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Oxidative and Frying Stabilities of *Monodora myristica* (Gaertn.) Dunal Seed Oil of Nigerian Origin

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HIGHLIGHTS

- *Monodora myristica* seeds had 37.64% oil yield and the oil was non-drying and free from rancidity.
- *M. myristica* seeds oil had better oxidative stability with 80% lesser peroxide formation than Kings vegetable oil.
- The frying stability of *M. myristica* seeds oil was better than Kings vegetable oil after frying.

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Acronyms and abbreviations
FFA=Free Fatty Acid
KVO=Kings Vegetable Oil
MMSO=Monodora myristica Seed Oil
PUFA=Polyunsaturated Fatty Acid

ABSTRACT

Background: The demand for vegetable oils is on the increase. Deep frying is the commonest method by which vegetable oils are consumed. The aim of this study was to extract oil from an underutilized oil seed and compare its physicochemical properties, frying, and oxidative stability with those of commercial refined palm oil.

Methods: Oil was extracted from *Monodora myristica* seeds using a soxhlet fat extractor and the percentage oil yield was determined. The physicochemical, oxidative, and frying stabilities of the extracted *M. myristica* Seed Oil (MMSO) were evaluated based on the standard procedure of the Association of Official Agricultural Chemists and official methods and recommended practices of the American Oil Chemists Society and compared with those of commercial refined palm oil- Kings Vegetable Oil (KVO). Data were statistically analyzed using SPSS version 20.

Results: The oil yield of *M. myristica* seed was 37.64%. The refractive index, specific gravity, moisture content (%), and peroxide value (mEq/kg) were respectively 1.470, 1.468, 0.923, and 0.917 for MMSO; and 0.220, 0.253, 1.05, and 3.50 for KVO. MMSO had better oxidative stability and showed 80% lesser peroxide formation than KVO. The frying stability of MMSO was better as it showed a lower increase in FFA (28.4%) and peroxide value (9.54 mEq/kg) than KVO (45.99% and 26.19 mEq/kg, respectively) after frying.

Conclusion: Deteriorative effect of oxidation and polymerization was lower in MMSO than in KVO indicating MMSO to be superior frying oil suitable for repeated frying.

Introduction

Vegetable oils are an important component of human livelihood all over the world (Ogunsina et al., 2014). The link between vegetable oils and good health has been stressed from many angles ranging from avoidance of

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cardiovascular diseases to functions in the various biochemical operations (Raphael et al., 2010). Vegetable oils supply the majority of the fatty acids, vitamin E, and certain phytochemicals needed in the daily human diet to promote appropriate physiological activities (Zhao et al., 2021). So far, world oil consumption was dominated by palm, soybean, rapeseed, and sunflower oils (Zhao et al., 2021). The demand for oils has escalated lately due to industrial and nutritional operations (Oti-Boakye et al., 2018). In Nigeria, the principal sources of edible oils are groundnut, palm, and coconut (Aremu et al., 2015). It is therefore necessary to explore lesser-known oilseed crops for oils (Mancini et al., 2015).

Monodora myristica (Gaertn.) dunal is a tropical tree from the custard apple or *Annonaceae* family and its ultimate economically essential parts are the seeds (Ojiako et al., 2010). The sweet-scented seeds are antiemetic, aperient, stimulant, stomachic, and tonic; and they are introduced in medicines to convey stimulating effects (Agiriga and Siwela, 2018). *M. myristica* seeds contain about 46.4% of a light golden brown crude oil (Agiriga and Siwela, 2018). The seed oil has a peculiar fatty acid profile which makes it appropriate for many food operations, consisting of 88.47% unsaturated fatty acids, of which linoleic and oleic acids are dominant (Bello et al., 2014). Many authors have reported that oils containing unsaturated fatty acids especially linoleic and oleic acids can be used to lower plasma cholesterol and are also healthy substitutes for hydrogenated vegetable oils (Ezeuko et al., 2017; Oti-Boakye et al., 2018). Olive oil, the widest known in this group, is rarely used for frying because it is expensive. The physicochemical composition and oil characterization of *M. myristica* Seed Oil (MMSO) of an African cultivar have been investigated by various authors in Delta state, Nigeria (Raphael et al., 2010), Ogun state, Nigeria (Ezeuko et al., 2017), Ghana (Oti-Boakye et al., 2018), Oyo state, South West Nigeria (Bello et al., 2014), and Imo state, Nigeria (Nwagbo et al., 2020) envisaging its prospect as another vegetable oil source.

