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Variations in Physicochemical Quality Indices of Avocado Pulp Oils from Selected Varieties Grown across Different Sites and Seasons in the Lake Victoria Crescent Agro-Ecological Zone of Uganda

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Abstract

This study evaluated the physicochemical quality indices of avocado pulp oils from four varieties (Fuerte, Hass, Reed and Semil 34) grown across three locations and two harvest seasons in Uganda's Lake Victoria Crescent Agro-ecological Zone. Parameters assessed included peroxide value (PV), acid value (AV), iodine value (IV), saponification value (SV) and thiobarbituric acid reactive substances (TBARS). The results revealed significant variations ($p < 0.05$) across varieties, sites and seasons. PVs were highest in Fuerte from MUZARDI during Season 1 (3.27 ± 0.36 meq O_2/kg), while Hass and Semil 34 oils showed greater oxidative stability across sites. AVs ranged from 0.30 ± 0.02 to 0.67 ± 0.02 mg KOH/g, with Reed exhibiting consistently higher values, suggesting greater hydrolytic degradation. TBARS values were generally low, with Hass in Season 2 showing the least (1.04 ± 0.11 mg MDA/kg). IVs peaked in Reed (88.81 ± 1.33 mg I_2/g), indicating a higher degree of unsaturation, while SVs ranged from 163.21 to 212.66 mg KOH/g, with Reed and Semil 34 showing the highest values. All indices fell within Codex Alimentarius limits, for virgin avocado oil, indicating acceptable oil quality. These findings highlight the influence of genotype and environment on avocado oil quality and provide guidance for optimizing harvest timing, variety selection and oil processing in Uganda and similar agro-ecological regions.

Keywords

Physicochemical Parameters, Avocado Oil, Varieties

1. Introduction

Avocado (Persea Americana) has emerged as a globally significant fruit due to its nutritional richness and the exceptional quality of its oil, which is increasingly valued for nutritional, cosmetic, and pharmaceutical applications [1]. Avocado oil, often referred to as "green gold," is characterized by a favorable fatty acid profile, high oxidative stability, and functional bioactive compounds such as phytosterols and tocopherols [2]. With rising consumer demand for healthy plant-based oils, the global avocado oil market is projected to grow steadily, driven by health-conscious trends and diversification in cosmetic and food industries [3] [4].

Global avocado production reached approximately 8.98 million metric tons in 2022, reflecting a 4.7% increase from the previous year and an estimated compound annual growth rate of 7% between 2012 and 2022 [5]. This sustained growth highlights the increasing global demand for avocados. Additionally, the global avocado market is projected to expand significantly, from USD 9 billion in 2021 to nearly USD 20 billion by 2026, driven by rising consumption and industrial utilization, including oil extraction for cosmetic and nutraceutical purposes [6].

In sub-Saharan Africa, including Uganda, avocado cultivation is expanding, particularly in agro-ecological zones such as the Lake Victoria Crescent, which offers favorable climatic and soil-related conditions [7]. The extent to which these factors influence oil quality remains largely undocumented. However, the physicochemical quality of avocado pulp oils can vary significantly with variety, geographical location and seasonality; factors that influence lipid composition, oxidative stability and shelf life [8]. Despite the increasing agronomic interest and value addition potential of avocado oil in Uganda, systematic studies evaluating these variations remain limited.

Understanding how site-specific environmental variables and seasonal dynamics affect physicochemical indices such as acid value (AV), iodine value (IV), peroxide value (PV), saponification value (SV) and thiobarbituric acid reactive substances (TBARS) is critical for optimizing postharvest handling, processing and market positioning [9] [10].

This study assessed the variations in these key oil quality parameters among selected avocado varieties cultivated across multiple sites and seasons within the Lake Victoria Crescent agro-ecological zone. The findings aim to inform both producers and processors on cultivar-site-season interactions that influence oil stability and quality, with implications for value chain development and standards compliance in Uganda and beyond.

