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Analysis of oxidative stability and fatty acids profile of coconut oil and flaxseed oil blends

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SUMMARY: This study aimed to analyze the oxidative stability of coconut oil and flaxseed oil blends. Coconut oil: flaxseed oil was mixed at different ratios on weight basis (95:5, 90:10, 85:15, 80:20, and 75:25). The oxidative stability was measured using acid value, iodine value, peroxide value, and saponification value under accelerated oven storage and frying conditions. The fatty acid profile was determined by gas-liquid chromatography. According to the results, all blends showed acceptable oxidative stability under both conditions. They showed storage stability up to 14 months under ambient conditions. Blended oils had a more balanced SFA: MUFA: PUFA ratio than the original oils. Blending the oils at the ratio of 80:20 (coconut oil: flaxseed oil) showed the desirable omega-3 and omega-6 fatty acid composition before and after frying. Therefore, the blending of flaxseed oil with coconut oil could widen the applicability of flaxseed oil.

KEYWORDS*: Blending; Coconut oil; Flaxseed oil; Omega-3 fatty acids; Oxidation; Oxidative stability*

RESUMEN: ***Análisis de estabilidad oxidativa y perfil de ácidos grasos de mezclas de aceite de coco y aceite de linaza***. Este estudio tuvo como objetivo analizar la estabilidad oxidativa de las mezclas de aceite de linaza y aceite de coco. Los aceites de coco y de linaza se mezclaron en diferentes proporciones en peso (95:5, 90:10, 85:15, 80:20 y 75:25). La estabilidad oxidativa se midió utilizando el índice de acidez, el índice de yodo, el índice de peróxido y el índice de saponificación, bajo almacenamiento y fritura en horno acelerado. El perfil de ácidos grasos se determinó mediante cromatografía gas-líquido. Según los resultados, todas las mezclas mostraron una estabilidad oxidativa aceptable en ambas condiciones. Mostraron estabilidad en almacenamiento de hasta 14 meses en condiciones ambientales. Las mezclas tenían una proporción de SFA: MUFA: PUFA más equilibrada que los aceites originales. La mezcla de aceites en una proporción de 80:20 (aceite de coco: aceite de linaza) mostró la composición deseable de ácidos grasos omega-3 y omega-6 antes y después de freír. Por lo tanto, la mezcla de aceite de linaza con aceite de coco podría ampliar la aplicabilidad del aceite de linaza.

PALABRAS CLAVE*: Aceite de coco; Aceite de linaza; Ácidos grasos omega-3; Estabilidad oxidativa; Mezcla; Oxidación.*

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1. INTRODUCTION

Nowadays, the use of omega-3 fatty acids in human nutrition is one the most contemporary topics worldwide due to their role in improving human health. The omega-3 fatty acids include α-linolenic acid (ALA, C18:3), eicosapentaenoic acid (EPA, C20:5), docosapentaenoic acid (DPA, C22:5), and docosahexaenoic acid (DHA, C22:6). These are the essential fatty acids that help manage chronic diseases such as type 2 diabetes, cardiovascular diseases, hypertension, neurodegenerative diseases (Alzheimer's disease), dementia, depression, visual and neurological development, and certain types of cancers (Shahidi and Ambigaipalan, 2018).

Fish oil is a widely used omega-3 supplement (Tur *et al*., 2012). However, most vegetarians and non-fish eaters who neglect to intake fish oil consider plant sources of omega-3 fatty acids. Flaxseed (*Linum usitatissimum* L.) oil is the richest plant source of omega-3 fatty acids, ALA which is

proven to have many health benefits (Joshi *et al*., 2022). Flaxseed has been well known for reducing the risks associated with cardiovascular diseases and some types of cancers owing to lignans and omega-3 fatty acids. Extensive studies related to flaxseed and flaxseed oil reported that they have cardioprotective, antidiabetic, anticancer, and hepatoprotective properties (Dunford, 2015). Flaxseed oil consists of 9% saturated fatty acids (SFAs), 73% polyunsaturated fatty acids (PUFAs), and 18% monounsaturated fatty acids (MUFAs). Even though flaxseed oil contains antioxidants such as tocopherols and beta-carotene, it is highly susceptible to oxidation (Ebrahimi *et al*., 2021) making them the biggest challenge in food applications, even though several studies are still underway.