Deep frying is the popular way in which vegetable oils are used in human nutrition (Ogunsina et al., 2014). The frequent use of frying oils, usually at very high temperatures in the presence of air and moisture is a common practice in the food industry (Lalas et al., 2006). This usually changes the physicochemical properties of the frying oil, thus leading to the formation of unwanted constituents that may have adverse effects on consumers' health (Hammouda et al., 2019). The amount of Free Fatty Acid (FFA) gives critical information about the hydrolytic rancidity in continuous deep fat frying operations (Hammouda et al., 2019). Oxidative and frying stabilities are therefore important qualities for frying oils. Frying stability of *Moringa stenopetala* seed oil (Lalas et al., 2006), as well as *M. oleifera Jaffna* variety of Indian origin (Ogunsina et al., 2014), has been studied.

Refined palm oil is very popular as cooking oil in Nigeria because of its low cost and higher stability during frying compared to other edible oils (Uddin et al., 2020). In this study, the physicochemical characteristics of MMSO of Nigerian origin obtained by solvent extraction were evaluated in comparison with that of commercial refined palm oil. The oxidative and frying stabilities of the solvent-extracted MMSO which has not been reported so far were also evaluated in comparison with that of the commercial refined palm oil.

Materials and methods

Materials

Dried *M. myristica* seeds without any pest infestation or damage harvested wild at Oke Oro Ekiti were purchased from Oja Oba (Kings Market) Ado-Ekiti, Ekiti state, Nigeria. Refined palm oil as Kings Vegetable Oil (KVO) was procured from a Nigerian supermarket in South Africa and kept in a cool dry place prior to analysis. All the chemicals/reagents used were from Sigma-Aldrich Co., Ltd. (Steinheim, Germany).

Extraction of MMSO

M. myristica seeds were thoroughly cleaned and extraneous materials were removed. They were subsequently dehulled. Dehulled seeds were milled into fine flour using an electric grinder- KenStar super blender, model No: KS-988, Malaysia. Oil was extracted from the fine flour using a Buchi 810 soxhlet fat extractor (BÜCHI Labortechnik AG, Flawil, Switzerland) with n-hexane as the extracting solvent. The extraction was done bit by bit within 96 h. A rotary evaporator set up at temperatures between 40-50 ^{o}C was used to remove the excess solvent. The oil was kept in amber bottles wrapped with nylon to avoid oxidative rancidity and stored at room temperature until required.

Determination of percentage oil yield

The percentage yield of oil recovered after extraction was determined using the equation below as described by Ezeuko et al. (2017).

Yield of oil (%)=(weight of oil (g)/weight of sample (g))×100

Physical properties of MMSO and KVO

The refractive index was determined using a calibrated Abbe Refractometer (Model NAR-3 T, ATAGO Co.,

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Japan). Specific gravity was calculated using a 10 ml pycnometer bottle as described by Ogunsina et al. (2014). Color was determined by visual perception. Viscosity was determined using a viscometer (Model R1:3:M-3, Rheology International Ltd, Ireland) as described by Ogunsina et al. (2014). Oil samples (80 ml) were filled into a 100 ml sample adaptor. The ASTM spindle size (number 3) was immersed into the oil to the marked portion. Viscosity was measured under ambient temperature conditions (26±2 °C) at 30 rpm rotor speed.

Chemical properties of MMSO and KVO

Moisture content was determined according to AOAC (2002). Iodine value, peroxide value, saponification value, percentage FFA, unsaponifiable matter content, and acid value were determined as described by AOCS (2004). The total polar matter was determined using the Fri-check instrument (Grote Bean, 375, B2,235 Hulshout, Belgium) as described by Ogunsina et al. (2014). Oil samples were filled into the cylindrical sensor tube and the tube was inserted into the Fri-check unit. The displayed reading on the digital display was taken as the percent total polar matter content of the sample.

