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Evaluation of the Nutritional and Industrial Implications of Avocado Pulp Oil from Selected Varieties Grown across Different Sites and Seasons in the Lake Victoria Crescent Agro-Ecological Zone

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Abstract

This study evaluated the nutritional and industrial quality of avocado pulp oil extracted from four varieties (Hass, Fuerte, Reed, Semil 34) grown across three sites (Kamenyamiggo, Mukono Zonal Agricultural Research and Development Institute, National Forestry Resources Research Institute) and two harvest seasons in Uganda's Lake Victoria Crescent Agro-ecological Zone. Key physicochemical parameters assessed included acid value, iodine value, saponification value, oleic acid and linoleic acid content. The results revealed significant ($p < 0.05$) variations across site-season-genotype combinations. Acid values ranged from 0.30 ± 0.02 to 0.67 ± 0.02 mg KOH/g, all below Codex Alimentarius thresholds, indicating minimal hydrolytic degradation. Iodine values varied between 60.97 ± 3.02 and 88.81 ± 1.33 mg I_2/g, with Reed and Fuerte showing higher unsaturation, desirable for nutritional use but limiting oxidative stability. Saponification values ranged from 163.21 ± 5.94 to 212.66 ± 18.04 mg KOH/g, with Reed and Semil 34 showing higher values suitable for soap and cosmetic industries. Oleic acid ranged from 42.79% to 47.88%, highest in Hass, while linoleic acid spanned 10.71% to 15.44%, highest in Hass and lowest in Reed. The findings highlight Hass as optimal for nutritional oil applications due to high MUFA content and oxidative stability, while Reed and Semil 34 offer industrial advantages. This study informs site-specific cultivar selection and value-addition strategies for Uganda's growing avocado industry.

Keywords

Avocado Pulp Oil, Acid Value, Iodine Value, Saponification Value, Oleic Acid, Linoleic Acid

1. Introduction

Avocado (*Persea Americana* Mill.) has gained prominence globally as both a nutritious fruit and a valuable source of plant-based oil, with increasing interest in its pulp oil due to its favorable lipid profile, including high levels of monounsaturated fatty acids (MUFAs), tocopherols, and phytosterols [1] [2]. As consumer demand shifts toward healthier and functional oils, avocado pulp oil has emerged as a promising candidate for both nutritional and industrial applications, especially in cosmetics, pharmaceuticals and nutritional uses [3]. Unlike conventional seed-based oils, avocado oil is extracted from the fruit's mesocarp and can be consumed in its virgin state without refining, preserving its nutritional integrity [4].

In sub-Saharan Africa, avocado cultivation has expanded significantly, especially in Kenya, South Africa, Tanzania and Uganda, driven by regional and international trade opportunities [5]. Uganda's Lake Victoria Crescent agro-ecological zone provides ideal conditions for avocado production due to its fertile soils, bimodal rainfall and varied altitudes. However, the quality and composition of avocado pulp oil can be significantly influenced by varietal genotype, growing site and seasonality [6]-[8]. Despite the crop's increasing commercial importance, limited research exists in Uganda on how these agro-environmental variables affect the physicochemical and nutritional properties of avocado oil.

Understanding the variability in key oil quality parameters is essential for optimizing both nutritional value and industrial suitability. Acid value, a marker of free fatty acid content, reflects oil degradation and storage stability, while iodine value indicates the degree of unsaturation and hence oil drying capacity [9]. Saponification value provides an indication of the average molecular weight of the fatty acids present, influencing soap and cosmetic applications [10]. Meanwhile, the oleic and linoleic acid contents define the oil's nutritional profile and oxidative stability, critical attributes for both food and non-food uses [11].

This study evaluated the acid value, iodine value, saponification value, oleic acid content and linoleic acid content of oils extracted from selected avocado varieties grown across different locations and seasons in Uganda's Lake Victoria Crescent Zone. By revealing how site-season-genotype interactions influence oil quality, the study aims to generate evidence that informs cultivar selection, harvest timing and value-addition strategies tailored for both domestic and export markets.