2. Materials and Methods

2.1. Study Area and Experimental Design

This study was carried out in the Lake Victoria Crescent Agro-ecological Zone of Uganda, targeting three distinct geographical sites: Mukono Zonal Agricultural Research and Development Institute (MUZARDI) in Ntawo (latitude: 0.380N, longitude 32.750E), National Forestry Resources Research Institute (NaFORRI),

(latitude 0.420N and longitude 32.730E and Kamenyamiggo (KMG), Lwengo district (Latitude: 0.18˚S, Longitude 31.39˚E). These locations were purposively selected due to their active avocado production and difference in the microclimates. KMG, which is farther inland, has different soil and vegetation characteristics, experiencing a drier microclimate with more potential for moisture stress and soil limitations, while NaFORRI's microclimatic condition is characterized by a forested environment providing a cooler, more humid microclimate compared to MUZARDI's, which is more open agricultural landscape where climate effects are more pronounced within the Lake Victoria Crescent Agro-ecological Zone, Central Uganda.

The study was carried out across two consecutive harvest seasons: Season 1 (March-May 2023) and Season 2 (September-November 2023), using a factorial design to assess the effects of geographical location, avocado variety and season on the physicochemical properties of avocado pulp oils.

2.2. Avocado Varieties and Fruit Sampling

Four avocado varieties, Hass, Fuerte, Reed, and Semil 34, were selected based on their predominance in Uganda. Hass is the most dominant variety cultivated by most farmers, accounting for approximately 80% - 83%, Fuerte contributes 10% - 15%, Reed and Semil 34 both contribute 5% - 10% of the avocado production in Uganda [11]. Ripe fruits were manually harvested from five trees per variety at each site. The fruits were manually sorted, cleaned to remove dirt and debris and washed with clean water. They were then kept at room temperature (25˚C) to ripen uniformly before oil extraction.

2.3. Avocado Oil Extraction

Avocado oil was extracted from the ripe pulp using the cold-press method adapted from [12]. Briefly, dried avocado pulp was mechanically pressed at room temperature using an oil press machine at the MUZARDI Value Addition Laboratory. This technique preserves the oil's sensory and compositional integrity. The extracted oils were collected, filtered, and stored in amber glass bottles at 4˚C pending analysis.

2.4. Determination of Physicochemical Quality Indices

All analyses were performed in triplicate for each sample. The following standardized methods were applied.

2.4.1. Peroxide Value (PV)

Peroxide value was determined following the method of [12]. Three milliliters of oil were measured into a 250 mL Erlenmeyer flask, followed by 50 mL of a solvent mixture (acetic acid: chloroform). Then, 1 mL of saturated potassium iodide was added, and the mixture was agitated for 60 seconds. After adding 100 mL of distilled water, the solution was titrated with 0.1 M sodium thiosulfate using 1 mL of starch indicator until the color changed from deep blue to colorless. PV (milli

equivalents of peroxide per liter) was calculated as:

$$\text{PV} = (100N(S - B)/(\text{weight of sample}) \text{ (g)}$$

where N is normality of sodium thiosulfate, S is sample titration volume, and B is blank titration volume.

2.4.2. Acid Value (AV)

Acid value was determined according to [13]. 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:

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

2.4.3. Thiobarbituric Acid Reactive Substances (TBARS)

TBARS values were measured based on [14]. A 0.2 mL oil aliquot was homogenized in 5 mL of 1-butanol and diluted to 25 mL. Two and a half milliliters of the extract was reacted with 2.5 mL of freshly prepared TBA reagent (67 mg TBA in 1 mL DMSO, topped up with 9 mL distilled water) in a test tube. The mixture was incubated in a water bath at 95˚C for 2 hours, cooled, and the absorbance was read at 530 nm. TBARS (mg MDA eq/kg oil) was calculated as:

$$\text{TBARS} = (50 * (As - Ab))/(\text{weight of sample})$$

where As = Absorbance of the sample, Ab = Absorbance of the blank.

2.4.4. 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 of 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:

$$\text{IV} = ((\text{Volume of sodium thiosulfate (mL)} \times M \times 12.691))/(\text{Weight of the sample (g)})$$

where M = molarity of sodium thiosulfate.

2.4.5. Saponification Value (SV)

Saponification value was measured following [16]. Two milliliters of oil were mixed with 25 mL of 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:

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

where V_0 = volume of HCl for blank, V_1 = volume of HCl for sample, and C = HCl concentration.

2.5. Statistical Analysis

All measurements were performed in triplicates. Data were analyzed using Gen-

Stat 14.1 (VSN International, UK). A three-way ANOVA was used to assess the main and interaction effects of variety, site and season on physicochemical properties. Where significant differences were observed ($p < 0.05$), Duncan's Multiple Range Test was applied for post hoc comparisons. Results were presented as means ± standard deviation (SD).