Oxidative stability

The oxidative stability of MMSO and KVO was evaluated using the procedure of Bhatnagar et al. (2009). Oil samples (about 40 g×3 batches) in 50 ml beakers were incubated at 37 ºC and 55% relative humidity in a laboratory incubator. The peroxide value of oil samples was determined in duplicates (2 g×2) at weekly intervals for six weeks.

Frying stability

The frying stability of MMSO was investigated in comparison with KVO using the method described by Lalas et al. (2006) with minor modifications. About 5 kg of fresh potatoes procured from a local supermarket in Pietermaritzburg, South Africa were peeled and sliced into discs of average thickness and diameter, 1.5 mm and 51 mm, respectively. Two kg each of MMSO and KVO were used for frying. Potato slices (10 batches of 250 g each) were fried in oil samples heated to 180±5 °C in 10 repeated sessions spanning a total time of 2 h. The frying oil was not changed in-between frying. Oil samples were analyzed in duplicates before and after frying. The FFA, peroxide value, and viscosity of oil samples drawn before and after frying were determined.

Statistical analysis

Data generated were subjected to statistical analysis using SPSS statistical software package (version 20, SPSS Inc., USA). Data were subjected to one-way analysis of variance (ANOVA) and post-hoc Duncan's Multiple Range Test (DMRT) to determine statistical differences and the level of significance ($p \leq 0.05$). Data were presented as mean value±standard deviation.

Results

The percentage amount of oil extracted from *M. myristica* seeds (oil yield) was 37.64% and the oil was observed to be golden brown in color while KVO was observed to be golden yellow in color.

The refractive index, specific gravity, moisture content (%), and peroxide value (mEq/kg) were respectively 1.470, 1.468, 0.923, and 0.917 for MMSO; and 0.220, 0.253, 1.05, and 3.50 for KVO. Some of the physical and chemical properties of the freshly expressed MMSO and KVO are shown in Tables 1 and 2, respectively.

MMSO had better oxidative stability and showed 80% lesser peroxide formation than KVO. Changes in the peroxide value of MMSO and KVO during incubation at 37 °C and 55% relative humidity are shown in Figure 1 and the mean±standard deviation of each point is shown in Table 3. The results indicated a greater inhibitory effect of MMSO against the formation of peroxides than KVO ($p<0.05$). The frying stability of MMSO was better as it showed a lower increase in FFA (28.4%) and peroxide value (9.54 mEq/kg) than KVO (45.99% and 26.19 mEq/kg, respectively) after frying. Also, the data from the frying study is given in Figure 2.

Table 1: Physical properties of *Monodora myristica* Seed Oil (MMSO) and Kings Vegetable Oil (KVO)

Oil samples	Oil color	Refractive index (at 38 ºC)	Specific gravity (at 38 ºC)	Viscosity (mPa.s)
MMSO	Golden brown	1.470±0.028 [a]	0.923±0.042 [a]	41.5±0.000 [a]
KVO	Light yellow	1.468±0.000 [a]	0.917±0.184 [a]	43.00±0.778 [a]

Data in same column with different letters are significantly different ($p \leq 0.05$).

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Table 2: Chemical properties of *Monodora myristica* Seed Oil (MMSO) and Kings Vegetable Oil (KVO)

Parameters	MMSO	KVO
Moisture content (%)	0.220±0.071 [a]	0.253±0.014 [a]
Peroxide value (mEq/kg)	1.05±0.014 [b]	3.50±1.177 [a]
Acid value (mg KOH/g)	1.32±0.042 [a]	2.54±0.585 [a]
Saponification value (mg KOH/g)	227.28±1.867 [a]	163.35±5.261 [b]
FFA (%)	1.44±0.071 [a]	1.75±0.240 [a]
Iodine value (g/100 g)	71.325±2.871 [b]	105.10±6.208 [a]
Unsaponifiable matter (g/kg)	1.08±0.042 [b]	2.415±0.099 [a]
Total polar matter (%)	2.55±0.000 [b]	4.85±0.057 [a]

FFA=Free Fatty Acid; Data in same row with different letters are significantly different ($p \leq 0.05$).