Oxidation is one of the main problems encountered by food industries, as oxidation deteriorates sensory and nutritional qualities. The oxidation of lipids occurs during storage as well as processing such as frying. The simplest technique for stabilizing frying oils is altering the fatty acid composition of the oil by blending it with another oil with high oxidative stability characteristics (Farhoosh *et al*., 2009).

In the present study, coconut (*Cocos nucifera*) oil has been blended with flaxseed oil. Coconut oil is highly stable against oxidation owing to its high content of SFAs (more than 90%) (Ramos *et al*., 2019). In addition to its superior oxidative stability, it contains a high percentage of medium-chain fatty acids, namely lauric acid, which provides beneficial health properties. Approximately 60% of the fatty acids in coconut oil are short-chain fatty acids and medium-chain fatty acids which are effortlessly digestible (Jayasekara *et al*., 2007). The World Health Organization (WHO) recommended to reduce the intake of SFAs which has been linked to a significant reduction in coronary heart disease when replaced with PUFAs (WHO, 2018). The blending of various vegetable oils with different degrees of saturation can create new oils with desirable characteristics such as nutritional status and oxidative stability. Therefore, blending coconut oil and flaxseed oil can produce an oil blend with desirable SFA, MUFA, and PUFA contents with oxidative stability.

The studies on preparing blended oil using coconut oil and flaxseed oil are much limited. Considering the nutritional importance of flaxseed oil, this study aimed to produce a blend of flaxseed oil and coconut oil with high oxidative stability, a balanced fatty acid profile (SFA: MUFA: PUFA), and rich in omega-3 fatty acids suitable for various food processing applications.

2. MATERIALS AND METHODS

2.1 Materials

Coconut oil (virgin), flaxseed oil (cold-pressed), and fresh potatoes were purchased from the local market in Sri Lanka. All chemicals and Gas Chromatography standards (FAME 37 Component Mix) were purchased from Sigma Aldrich, USA.

2.2 Methods

2.2.1. Sample preparation

Coconut oil and flaxseed oil blends were prepared in different ratios on weight basis (95:5, 90:10, 85:15, 80:20, and 75:25). Oil samples were weighed and thoroughly mixed using a magnetic stirrer (witeg MSH-30A) for 30 minutes, flushed with nitrogen and stored at -20 °C until analysis within a week.

2.2.2. Oven storage

The storage study was performed according to the AOCS Recommended Practice Cg 5-97 (AOCS, 2009a). The same amount of sample (50 g) was taken into sample bottles (100 mL, clear glass bottle, O.D. 51.7 mm × H. 94.5 mm) loosely capped and stored at 65 °C for 14 days in an incubator (Memmert IN55plus) provided with ventilation. Samples were taken on the 1st, 3rd, 7^{th,} and 14th days of storage and analyzed.

2.2.3. Frying test

Fresh potatoes were cut into uniformly-sized pieces (3cm ×1cm ×1cm) using a mechanical slicer and fried in the oils and their blends continuously for four hours, and the oil samples were collected for analysis in every one-hour interval. Each hour is considered as one frying cycle. Samples were collected up to the 4th frying cycle. The temperature was maintained at 180 ± 5 °C throughout the frying and the ratio of oil: potato was kept constant.

2.3. Analysis of samples

2.3.1. Determination of acid value

The AOCS method was used to determine the acid value of the samples (AOCS, 2009b). About 4 g of the sample was weighed precisely into a clean dry Erlenmeyer flask and 25 mL of ethanol was added. The flask was then shaken to dissolve the oil. Then the contents were boiled in a water bath for 30 min (Witeg-digital control system). The hot mixture was titrated with a 0.01 N ethanolic KOH solution with phenolphthalein as an indicator until the pink color persisted for 30 seconds.

2.3.2. Determination of iodine value

The iodine value was determined according to the AOAC official method 993.2 (AOAC, 2000a). About 0.2 g sample was taken into a glass conical flask with a stopper and dissolved completely in chloroform. Then Wijs reagent (25 mL) was added and kept in the dark for 30 min followed by the addition of 10 mL of 15% potassium iodide solution. Immediately, the mixture was titrated with a 0.01N sodium thiosulfate solution with starch indicator while shaking vigorously until the color disappeared. A blank was also carried out in parallel to calculate the iodine value.