3. Results and Discussion

3.1. Peroxide Values of Oils from Different Avocado Varieties

As shown in Table 1, peroxide values (PV), which indicate the extent of primary lipid oxidation in oils [17] [18], varied significantly across avocado varieties, locations and seasons ($p < 0.05$). Overall, higher PVs were observed during Season 1 compared to Season 2 for most varieties, especially at MUZARDI and NaFORRI. For instance, Fuerte from MUZARDI recorded the highest PV (3.27 ± 0.36 meq O_2/kg) in Season 1, while the same variety had a lower value (2.18 ± 0.38 meq O_2/kg) in Season 2. Similar trends were observed in Semil 34 at NaFORRI (3.06 ± 0.08 in Season 1 vs. 2.53 ± 0.26 in Season 2), suggesting greater oxidative degradation in the earlier season. This could be attributed to higher ambient temperatures and relative humidity during Season 1, which accelerate lipid oxidation [19]. Additionally, Reed from MUZARDI also showed a striking increase in PV during Season 2 (3.06 ± 0.08), likely due to site-specific postharvest handling or delayed ripening due to enzymes such as lipoxygenases and peroxidases remain active for an extended period, factors known to influence peroxide accumulation [20].

Table 1. Seasonal variations of peroxide values (meq O_2/kg) of oils extracted from different varieties from different locations.

		Avocado Varieties			
Location	**Season**	**Fuerte**	**Hass**	**Reed**	**Semil 34**
KMG	Season 1	2.43 ± 0.26^{def}	2.53 ± 0.10^{bcde}	2.93 ± 0.21^{abc}	2.49 ± 0.10^{de}
	Season 2	3.07 ± 0.11^{a}	2.25 ± 0.20^{def}	2.27 ± 0.30^{def}	2.23 ± 0.13^{f}
MUZARDI	Season 1	3.27 ± 0.36^{a}	2.49 ± 0.10^{de}	2.45 ± 0.10^{de}	2.90 ± 0.21^{ab}
	Season 2	2.18 ± 0.38^{ef}	2.02 ± 0.13^{f}	3.06 ± 0.08^{a}	2.27 ± 0.30^{def}
NaFORRI	Season 1	2.63 ± 0.40^{bcd}	2.27 ± 0.30^{def}	2.24 ± 0.19^{def}	3.06 ± 0.08^{a}
	Season 2	2.33 ± 0.22^{def}	2.45 ± 0.10^{de}	2.49 ± 0.10^{bde}	2.53 ± 0.26^{bde}

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.

The observed seasonal and varietal variations in PVs may also be linked to differences in inherent antioxidant content and fatty acid composition among avocado genotypes. Hass and Semil 34 consistently demonstrated lower PVs across most locations and seasons, implying better oxidative stability; consistent with findings by [21], who noted that Hass contains higher tocopherol and monoun-

saturated fatty acids than other varieties. On the other hand, the elevated PVs in Fuerte and Reed oils, particularly from MUZARDI and KMG, suggest these varieties are more susceptible to peroxidation, potentially due to higher polyunsaturated fatty acid (PUFA) content, which oxidizes more readily [22]. Despite some seasonal differences, all peroxide values remained below the Codex Alimentarius limit for virgin avocado oil of 10 meq O_2/kg for virgin oils, indicating acceptable quality [23]. These findings highlight the role of site-season-genotype interactions in determining oil stability, reinforcing the need for optimized harvesting, processing and storage tailored to each production environment.

3.2. Acid Values of Oils from Different Avocado Varieties

Acid value (AV), a measure of free fatty acid content and an indicator of oil hydrolytic degradation [13], exhibited notable variation across seasons, avocado varieties and locations ($p < 0.05$) as shown in **Table 2**. Reed consistently exhibited the highest acid values across all sites and seasons, with the highest recorded at MUZARDI in Season 1 (0.67 ± 0.02 mg KOH/g) and NaFORRI in Season 2 (0.62 ± 0.01 mg KOH/g). In contrast, Hass and Semil 34 demonstrated lower AVs, particularly Hass at NaFORRI in Season 1 (0.30 ± 0.02 mg KOH/g), suggesting better oxidative and hydrolytic stability. These differences are likely influenced by the varietal differences in lipase activity, moisture content and postharvest handling characteristics [24]. Avocado oil with higher free fatty acids (*i.e.*, higher AV) can result from enzymatic breakdown of triglycerides, especially when fruits are harvested overripe or improperly stored [21] [25].