Table 3: Mean±standard deviation of the oxidative stability of *Monodora myristica* Seed Oil (MMSO) and Kings Vegetable Oil (KVO)

Incubation period (days)	Peroxide value (mEq/kg)	
	MMSO	KVO
0	1.05±0.156 [b]	3.5±0.127 [a]
7	2.85±0.127 [b]	10.75±0.000 [a]
14	3.31±0.424 [b]	12.66±1.443 [a]
21	3.71±0.212 [b]	17.06±1.626 [a]
28	3.84±1.202 [b]	20.75±1.245 [a]
35	4.99±0.240 [b]	23.79±1.344 [a]
42	5.21±1.400 [b]	29.92±1.301 [a]

Data in same row with different letters are significantly different ($p \leq 0.05$)

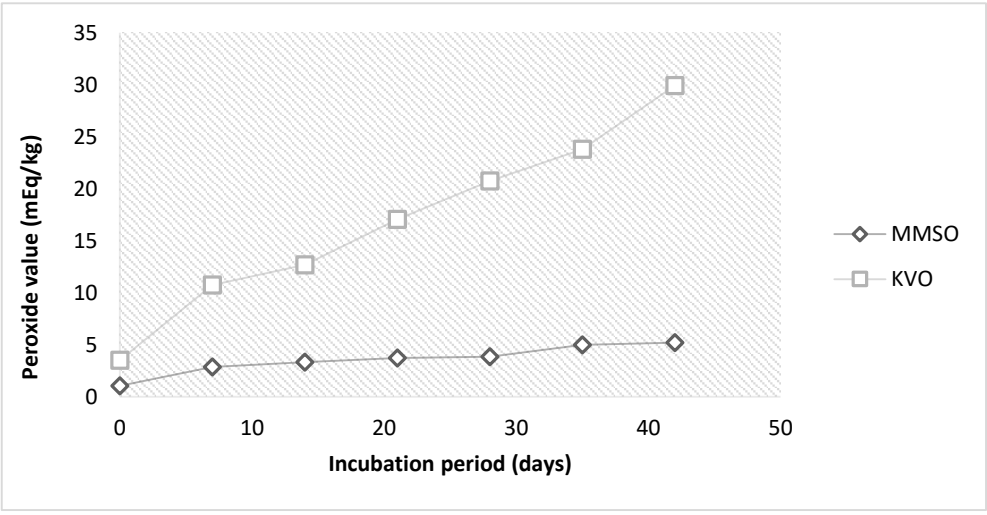

Figure 1: Oxidative stability of Monodora myristica Seed Oil (MMSO) and Kings Vegetable Oil (KVO)

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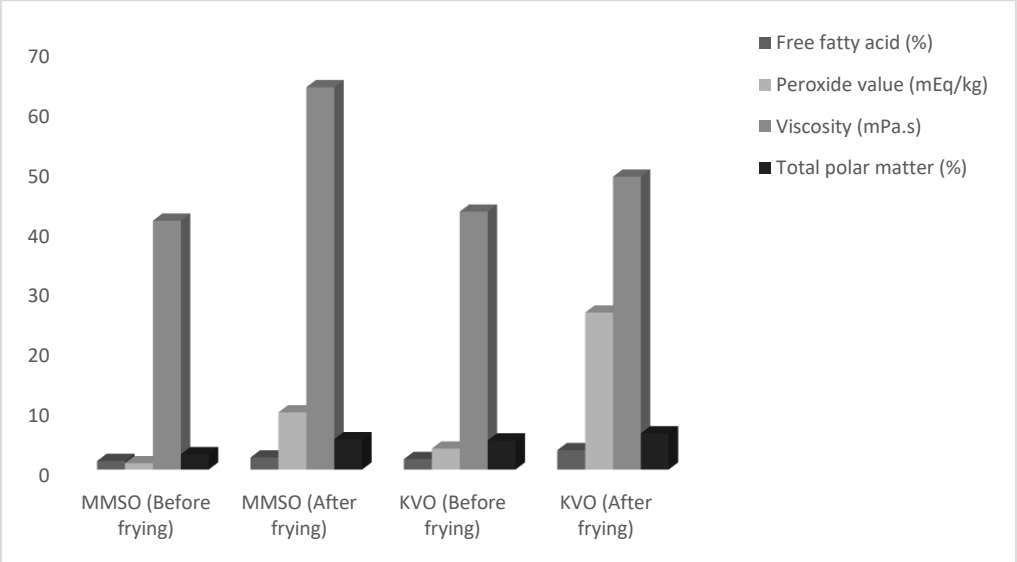

