20:3*ω*3-eicosatrienoic acid; 20:4*ω*6-arachidonic acid; C21:0-Heneicosanoic acid; 22:1*ω*9-erucic acid; C22:0-behenic acid; 23:0-tricosylic acid; 24:0-lignoceric acid.

Linoleic acid and 18:3ω3 are essential polyunsaturated FA (PUFA) that must be provided by foods since they are necessary for health but cannot be synthesized in the human body (Kaur et al., 2014). Dietary essential FA intake has been positively correlated with reduced cardiovascular, neurological, visual, and cancer disorders. At more than 4.5% of energy intake, 18:2ω6 mitigates the hypercholesterolemic effect of palmitic acid (French et al., 2002). Linoleic acid also has strong anti-carcinogen effects

and lowers cardiovascular disease (CVD) (Li et al., 2014). Gamma-linolenic acid is an important "conditionally" essential FA that is metabolized to dihomo-γ-linolenic acid (DGLA; 20:3ω6), which is cyclooxygenated to series 1 eicosanoids (prostaglandin PGE1 and leukotriene LTC3). The PGE1 and LTC3 possess anti-inflammatory, antiproliferative, antiatherogenic, and vasodilatory effects (Martini, 2021). Oleic acid inhibits cancer cell growth and survival most especially in low metastatic carcinoma cells such as gastric carcinoma SGC7901 and breast carcinoma MCF-7 cell lines (Li et al., 2014). Palmitic acid has long been reputed for its detrimental health effects (Carta et al., 2017). However, a balanced dietary PA/PUFA ratio is associated with positive effects (Carta et al., 2017). For example, PA is a precursor of biologically active molecules such as palmitoylethanolamide (PEA; $C_{18}H_{37}NO_2$) which is anti-inflammatory, anticonvulsant, antimicrobial and neuroprotective (Clayton et al., 2021). A relative proportion of PA/PUFA < 1 implies that PA should not deter consumers from coffee consumption. In food, PA improves the textural properties of foods such as cookies, ice cream, and soft candies (Wagemaker et al., 2011; Tsegay et al., 2020). Fatty acids with odd carbon numbers such as C15:0, C17:0, C21:0, and C23:0 have been reported in green coffee bean lipid in concentrations varying from trace (< 0.05%) to 0.34% of total FA. Studies have suggested potential health benefits for C15:0 and C17:0, such as lowering the risk of T2DM and CVD, and improvement of risk factors such as blood pressure, plasma triglycerides, and insulin resistance (De Oliveira Otto et al., 2018). Green coffee bean lipid also contains enzymes that stimulate detoxification and aid in cleansing, thus making it ideal to help treat acne-prone skin (Wagemaker et al., 2011).

3.3 Nutritional quality indices of green coffee bean lipid

Elaidic acid (C18:1ω9*t*), a trans-FA (TFA), was detected in low amounts in all coffee lipids except those from Ibanda and Rukungiri (Table 4). Trans FA in lipids from green Arabica and Robusta coffee ranged between 0.07 and 1.57%, and ND and 0.75%, respectively. Lipids in coffee from Maracha had the highest amounts of C18:1ω9*t*. Low levels of 18:1ω9*t* in coffee lipid were correlated with sensory characteristics of coffee implying that the FA is a possible discriminator of coffee quality (Figueiredo et al., 2015). However, excessive TFA intake is associated with an increased risk of CVD, cancer, and diabetes (Islam et al., 2019). Similarly, the heart has been identified as a principal target organ for toxicity following short-term or long-term exposure to diets with lipids containing 22:1ω9 (EFSA, 2016). The most common and sensitive effect observed in all species is myocardial lipidosis, which is an accumulation of triacylglycerols as neutral lipid droplets in the myocardium. Recent recommendations from medical professional associations in Europe and the US indicate that consumption of TFA should be as low as possible (EFSA, 2018). Therefore, European Union (EU) Commission Regulation EU 2019/649 of 24 April 2019 amending Annex III to Regulation (EC) No 1925/2006 of the European Parliament and of the Council as regards trans-fat, other than trans-fat naturally occurring in fat of animal origin, set a maximum limit of trans fats in food intended for the final consumer and for supply to retail as 2 g per 100 g of fat (EU, 2019). Similarly, the European Food Safety Authority (EFSA) proposed a maximum content of 22:1ω9 in edible oils of 2% and also suggested a tolerable daily intake of 7 mg 22:1ω9 per kg body weight (EFSA, 2016). The findings of this study imply that the TFA and 22:1ω9 contents of the GCB were within international limits.

Saturated FA varied between 35.04 and 49.2% in the coffee lipids. Rukungiri coffee lipid had a higher SFA content than other coffee lipids. Total MUFA ranged from 3.89 to 22.34% meaning that the coffee lipids of this study were higher in MUFA than previously reported (Speer & Kölling-Speer, 2006; Oliveira et al., 2006).