Table 2. 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.

Seasonal patterns also emerged, with generally higher acid values recorded in Season 1 compared to Season 2 for most varieties, especially for Reed and Fuerte at MUZARDI and KMG. This seasonal increase may be attributed to greater humidity and higher ambient temperatures during Season 1, which accelerate enzymatic and microbial activity leading to triglyceride hydrolysis [19]. These findings

align with observations by [20], who noted seasonal influences on oil quality indices in avocado varieties from East Africa. Despite these variations, all AVs remained well below the Codex Alimentarius maximum limit for virgin avocado oil of 4.0 mg KOH/g for virgin avocado oils [23], indicating that the oils analyzed were of good quality. The results emphasize the importance of cultivar selection and harvest timing in managing oil acidity, with implications for oil extraction and value chain optimization in Uganda and similar agro-ecological settings.

3.3. Thiobarbituric Acid Reactive Substances of Oils from Different Avocado Varieties

Thiobarbituric acid reactive substances (TBARS), which measure secondary lipid oxidation products like malondialdehyde (MDA) [26] [27], varied across varieties, seasons and locations, although most differences were statistically non-significant ($p > 0.05$) as indicated in **Table 3**. The highest TBARS value was recorded in Reed from NaFORRI in Season 2 (1.87 ± 0.05 mg MDA/kg), followed closely by Reed from KMG in Season 1 (1.84 ± 0.16 mg MDA/kg). In contrast, Hass and Semil 34 from NaFORRI in Season 1 and 2 consistently exhibited the lowest values, with the lowest being Hass in Season 2 (1.04 ± 0.11 mg MDA/kg). These results suggest that Reed may be more susceptible to lipid peroxidation, possibly due to its higher polyunsaturated fatty acid content or lower natural antioxidant levels, as previously observed by [21] [28]. Lower TBARS values, such as those recorded in Hass, indicate greater oxidative stability, a quality highly desirable for edible oils.

Table 3. Seasonal variations of Thiobarbituric acid reactive substances value (mg MDA/kg) of oils from different avocado varieties from different locations.

		Avocado Varieties			
Location	**Season**	**Fuerte**	**Hass**	**Reed**	**Semil 34**
KMG	Season 1	1.51 ± 0.38^{ab}	1.43 ± 0.18^{ab}	1.84 ± 0.16^{a}	1.38 ± 0.49^{ab}
	Season 2	1.67 ± 0.20^{ab}	1.39 ± 0.17^{ab}	1.60 ± 0.44^{ab}	1.42 ± 0.53^{ab}
MUZARDI	Season 1	1.38 ± 0.18^{ab}	1.38 ± 0.20^{ab}	1.37 ± 0.45^{ab}	1.37 ± 0.15^{ab}
	Season 2	1.36 ± 0.40^{ab}	1.34 ± 0.09^{ab}	1.57 ± 0.30^{ab}	1.14 ± 0.21^{b}
NaFORRI	Season 1	1.26 ± 0.62^{ab}	1.12 ± 0.11^{b}	1.12 ± 0.20^{b}	1.13 ± 0.28^{b}
	Season 2	1.27 ± 0.50^{ab}	1.04 ± 0.11^{b}	1.87 ± 0.05^{a}	1.67 ± 0.37^{ab}

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.

Seasonal trends revealed a moderate increase in TBARS values during Season 2 at most locations, particularly for Reed and Semil 34, suggesting enhanced lipid oxidation likely due to greater postharvest exposure to oxygen, light or temperature fluctuations during oil processing or fruit storage [19]. Interestingly, MUZARDI recorded the most stable TBARS values across all varieties and seasons, possibly reflecting better environmental or postharvest handling conditions. Alt-

hough the recorded values were within the acceptable oxidative threshold for edible plant oils (typically < 2.0 mg MDA/kg), elevated TBARS in Reed oil samples may affect shelf life and sensory quality. These observations are consistent with studies from East Africa and beyond [25] [29], emphasizing the need to consider both genotype and seasonal timing in optimizing avocado oil quality in Uganda's agro-ecological zones.