2. Materials and Methods

2.1. Study Area and Experimental Design

The avocado fruits were obtained from Mukono ZARDI (MUZARDI) in Ntawo, (latitude: 0.35˚N, longitude 32.75˚E with average annual precipitation of 120.74 mm and average annual temperature of 23.83˚C, soil pH of 5.79, organic matter content of 7.7%, loamy Rhodic Ferralsol soil type), National Forestry Resources Research Institute (NaFORRI), (latitude 0.35˚N and longitude 32.75˚E having an average annual precipitation of 124.92mm, average annual temperature of 24.12˚C, soil pH of 6.8, organic matter content of 3.8%, loamy Rhodic Ferralsol soil types) and Kamenyamiggo, Lwengo district (Latitude: 0.18˚S, Longitude 31.39˚E with average annual precipitation of 123.12 mm and average annual temperature 22.84˚C, soil pH of 5.08, organic matter content of 2.78% sandy Rhodic Ferralsol soil type), locations selected from the Lake Victoria Crescent Agro-Ecological Zone.

The study employed a factorial experimental design over two consecutive harvest seasons; Season 1 (March-May) and Season 2 (September-November), to evaluate the effects of variety, site and season on the physicochemical and nutritional properties of avocado pulp oil.

2.2. Avocado Varieties and Fruit Sampling

Four avocado varieties (Hass, Fuerte, Reed and Semil 34) were selected based on their preference and economic relevance in Uganda [12]. Mature avocado fruits were selectively harvested through observation of: i) the peel color and texture, selecting ones with rough and duller peels; ii) the pedicel, selecting for fruits with pedicels which had begun drying. From each site, six mature fruits were manually harvested from five healthy trees per variety per season. Fruits were sorted to remove damaged specimens, washed to eliminate surface debris, and stored at ambient temperature (22˚C - 25˚C) to allow uniform postharvest ripening prior to oil extraction.

2.3. Avocado Oil Extraction

Oil was extracted from the ripe mesocarp using the cold-press method, adapted from [13], to preserve the oil's nutritional and compositional integrity. Briefly, the pulp was dried and mechanically pressed at room temperature using an oil press located at the MUZARDI value addition laboratory. The extracted oil was filtered, transferred to amber glass bottles, and stored at 4˚C to prevent oxidation before analysis.

2.4. Determination of Physicochemical Parameters

All analyses were performed in triplicate using standardized protocols to determine key oil quality attributes: acid value, iodine value, saponification value, and fatty acid composition (oleic and linoleic acid content).

2.4.1. Acid Value (AV)

Acid value was determined according to [14]. Three milliliters of oil was dissolved in 10 mL of n-hexane in a 100 mL Erlenmeyer flask. Three drops of 1% phenolphthalein were added, followed by titration with 0.1 N KOH until a persistent pink color appeared. AV (mg KOH/g oil) was calculated as:

$$\text{AV} = \frac{\text{titre value} * \text{KOH concentration} * 56.11}{\text{weight of sample}(g)}$$

2.4.2. Iodine Value (IV)

Iodine value was determined using a modified method from [15]. A 0.5 g oil sample was dissolved in 15 mL of ethanol, followed by the addition of 20 mL 0.1 M ethanolic iodine solution. After mixing for 5 minutes, 100 mL of distilled water was added. The mixture was titrated with 0.1 M $Na_2S_2O_3$ until a pale-yellow color was observed. Then, 3 mL of 1% starch was added, and titration continued until the blue color disappeared. IV (g I_2/100 g oil) was calculated as:

$$\text{IV} = \frac{\left(\text{Volume of sodium thiosulfate}(\text{mL}) \times \text{M} \times 12.691\right)}{\text{weight of the sample}(g)}$$

where M = molarity of sodium thiosulfate.

2.4.3. Saponification Value (SV)

Saponification value was measured following [10]. Two milliliters of oil was mixed with 25 mL ethanolic KOH. A blank was prepared similarly without oil. Samples were refluxed in a water bath for 30 minutes, cooled and titrated with 0.5 M HCl using phenolphthalein indicator until the pink color disappeared. SV (mg KOH/g oil) was calculated as:

$$\text{SV} = \frac{\left[(V_0 - V_1) \times C \times 56.1\right]}{\text{weight of sample}(g)}$$

where V_0 = volume of HCl for blank, V_1 = volume of HCl for sample, and C = HCl concentration, 6.1 = Molecular weight of KOH.