Figure 2: Frying stability of *Monodora myristica* Seed Oil (MMSO) and Kings Vegetable Oil (KVO)

Discussion

Oil yield or the amount of oil obtained from processing an oil seed is a critical factor for seed oil processors because it affects their gross income (Kaseke et al., 2021). The percentage oil yield of *M. myristica* seeds was 37.64% and the oil is golden brown in color while KVO is golden yellow in color. However, Ezeuko et al. (2017) reported an oil yield of 36.04% from the *M. myristica* seeds they analyzed. On the other hand, Bello et al. (2014), extracted oil from *M. myristica* seeds and reported an oil yield of 25.40%. The differences in the oil content of *M. myristica* seeds analyzed in this study and those from other studies might be due to the impact of processing parameters, including extraction time, pressure, heating temperature, particle size, moisture content, fruit maturity, applied pressure, and geographical location, among other factors (Ezeuko et al., 2017; Kaseke et al., 2021).

Moisture content determines product quality (Nwagbo et al., 2020) and it is an important characteristic of oils and fats. Low moisture content improves shelf life by prohibiting oxidation and rancidity processes while high moisture content in vegetable oil accelerates hydrolytic rancidity and FFA values (Mansor et al., 2012). The moisture content of the freshly expressed MMSO (0.220%) and KVO (0.253%) was within the quality standard of 0.29% or less in vegetable oils (Codex Alimentarius, 2013). Nwagbo et al. (2020) reported a moisture content of 1.078% for freshly expressed crude palm oil of Nigerian origin. Differences in the moisture content of *M. myristica* seeds analyzed in this study and other seed crops might be due to environmental conditions, seed maturity, seed type, and processing parameters.

The specific gravity of oil is the ratio of the mass of a given volume of oil to the mass of an equal volume of water (Aremu et al., 2015). The specific gravity of MMSO and KVO were 0.923 and 0.917, respectively and they did not differ significantly (p>0.05). Both oils had a specific gravity of less than one, indicating that they are less dense than water (Uddin et al., 2020). This is an advantage since they can act as a potential fuel source in biodiesel production for fuel injector engines which depends on fuel with very low density (Bello et al., 2014). The specific gravity of the oils in this study is within the range of value reported for crude and refined sunflower oil (Pal et al., 2015). They are however, higher than the 0.82-0.92 range reported by Akubugwo and Ugbogu (2007) for *Landolphia owariensis* seed oil and *Napoleona imperialis* seed oil. Low specific gravity reduces the mass and density of the oil during frying while high specific gravity could be an indication of high molecular weight and unsaturated fatty acid (Uddin et al., 2020).

The viscosity of edible oils is a parameter used to describe their quality and it is important in the design of process equipment for the edible fat and oil industry

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(Ogunsina et al., 2014). Oils with low viscosity values are light and probably highly unsaturated while high viscosity values in oil may be due to the presence of suspended particles in the crude oil sample (Aremu et al., 2015). The viscosity of MMSO and KVO (41.5 and 43.00 mPa.s) did not differ significantly (p>0.05). Differences in the viscosity of oils might be due to the difference in the fatty acid composition of the oils (Sahasrabudhe et al., 2017).

The refractive index of oil is the ratio of the speed of light at a definite wavelength to its speed in the oil (Aremu et al., 2015). It is often applied to identify and characterize food materials, including seed oil (Kaseke et al., 2021). Refractive index increases as the double bond increases meaning a high degree of unsaturation (Aremu et al., 2015). The refractive index of MMSO and KVO were 1.470 and 1.468, respectively and comparable to the value reported for the seed oil of *Telfairia occidentalis*, 1.462 (Bello et al., 2011). It is however higher than the value (1.449) reported for akee apple seed oil (Aremu et al., 2015). There was no significant difference (p>0.05) in the values of the refractive index of the oils thus, suggesting that there was no significant difference in the degree of flow or thickness of the oils at room temperature (Aremu and Akinwumi, 2014).