3.4. Iodine Values of Oils from Different Avocado Varieties

As reported in Table 4, Iodine value (IV) which is a measure of unsaturation in fats and oils [30], varied significantly across avocado varieties, sites and seasons ($p < 0.05$), indicating that environmental and genetic factors influence fatty acid composition. Fuerte and Reed varieties generally exhibited the highest IVs, particularly at KMG in Season 1 (87.93 ± 2.14 and 88.81 ± 1.33 mg I_2/g, respectively), suggesting a higher proportion of unsaturated fatty acids such as oleic and linoleic acids. On the other hand, the lowest IVs were recorded in Hass and Semil 34 at MUZARDI and NaFORRI in Season 2, with values as low as 60.97 ± 3.02 mg I_2/g and 61.97 ± 2.11 mg I_2/g, respectively. This reflects a relative increase in saturated fatty acids under certain seasonal and site-specific conditions. The seasonal decline in IVs, especially between Season 1 and Season 2 in varieties like Hass and Semil 34, may be due to climatic stressors (e.g., temperature and rainfall) that modulate lipid biosynthesis during fruit development [21] [31].

Table 4. 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.

These findings are consistent with previous studies which demonstrate that environmental variables such as temperature, altitude and harvest timing can significantly influence the degree of unsaturation in avocado oils [29] [32]. Worth noting is that the values obtained in this study fall within the range reported for cold-pressed avocado oils (60 - 90 mg I_2/g), supporting their classification as unsaturated vegetable oils with nutritional and oxidative benefits [33]. Higher IVs, as observed in Fuerte and Reed, are desirable for cardiovascular health due to their

richness in monounsaturated fats [34]. However, greater unsaturation may also predispose oils to oxidation if not properly stored. These results affirm the importance of varietal selection and harvest timing in optimizing oil quality for industrial and nutritional applications in Uganda and similar agro-ecological zones.

3.5. Saponification Values of Oils from Different Avocado Varieties

The saponification values (SV), which indicate the average molecular weight of fatty acids in oils [35], showed significant variation across avocado varieties, locations and seasons ($p < 0.05$) as reported in Table 5. Reed and Semil 34 varieties consistently exhibited higher SVs, with the highest value (212.66 ± 18.04 mg KOH/g) recorded for Reed at NaFORRI during Season 2, suggesting a predominance of shorter-chain fatty acids or higher proportions of triglycerides with lower molecular weights. In contrast, Hass oils had significantly lower SVs, particularly at NaFORRI in Season 1 (163.21 ± 5.94 mg KOH/g), implying a dominance of longer-chain fatty acids or higher molecular weight triglycerides. Fuerte and Semil 34 varieties generally displayed moderate to high SVs, with values ranging from approximately 179 to 201 mg KOH/g, indicating considerable variability based on both genetic and environmental factors.

Table 5. 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.

These findings align with previous studies indicating that varietal genetics, soil nutrient composition and climatic factors influence fatty acid biosynthesis and accumulation in avocado fruits [21] [34]. For instance, higher ambient temperatures and adequate rainfall during fruit development may enhance lipid metabolism, promoting the formation of medium-chain fatty acids and increasing SVs [31]. The seasonal fluctuation in SVs; especially the increase in Season 2 for some varieties, could also be attributed to differences in fruit maturity and harvest timing, as lipase activity and lipid accumulation are influenced by environmental stress and ripening stage [29] [36]. The range of SVs observed in this study (163 - 213 mg KOH/g) is within the typical range for edible oils and comparable to cold-

pressed avocado oils reported in other studies [32], confirming the suitability of these Ugandan avocado varieties for nutritional and industrial applications like soap manufacturing.

4. Conclusion

The observed variations underscore the critical role of variety, location, and seasonal dynamics in shaping the physicochemical properties of avocado pulp oils. Despite these variations, all oils met Codex standards for virgin avocado oils. Understanding these interactions can inform targeted selection of varieties and production conditions to optimize oil stability, composition, and suitability for specific end uses. This knowledge is particularly valuable for producers, processors, and policymakers aiming to enhance the value of avocado oil in both local and international markets, while supporting its diverse applications in nutrition, cosmetics, and industry in Uganda.

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Contributions of Authors

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 that they have no conflicts of interest.

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