2.4.4. Fatty Acid Composition

The fatty acid composition of avocado oil samples specifically oleic acid and linoleic acid was determined using gas chromatography-mass spectrometry (GC-MS). Sample preparation followed the method of [16], involving the formation of fatty acid methyl esters (FAMEs). The analysis was performed using an Agilent 7890B gas chromatograph coupled with an Agilent 5977A mass selective detector (Agilent Technologies, Santa Clara, CA, USA). Separation was achieved on a DB-23 fused-silica capillary column (60 m × 0.25 mm i.d., 0.25 μm film thickness; 50% cyanopropyl-methylpolysiloxane stationary phase), which provides excellent resolution of saturated and unsaturated fatty acid methyl esters. Helium (99.999% purity) was used as the carrier gas at a constant flow rate of 1.0 mL min^{-1}. A 1 μL aliquot of the FAME solution was injected in split mode (20:1), with the injector temperature maintained at 250˚C. The oven temperature program was as follows: 50˚C (1 min), increased at 25˚C min^{-1} to 175˚C (10 min), followed by 4˚C min^{-1} to 230˚C and held for 10 min. The transfer line, ion source, and quadrupole temperatures were maintained at 280˚C, 230˚C, and 150˚C, respectively. Mass spectra were acquired under electron ionization (EI) at 70 eV in full-scan mode over an m/z range of 40 - 500, conditions widely recommended for FAME analysis by GC-

MS. The fatty acids were identified by comparing their retention times with those of authentic FAME standards and by matching their mass spectra with the NIST Mass Spectral Library (NIST23). Only compounds with retention time agreement and spectral match factors greater than 90% were accepted as positively identified. Quantification was carried out using the external standard calibration method. Standard solutions of methyl oleate and methyl linoleate were prepared at five concentration levels to generate calibration curves by plotting peak area against concentration. Calibration curves exhibited excellent linearity ($R^2 \geq 0.995$). Methyl nonadecanoate (C19:0 methyl ester) was added as an internal standard before derivatization to correct for extraction, methylation, and injection variability. The concentrations of oleic and linoleic acids were calculated from the calibration equations and expressed as the percentage of total identified fatty acids using peak-area normalization. All analyses were performed in triplicate, and the results were reported as mean ± standard deviation.

2.5. Statistical Analysis

All measurements were conducted in triplicate. Data were analyzed using GenStat 64-bit Release 14.1 (VSN International, UK). A three-way ANOVA assessed the main and interaction effects of variety, site and season on each oil quality parameter. Where significant differences occurred ($p < 0.05$), Duncan's Multiple Range Test was used for multiple comparisons. Results are presented as means ± standard deviation (SD).

3. Results and Discussion

3.1. Acid Values of Oils from Different Avocado Varieties

Acid values, a measure of free fatty acid content and an indicator of oil hydrolytic degradation [14], varied significantly across varieties, locations and seasons, ranging from 0.30 ± 0.02 mg KOH/g (Hass at NaFORRI, Season 1) to 0.67 ± 0.02 mg KOH/g (Reed at MUZARDI, Season 1) as reported in **Table 1**. Generally, Reed exhibited the highest acid values across all sites and seasons, while Hass consistently recorded the lowest, particularly in NaFORRI during Season 1. Seasonal differences were notable, with most varieties showing slightly higher AVs during Season 1 than in Season 2, especially at MUZARDI and KMG. These seasonal trends may be attributed to climatic variations, such as increased humidity and temperature fluctuations in Season 1, which can accelerate lipolytic enzyme activity, leading to the release of free fatty acids [17]. The moderately higher AVs observed in MUZARDI and NaFORRI compared to KMG may also reflect site-specific microclimates and postharvest handling practices that influence enzymatic degradation of triacylglycerols [18].