Lipids from Masaka coffee had the highest MUFA content and Ibanda coffee had the lowest. The total PUFA ranged from 34.29 to 45.70%. Maracha coffee lipid had the highest concentration of PUFA, whereas Rukungiri coffee lipid had the lowest amounts. The findings of this study are in agreement with previous reports that green coffee bean contains more UFA than SFA (Speer & Kölling-Speer, 2006; Romano et al., 2014; Dong et al., 2015).

The ratios; PUFA/SFA and ω6:ω3 PUFA are widely used to evaluate the nutritional value of fat for human consumption. Foods with a PUFA/SFA ratio < 0.45 have been considered undesirable to the diet as they influence the increase of blood cholesterol (Wołoszyn et al., 2020). Nonetheless, the beneficial effect of C18:2ω6 on health is produced when the PUFA/SFA ratio is < 1.5 (Naydenova et al., 2014). The observed PUFA/SFA ratio of 0.7 to 1.3 would favor a reduced risk of CVD implying that GCB lipid can be used as a dietary supplement (Dong et al., 2015). According to Wołoszyn et al. (2020), because the PUFA/SFA generalizes all FA as inducers of increased blood cholesterol and does not consider the metabolic effects of MUFA, its impact when evaluated separately is limited. Therefore, knowledge of the relationship between ω6 and ω3 PUFA is another important factor in human health. An unbalanced ω6/ω3 ratio in favor of ω6 PUFA is highly prothrombotic and proinflammatory, which contributes to the prevalence of atherosclerosis, obesity, and diabetes (Gómez Candela et al., 2011). The optimum ratio between ω6 and ω3 FA should be close to 1:1 to 4:1, and should not exceed 10:1 (Gómez Candela et al., 2011). The results of this study show that coffee lipids had ω6/ω3 ratio in large excess of 10:1 implying that it requires blending with other oils that are rich in ω3 FA to improve the nutritional quality.

Table 4. PUFA/SFA and ω6/ω3 PUFA ratios of the oils obtained from *Coffea arabica* and *Coffea canephora* var. Robusta green beans from different coffee regions of Uganda.

FA	Arabica coffee					Robusta coffee						
	1	2	3	4	5	6	7	8	9	10	11	12
∑SFA	40.06	35.11	48.99	46.49	38.52	35.04	37.33	35.99	35.39	48.64	49.2	41.95
∑MUFA	16.56	19.19	12.75	16.91	20.19	21.72	20.8	21.04	22.34	3.89	16.51	21.07
∑PUFA	43.38	45.7	38.26	36.61	41.29	43.24	41.87	42.97	42.27	34.94	34.29	36.98
∑TFA	1.39	1.57	0.07	0.98	0.69	0.73	0.72	0.7	0.75	ND	ND	0.65
∑ω3 PUFA	1.51	3.56	1.09	2	1.6	1.82	1.83	1.74	ND	0.62	0.55	1.94
∑ω6 PUFA	41.87	42.15	37.17	34.61	39.69	41.42	40.05	41.23	42.27	34.32	33.73	35.03
∑ω6/∑ω3	27.73	11.84	34.1	17.31	24.81	22.76	21.89	23.7	_	55.35	61.33	18.06
PUFA/SFA	1.08	1.3	0.78	0.79	1.07	1.23	1.12	1.19	1.19	0.72	0.7	0.88
PA/PUFA	0.82	0.67	1.24	1.26	0.90	0.78	0.87	0.79	0.80	1.24	1.39	1.10

Note: 1. Kisoro; 2. Maracha; 3. Bugisu; 4. Rwenzori; 5. Mbarara; 6. Kayunga; 7. Ntungamo; 8. Luwero; 9. Masaka; 10. Ibanda; 11. Rukungiri; 12. Iganga. SFA: Saturated fatty acid; MUFA: Monounsaturated fatty acids; PA; palmitic acid; PUFA: Polyunsaturated fatty acids; PUFA/SFA: ∑PUFA/∑SFA; TFA: trans fatty acids.

4. Conclusion

Green coffee beans were low in lipids and the content varied between samples from different regions and varieties. Palmitic, linoleic, oleic, and arachidic acids were predominant FA. The lipids of the green coffee beans were safe for human consumption with respect to trans-fatty acids and erucic acid. The GCB can be a supplementary source of linoleic, oleic, and palmitic acids for industrial use. A high PUFA/SFA ratio and a low PA/PUFA mean that green coffee bean lipids should make a good contribution to a healthy diet. However, the high ω6:ω3 ratio means that the green coffee bean lipid would have to be blended with other oils rich in ω3 FA-to enhance the nutritional value. Coffee lipid can be a source of 16:0 and 18:2ω6, which are building blocks for a large variety of high-value starting materials for the food and pharmaceutical industries. However, the formation of small amounts of trans-fatty acids during lipid extraction and processing may limit the utilization of coffee lipids.

Acknowledgments

This work was supported by the Government of Uganda. We are grateful to Ms. Judith Engena of UCDA and the coffee dealers in the Luwero, Iganga, Maracha, and Kisoro districts for supplying the green coffee beans. The staff of Chemiphar Uganda (Ltd) are acknowledged for their technical support. Mr. George William Magawa (Cartographer, Makerere University) and Dr. Peter Yiga (Katholieke Universiteit Leuven) are equally acknowledged.

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