Technically, iodine value is the amount of iodine, measured in g, absorbed by 100 g of a given oil sample (Akubugwo and Ugbogu, 2007). It is an index for assessing the level of unsaturation in fatty acids and the ease with which the oil can go rancid (Mbatchou and Kosoono, 2012) and gives an indication of the oil's stability and health properties (Akubugwo and Ugbogu, 2007). Studies have shown that the greater the degree of unsaturation, the higher the iodine value, and the greater the likelihood of the oil becoming rancid by oxidation (Nwagbo et al., 2020). The iodine value of MMSO (71.325 g/100 g) was significantly (p≤0.05) lower than that of KVO (105.1 g/100 g). This difference arises principally from the differences in the fatty acid composition of these oils (Mbatchou and Kosoono, 2012). These values compare favorably with those reported for sesame seed oil (106 g/100 g) (Ogbonna and Ukaan, 2013) but lower than 122.56 g/100 g reported for soybean (Nehdi, 2011). The iodine values of the oil samples were less than 115, therefore they are non-drying, and as such, of good nutritional value and are good for use in food products and industrial applications (Bello et al., 2014; Olaniyi et al., 2014). MMSO is significantly (p≤0.05) more stable than KVO as a result of the low iodine value.

Peroxide value is defined as the number of peroxides in mEq for each kg (mEq/kg) of the sample (Nwagbo et al., 2020). Based on our results, the peroxide values of MMSO and KVO were 1.05 as well as 3.50 mEq/kg, respectively indicating significant (p≤0.05) differences. These values compare with *Dalbergia odorifera* seed oil (5.07 mEq/kg), and 4.13 mEq/kg reported for *M. myristica*, but lower than 8.85 mEq/kg reported for *Dioclea reflexa* (Raphael et al., 2010). Peroxide value depends on a number of factors such as the state of oxidation, the method of extraction, and the type of fatty acids present in the oil (Raphael et al., 2010). The range of values is lower than the Codex Alimentarius (2013) stipulated permitted maximum peroxide levels of 10 mEq/g or 10 mEq/kg for unrefined or refined oils indicating that the oils were of good quality. The oils are thus stable and would not easily go rancid. It was reported that fresh oils usually have peroxide values below 10 mEq/kg, especially in the early months of storage (Nwagbo et al., 2020). Peroxide values between 20 and 40 mEq/kg depict the onset of rancidity (Raphael et al., 2010). The peroxide value of MMSO (1.05 mEq/kg) was significantly (p≤0.05) lower than that of KVO (3.50 mEq/kg), suggesting minimal oxidation and stability of the oil to relative oxidation. The antioxidant properties of *M. myristica* extract have been reported (Agiriga and Siwela, 2018). This may be linked to its total phenol content. Phenolics are commonly known for their antioxidant effects. They react and capture free radicals thereby inhibiting oxidative stress. A highly positive relationship between total phenols and antioxidant activity appears to be the trend in many plant species (Agiriga and Siwela, 2018).

The acid value denotes the number of mg of KOH needed to neutralize the free acid in a 1 g sample and gives an indication of the edibility of the lipid and its suitability for use in the paint industry (Olaniyi et al., 2014). An increase in acid value depicts the breakdown of triacylglycerols in oil and an increased concentration of FFAs (Santos et al., 2021). The acid value of KVO and MMSO were 2.54 and 1.32 mg KOH/g, respectively indicating non-significant differences (p>0.05). The acid values reported in this study were lower than 3.56 mg KOH/g documented by Akubugwo and Ugbogu (2007) for *Chrysophylum albidum* oil and 3.48 mg KOH/g reported by Bello et al. (2011) for *T. occidentalis* seed oil. Minor differences in values obtained may be due to the extraction process and seed variety. Oils with acid values of more than one indicate edible oil whilst pharmaceutical oil must not contain acidity at all (Olaniyi et al., 2014). The acid values of the oil samples were more than one signifying the edibility of the oils (Olaniyi et al., 2014). The acid value of MMSO is lower than KVO which may signify a lower degree of susceptibility of the oil to rancidity and a higher degree of stability.