From an industrial standpoint, all acid values were below 2.0 mg KOH/g, the Codex Alimentarius threshold for virgin edible oils [19], indicating good oil quality and minimal hydrolytic rancidity. The relatively low AVs of Hass across all sites and seasons suggest it may be the most stable variety under varying environmental conditions, aligning with findings by [20], who reported lower AVs in Hass oils compared to Fuerte and Reed under tropical conditions. In contrast, Reed's higher AVs are consistent with its higher susceptibility to oxidation and degradation, possibly due to a greater proportion of unsaturated lipids that are more prone to hydrolysis [21]. The observed variations reinforce the importance of genotype-environment interactions in determining oil quality attributes, suggesting that strategic matching of avocado varieties to optimal site-season combinations could enhance oil stability and processing value in Uganda and similar agro-ecological regions.

Table 1. Seasonal variations of acid values (mg KOH/g) of oils from different avocado varieties and locations.

		Avocado Varieties			
Location	**Season**	**Fuerte**	**Hass**	**Reed**	**Semil 34**
KMG	Season 1	0.48 ± 0.03^{fg}	0.46 ± 0.02^{efg}	0.59 ± 0.03^{jk}	0.40 ± 0.01^{bcd}
	Season 2	0.50 ± 0.02^{gh}	0.44 ± 0.03^{cde}	0.55 ± 0.04^{ij}	0.45 ± 0.03^{efg}
MUZARDI	Season 1	0.53 ± 0.02^{hi}	0.37 ± 0.04^{b}	0.67 ± 0.02^{k}	0.43 ± 0.02^{cde}
	Season 2	0.40 ± 0.01^{bcd}	0.39 ± 0.02^{bcd}	0.54 ± 0.03^{hi}	0.40 ± 0.01^{bcd}
NaFORRI	Season 1	0.54 ± 0.02^{hi}	0.30 ± 0.02^{a}	0.62 ± 0.03^{k}	0.44 ± 0.02^{cde}
	Season 2	0.43 ± 0.02^{cde}	0.40 ± 0.02^{bcd}	0.62 ± 0.01^{k}	0.43 ± 0.04^{cde}

Values are means of three determinations ± standard deviation. Means followed by the same letter are not significantly different ($p < 0.05$) according to three-way ANOVA followed by Duncan's multiple range test.

3.2. Iodine Values of Oils from Different Avocado Varieties

Iodine values, which indicate the degree of unsaturation in oils, varied significantly across avocado varieties, locations and seasons, ranging from 60.97 ± 3.02 mg I_2/g (Semil 34, NaFORRI, Season 2) to 88.81 ± 1.33 mg I_2/g (Reed, KMG, Season 1) as shown in **Table 2**. Generally, Fuerte and Reed exhibited higher iodine values, suggesting a greater proportion of unsaturated fatty acids, especially linoleic and linolenic acids, compared to Hass and Semil 34. At KMG during Season 1, both Fuerte and Reed recorded the highest IVs (>87 mg I_2/g), indicating a favorable unsaturated profile. In contrast, consistently lower IVs were recorded for Hass, especially at MUZARDI and NaFORRI during Season 2. Seasonal variation was evident across most varieties and sites, with higher IVs generally recorded in Season 1, likely due to more favorable growing conditions that promote synthesis of unsaturated fatty acids during fruit development [22]. This aligns with the understanding that temperature, sunlight intensity and water availability influence fatty acid desaturation in plant oils [23].

Higher iodine values indicate greater unsaturation and potential nutritional benefits, as unsaturated lipids play a role in cardiovascular health and lipid metabolism [24]. However, increased unsaturation also implies lower oxidative stability, which may limit shelf life unless oils are properly stored or stabilized with antioxidants [18]. These findings align with previous studies which reported that Reed and Fuerte varieties tend to accumulate more unsaturated lipids than Hass, making them more suitable for nutritional applications but potentially less ideal for long-term industrial uses unless refined [20]. Notably, Semil 34 showed high variability in IVs across seasons and sites, with the highest value (88.21 ± 1.26 mg I_2/g) at MUZARDI in Season 2 and the lowest (60.97 ± 3.02 mg I_2/g) at NaFORRI in the same season. This highlights the strong effect of genotype-environment interaction on oil composition. Generally, these results suggest that site and seasonal conditions must be carefully considered in optimizing avocado oil quality for both nutritional value and industrial processing.

Table 2. Seasonal variations of iodine values (mg I_2/g) of oils from different varieties from different locations.

		Avocado Varieties			
Location	**Season**	**Fuerte**	**Hass**	**Reed**	**Semil 34**
KMG	Season 1	87.93 ± 2.14^{a}	70.24 ± 1.27^{cd}	88.81 ± 1.33^{a}	78.51 ± 0.72^{b}
	Season 2	78.51 ± 3.04^{b}	64.15 ± 1.08^{d}	68.89 ± 0.99^{cd}	68.89 ± 1.22^{cd}
MUZARDI	Season 1	67.11 ± 1.26^{d}	78.13 ± 3.24^{a}	67.5 ± 1.26^{d}	76.53 ± 1.40^{b}
	Season 2	78.51 ± 2.29^{b}	61.97 ± 2.11^{e}	71.82 ± 1.41^{c}	88.21 ± 1.26^{a}
NaFORRI	Season 1	76.53 ± 1.24^{b}	78.51 ± 1.27^{b}	76.44 ± 1.09^{b}	87.93 ± 1.43^{a}
	Season 2	86.13 ± 1.23^{a}	68.89 ± 1.14^{cd}	66.97 ± 0.57^{e}	60.97 ± 3.02^{e}

Values are means of three determinations ± standard deviation. Means followed by the same letter are not significantly different ($p < 0.05$) according to three-way ANOVA followed by Duncan's multiple range test.

3.3. Saponification Values of Oils from Different Avocado Varieties

Saponification values, which reflect the average molecular weight or chain length of fatty acids in an oil, showed significant variation across avocado varieties, seasons and sites, ranging from 163.21 ± 5.94 mg KOH/g (Hass at NaFORRI, Season 1) to 212.66 ± 18.04 mg KOH/g (Reed at NaFORRI, Season 2) as indicated in **Table 3**. In general, Reed and Semil 34 oils recorded the highest SVs across multiple sites, indicating a higher proportion of short- and medium-chain fatty acids with lower molecular weights. Conversely, Hass oils exhibited the lowest SVs, particularly at NaFORRI and MUZARDI, suggesting a dominance of long-chain fatty acids, which are associated with lower saponification values [8] [10]. Seasonally, most varieties demonstrated increased SVs in Season 2, possibly due to favorable fruit maturation and biochemical conversion pathways that promote fatty acid biosynthesis under slightly cooler and drier post-rainy conditions [18].

High saponification values are industrially significant as they indicate suitability for soap and cosmetic production, where short-chain fatty acids provide better lathering properties [25]. The consistently high SVs observed in Reed and Semil 34 align with reports by [24], who noted these varieties to possess higher levels of palmitic and stearic acids; components normally linked to higher SVs. The notably low values for Hass, especially at NaFORRI (163.21 mg KOH/g), suggest its oil may be better suited for nutritional and cooking applications, where longer-chain monounsaturated fatty acids like oleic acid are more desirable for health and oxidative stability [20]. These findings emphasize the importance of matching avocado varieties to end-use applications based on their oil characteristics and support the need for region-specific harvesting and processing strategies in Uganda's avocado value chain.

Table 3. Seasonal variations of saponification values (mg KOH/g) of oils extracted from different varieties from different locations.

		Avocado Varieties			
Location	**Season**	**Fuerte**	**Hass**	**Reed**	**Semil 34**
KMG	Season 1	184.10 ± 8.78^{cde}	177.13 ± 8.40^{fgh}	200.73 ± 6.69^{abc}	194.31 ± 4.45^{bcde}
	Season 2	195.51 ± 6.89^{bcde}	179.36 ± 4.11^{efg}	195.35 ± 6.83^{bcde}	201.24 ± 8.71^{ab}
MUZARDI	Season 1	195.44 ± 6.50^{bcde}	170.11 ± 7.94^{gh}	204.39 ± 9.57^{ab}	192.51 ± 2.97^{bef}
	Season 2	181.00 ± 8.70^{defg}	177.04 ± 8.25^{fgh}	191.81 ± 4.41^{bcd}	203.78 ± 7.43^{ab}
NaFORRI	Season 1	200.81 ± 7.05^{abc}	163.21 ± 5.94^{h}	196.73 ± 6.52^{bcd}	195.93 ± 5.95^{bcde}
	Season 2	179.37 ± 4.11^{efg}	181.72 ± 8.69^{defg}	212.66 ± 18.04^{a}	192.02 ± 2.54^{def}

Values are means of three determinations ± standard deviation. Means followed by the same letter are not significantly different ($p < 0.05$) according to three-way ANOVA followed by Duncan's multiple range test.