The saponification value is expressed as the number of mg of KOH required for saponifying 1 g of the sample (Raphael et al., 2010). It is used to compare the average

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fatty acid chain and reduces as the average fatty acid chain length increases (Mansor et al., 2012). The saponification values for MMSO and KVO were 227.28 and 163.35 mg KOH/g, respectively indicating significant differences ($p \leq 0.05$). It can be concluded that KVO contains the fatty acid with the longest chain length followed by MMSO (Mansor et al., 2012). The saponification values of the two oil samples were more than 100, therefore they can be used for making soap (Mansor et al., 2012). The saponification values obtained in this work were within the range of 5.58-249.90 mg KOH/g reported by Aremu et al. (2015) for some Nigerian oil seeds. It was however lower than the saponification value of coconut oil (258 mg KOH/g) (Mansor et al., 2012).

Unsaponifiable matter content is important in determining the suitability of oil for soap production and it simply denotes the water-soluble component of oil heated with KOH (Onwuliri et al., 2011). The amounts of unsaponifiable matters observed in MMSO and KVO were small, 1.08 and 2.415 g/kg, respectively. This observation corroborates earlier reports that the amount of unsaponifiable matter found in edible fats and oils is usually small, with high figures being indicative of contamination or adulteration (Onwuliri et al., 2011). The values obtained for the unsaponifiable matters in the oil samples were less than the maximum value of l0 g/kg recommended by National Agency for Food and Drug Administration and Control for edible oils (NAFDAC, 2019).

Frying oils undergo chemical deterioration during use and this leads to the formation of compounds that are more polar than the triacylglycerols of the oil. Collectively these compounds are called total polar materials, and the mass concentration of total polar materials is used as an indicator of the quality of frying oils (Hammouda et al., 2019). These total polar materials include hydrolysis products (polymerized triacylglycerols, oxidized triacylglycerols, diacylglycerols, and FFAs). For public health concerns, the content of total polar compounds in frying oil is regulated at not more than 25% (Chen et al., 2013). The total polar matter content of MMSO and KVO was 2.55 and 4.85%, respectively and they differed significantly ($p \leq 0.05$). This difference might be due to differences in the nature and composition of the oil samples. Chen et al. (2013) reported that oil type significantly affected the content of total polar materials in the oil.

The level of fat degradation is best expressed by the FFA as it evaluates the extent of hydrolysis (Onwuliri et al., 2011). FFA is an indication of raw material quality, the quality of the production process, and the final product (Mehmood et al., 2012). When their value exceeds a certain limit, it indicates low product quality (Adelakun and Oyinkansola, 2020). It is calculated as the percentage in weight of a specific FFA predominant in the sample, for example, oleic acid. The lower the FFA value, the better the quality of the oil. An increase in the amount of FFA indicates the presence of hydrolysis of triglycerides and glycerol which causes rancidity of the oil (Tavakoli et al., 2017). The FFA (%) values of MMSO and KVO are 1.44 and 1.75, respectively indicating insignificant differences ($p > 0.05$). The FFA values were within the quality standard of 3.3% for vegetable oils (Codex Alimentarius, 2013). However, Bello et al. (2014) reported FFA values of 32.52 and 1.71% for *M. myristica* and *Myristica fragrans*, respectively. The low value of FFA in MMSO may be due to the method of processing the oil seeds including the duration and storage conditions of the seeds (Japir et al., 2017).

The oxidative stability of vegetable oil is a measure of the length of time taken for oxidative deterioration to commence and its resistance to oxidation during processing and storage (Bello et al., 2014). It can be measured by determining peroxide values (Nwagbo et al., 2020). The peroxide value of oil samples reflects their state of oxidation and hence, the stability and quality of the oil (Bello et al., 2014). Lipid oxidation breaks down fatty acids thus causing a loss of nutritional quality and producing undesirable color, flavor, and toxic components making the food unacceptable to consumers (Ayibaene et al., 2021). The peroxide value of the various oil samples increased with an increase in storage time. This is in line with the findings of Bello et al. (2014) who reported a significant increase in peroxide value with increasing storage time in different oils. The peroxide value of KVO increased steadily from 3.50 mEq/kg on day zero to 29.92 mEq/kg on the 42th day, whereas for MMSO, it increased from 1.05 mEq/kg on day zero to 5.21 mEq/kg on the 42th day showing relatively better stability against oxidation. The steady rise in the peroxides in KVO may be attributed to the presence of more amounts of Polyunsaturated Fatty Acids (PUFA) than in MMSO since the oxidative stability of the oil is inversely proportional to its PUFA content (Bhatnagar et al., 2009). The oxidative stability of *M. myristica* seeds has been established (Agiriga and Siwela, 2018; Ayibaene et al., 2021). Also, Nwagbo et al. (2020) reported that *M. myristica* seeds extract imparted oxidative stability on stored crude palm oil.