3.4. Oleic Acid Content of Oils from Different Avocado Varieties

Oleic acid content, a key monounsaturated fatty acid (MUFA) contributing to both the nutritional and oxidative stability of edible oils, varied significantly across avocado varieties, seasons and locations, ranging from 42.79 ± 0.35% (Semil 34, MUZARDI, Season 2) to 47.88 ± 1.74% (Hass, NaFORRI, Season 2) as shown in Table 4. Among the four varieties, Hass consistently exhibited the highest oleic acid content across all sites and seasons, confirming its superior nutritional quality and resistance to oxidative degradation. Reed also showed relatively high and stable oleic acid levels (ranging between 44.98% and 47.74%), while Semil 34 recorded the lowest values overall, especially in Season 2. These varietal differences can be attributed to genetic factors governing fatty acid biosynthesis and lipid metabolism [24]. Notably, oleic acid levels were generally higher during Season 1 compared to Season 2, especially in Fuerte and Semil 34, suggesting that seasonal influences such as ambient temperature, rainfall and photoperiod can affect lipid desaturation pathways [26].

From a nutritional and industrial standpoint, higher oleic acid content is desirable because it enhances the oil's thermal stability, shelf life and health benefits, especially in lowering LDL cholesterol and reducing cardiovascular risk [27]. The superior oleic acid profile of Hass observed in this study aligns with earlier findings by [20], who reported that Hass avocado oil contains up to 60% oleic acid in certain environments. While the slightly lower values recorded here may reflect site-specific agro-ecological constraints, such as soil fertility and microclimate, they are still within acceptable ranges for high-quality oils. The relatively low and fluctuating oleic acid levels in Semil 34 suggest that it may be less suited for applications requiring long storage or high-heat processing, unless refined or blended with more stable oils. Generally, these findings highlight the potential of Hass and Reed as premium varieties for both nutritional and industrial avocado oil production in Uganda's Lake Victoria Crescent Zone.

Table 4. Seasonal variation of oleic acid content (%) of oils from different varieties across different locations.

		Avocado Varieties			
Locations	**Season**	**Fuerte**	**Hass**	**Reed**	**Semil 34**
KMG	Season 1	44.46 ± 1.26^{def}	46.37 ± 0.90^{abcd}	47.74 ± 1.36^{ab}	45.03 ± 1.60^{defg}
	Season 2	46.22 ± 1.83^{efg}	44.53 ± 1.27^{ghi}	44.98 ± 0.24^{cde}	43.36 ± 1.45^{fghi}
MUZARDI	Season 1	46.29 ± 1.03^{cde}	47.52 ± 0.53^{ab}	46.28 ± 1.09^{abcd}	44.6 ± 2.17^{ghi}
	Season 2	44.72 ± 1.48^{defg}	47.35 ± 1.07^{abc}	46.43 ± 1.60^{cd}	42.79 ± 0.35^{fghi}
NaFORRI	Season 1	45.16 ± 0.46^{efghi}	46.86 ± 1.43^{abcd}	46.45 ± 0.47^{bcd}	45.19 ± 1.18^{bcde}
	Season 2	45.65 ± 0.67^{abc}	47.88 ± 1.74^{a}	45.15 ± 0.24^{efgh}	43.90 ± 0.96^{efghi}

Values are means of three determinations ± standard deviation. Means followed by the same letter are not significantly different ($p < 0.05$) according to three-way ANOVA followed by Duncan's multiple range test.

3.5. Linoleic Acid Content of Oils from Different Avocado Varieties

Linoleic acid content, a polyunsaturated fatty acid (PUFA) essential for human health and a determinant of oil stability, varied significantly among avocado varieties, seasons, and locations, with values ranging from 10.71 ± 0.37% (Reed, KMG, Season 2) to 15.44 ± 1.77% (Hass, NaFORRI, Season 2) as reported in Table 5. Hass consistently exhibited the highest linoleic acid levels across most locations and seasons, with peak values observed during Season 2. In contrast, Reed showed notably lower linoleic acid contents, especially during Season 2 at KMG and NaFORRI. Seasonal differences were marked, with higher linoleic acid levels generally observed in Season 2, potentially due to increased enzymatic desaturation activity in response to cooler post-rainfall temperatures and higher humidity, which enhance the conversion of oleic to linoleic acid [28]. These findings align with previous studies by [29], who demonstrated that avocado oil fatty acid composition is sensitive to seasonal temperature fluctuations and genotype-environment interactions.