The stability of oil depends partly on the extent of deterioration during heating or storage (Hammouda et al., 2019). The measurement of FFA is a relatively simple test to evaluate the quality of the frying fat (Vicentini-Polette et al., 2021). The acidity, which is determined as mg of KOH required to neutralize the FFA in 1 g of sample, increases with the deterioration of the oil during

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deep-frying, forming FFA (Tavakoli et al., 2017; Vicentini-Polette et al., 2021). MMSO showed an FFA increase of 28.4% while KVO showed an FFA increase of 45.99% after frying. The food to be fried contains some water. In the presence of moisture, a chemical reaction is initiated in the frying oil which causes a progressive increase in FFA (Vicentini-Polette et al., 2021). The deteriorative effect of oxidation and polymerization was lower in MMSO than in KVO indicating MMSO to be superior frying oil suitable for repeated frying. In most deep fat frying operations, the amount of FFA produced by hydrolysis is too small to affect the quality of the food; adverse effects are usually due to the oxidation of unsaturated fatty acids (Hammouda et al., 2019). Peroxide formation under frying conditions was evident in both oils. The same observation was made by Japir et al. (2017) on various palm oil samples. The rate of peroxide formation was more in KVO than in MMSO. The peroxide value of MMSO increased from 1.05 to 9.54 mEq/kg before and after frying, respectively; whereas the corresponding change in KVO was from 3.50 to 26.19 mEq/kg.

An increase was observed in the viscosity of the oils after frying. This may be a result of the formation of high molecular weight polymers. The viscosity of MMSO increased higher than that of KVO after frying. This might be due to the refined nature of KVO since the refining process removes the phospholipids, waxes, and FFAs which are responsible for the increase in viscosity of frying oils (Ogunsina et al., 2014). The results showed that the content of total polar materials in MMSO and KVO increased linearly with frying time. Similar results were found in other studies (Chen et al., 2013). This increase is due to oxidation and thermal reactions during frying which leads to the formation of high molecular-weight compounds (Hammouda et al., 2019). Under the same frying conditions, MMSO had significantly ($p \leq 0.05$) lower content of total polar materials before and after frying (2.55 and 5.05%, respectively) than KVO (4.85 and 6.03%, respectively). This may be explained by the high content of PUFAs in KVO. It has been reported that oils with high total polar materials have high PUFAs (Hammouda et al., 2019). If used oil is frequently replenished with fresh oil during the process of frying, there is decreased formation of polar materials, di-acylglycerols, and FFAs. Maximum levels of 25% polar materials have been established as the upper limits of oil degradation for human consumption (Chen et al., 2013).

Conclusion

M. myristica seeds analyzed in this study had an appreciable amount of oil (37.64%) and this shows that if commercially exploited, they could serve as one of the major additional sources of oil. MMSO had physicochemical properties comparable to KVO and in some cases, had better performance. FFA, iodine value, and peroxide value of MMSO were significantly lower than those specified by legal standards, demonstrating good oxidative stability, excellent quality, and long shelf life. The deteriorative effect of oxidation and polymerization was lower in MMSO than in KVO indicating MMSO to be superior frying oil suitable for repeated frying. MMSO is therefore recommended for cooking because of its resistance to oxidation and polymerization.

Author contributions

A.N.A. performed the experiments and prepared the manuscript; S.V.A.U. supervised the work and edited the manuscript; O.A.O. conducted the statistical analysis; M.O.I. reviewed and edited the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

All the authors declared that this is no conflict of interest in the study.

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