Nutritionally, higher linoleic acid contributes to essential fatty acid intake and has been associated with cardiovascular benefits, although elevated levels can reduce oil oxidative stability due to its higher degree of unsaturation [30]. The high PUFA content in Hass oil, while favorable for dietary purposes, may necessitate protective packaging or antioxidants during processing to prevent rancidity. On the other hand, the lower linoleic acid levels in Reed and Fuerte oils may confer enhanced shelf stability, favoring industrial applications such as frying or cosmetics. Compared to earlier studies on avocado cultivars from Mexico and South Africa reporting linoleic acid ranges between 8% - 16% [21] [24], the values observed in this study fall within expected limits, though with site-specific fluctuations. These results highlight the importance of considering both variety and seasonal timing when targeting oil extraction for specific nutritional or functional uses in Uganda's Lake Victoria Crescent agro-ecological zone.

Table 5. Seasonal variations of linoleic acid content (%) of oils from different avocado varieties across different locations.

		Avocado Varieties			
Location	**Season**	**Fuerte**	**Hass**	**Reed**	**Semil 34**
KMG	Season 1	12.62 ± 2.15^{cde}	14.17 ± 1.08^{abcd}	12.64 ± 0.55^{cdefg}	13.88 ± 1.22^{abcde}
	Season 2	12.19 ± 0.93^{cdefg}	15.18 ± 1.05^{ab}	10.71 ± 0.37^{g}	11.95 ± 0.92^{defg}
MUZARDI	Season 1	11.85 ± 0.86^{efg}	14.33 ± 0.45^{abc}	12.28 ± 0.50^{cdefg}	14.11 ± 0.99^{abcd}
	Season 2	11.53 ± 1.22^{fg}	15.33 ± 0.70^{a}	11.71 ± 1.57^{efg}	13.09 ± 2.47^{bcdef}
NaFORRI	Season 1	13.56 ± 0.91^{cdef}	13.51 ± 1.17^{abcd}	14.35 ± 1.16^{abc}	12.28 ± 0.86^{cdefg}
	Season 2	11.66 ± 1.67^{efg}	15.44 ± 1.77^{a}	11.58 ± 0.50^{fg}	11.42 ± 1.09^{fg}

Values are means of three determinations ± standard deviation. Means followed by the same letter are not significantly different ($p < 0.05$) according to three-way ANOVA followed by Duncan's multiple range test.

4. Conclusion

This study highlights the critical importance of a cultivar-site-season-specific approach for optimizing avocado oil production in Uganda's Lake Victoria Crescent Zone. The findings show that tailored strategies are essential to maximize the nutritional and industrial value of the oil. For instance, the Hass cultivar, with its superior oleic acid content and oxidative stability, is a prime candidate for producing high-quality edible oils. Conversely, cultivars like Reed and Semil 34 are better suited for industrial applications due to their high saponification values. The research also reveals that a holistic understanding of the interaction between genotype, growing environment, and harvest timing is necessary for stakeholders to make informed decisions about resource allocation and market targeting. Ultimately, these insights can help Ugandan producers add significant value to their avocado crops by developing diverse product lines that meet specific market demands, from premium nutritional products to specialized industrial ingredients. This strategic framework can lead to greater profitability and sustainability for the local avocado industry.

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Author Contributions

Conceptualization, B.B, B.M.Z, K.H, M.S, K.F, I.J; methodology, B.B, K.H, I.J; formal analysis, B.B, K.H; investigation, B.B, K.H; resources, B.M.Z, M.S, K.F; writing-original draft preparation, B.B.; writing-review and editing, B.B, B.M.Z, K.H, M.S, K.F; visualization, B.B; supervision, B.M.Z, I.J, M.S, K.F.

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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