2.3.3. Determination of peroxide value

The peroxide value was determined according to the AOCS SURPLUS Method Cd 8-53 (AOCS, 2017). About 5 g of sample was taken into a 250-mL Erlenmeyer flask and it was closed immediately with a glass stopper. Then, 30 mL of a mixture of glacial acetic acid and chloroform (3:2, v/v) were added. After that, 0.5 mL of potassium iodide solution (saturated) was added and shaken well. The flask was then stored in the dark for 1 minute. 30 mL of distilled water was added and shaken well and titrated with 0.01 N sodium thiosulfate solution using a starch indicator. A blank test also was carried out in parallel.

2.3.4. Determination of saponification value

The saponification value of the samples was determined according to the AOAC method (AOAC, 2000b). About 3 g oil sample was dissolved in a 0.5 N ethanolic KOH solution and the mixture was refluxed for complete saponification for 2 h. Then, the solution was titrated with 1 N sulfuric acid solution using phenolphthalein as an indicator.

2.3.5. Analysis of fatty acid profile

Fatty Acid Methyl Esters (FAMEs) of the oil samples were prepared by transesterification (WHO, 2020). FAMEs were analyzed by Gas Chromatography (GC). About 50 mg oil was dissolved in 2 mL toluene in a screw-capped glass test tube and 1 mL of 7% BF_3 in methanol was added. Then the tube was heated at 100 °C for 45 minutes in an oven with occasional shaking. After 45 minutes, the tube was removed from the oven and allowed to cool to room temperature. Then 5 mL of distilled water, 1 mL of hexane, and 1 g of sodium sulfate were added and shaken well and left for the hexane to separate. The separated hexane layer was carefully transferred into the small vial. Finally, the vial with FAMEs was sealed with parafilm and stored at -20 °C until analysis by GC.

FAMEs were analyzed by injecting 1µl sample into the GC (Agilent technologies 7890B GC system), equipped with a flame ionization detector (FID) and a fused silica capillary column (100 m length, 0.250 mm diameter, 0.20 µm film) (SP®-2560 Capillary GC Column) using nitrogen as carrier gas (flow rate - 20 mL/min). The split ratio was 30:1 and the injector and detector temperatures were 220 and 260 °C, respectively. The initial column oven temperature was maintained at 140 °C for 5 minutes and increased to 240 °C at the rate of 4 °C/min, then maintained at that temperature for 10 minutes. Fatty acids were identified using authentic standards (FAME 37 Component Mix) by comparing their retention times (Sivakanthan *et al*., 2019).

2.4. Statistical analysis

All experiments were done in triplicate and the values are expressed as mean values. Statistical analysis was carried out by Completely Randomized Design (CRD) using the SAS for Academics. The mean values were compared using Duncan's Multiple Range Test (DMRT at $\alpha = 0.05$).

3. RESULTS AND DISCUSSION

3.1. Initial quality of oils

According to the Codex Alimentarius standard (Codex Alimentarius, 2021), the maximum level of acid value for cold-pressed and virgin oils should be 4.0 mg KOH/g oil, and peroxide value should be 15 meq O_2/kg oil.

In this study, the acid values for coconut oil and flaxseed oil were 1.06 ± 0.00 and 0.99 ± 0.01 mg KOH/g of oil, respectively. The peroxide value for coconut oil was 0.60 ± 0.00 meq O_2/kg of oil, whereas the peroxide value for flaxseed oil was 1.99 ± 0.01 meq O_2 /kg of oil. Therefore, the initial values for both coconut and flaxseed oil complied with the Codex Alimentarius standard.

3.2. Oxidative stability of oils and their blends under accelerated oven storage

The accelerated oven storage test has been widely used to study the stability of edible oils against oxidation. The storage of oil at 60 ± 5 °C accelerates the oxidation rate of the oil. In the accelerated oven storage method, one day of accelerated oven storage is considered equal to one month at ambient temperature (Evans *et al*., 1973).

3.2.1. Acid value

The acid value is a measure of rancidity as free fatty acids are generated during lipid oxidation and hydrolysis. The higher the acid value, the higher the amount of free fatty acids, which is interpreted as decreased oil quality (Choudhary, 2013). Changes in acid value during the storage period are presented in Figure 1a. The acid value for oils and their blends increased with storage. There was a significant difference between coconut oil and flaxseed oil ($p < 0.05$). However, there was no significant difference between blend 1 and 2, nor was blend 5 significantly different ($p > 0.05$). The results obtained were in accordance with Ngassapa *et al.* (2017), who reported that there was an increment in the acid value for oils and their blends stored at air-free ambient temperature compared to oil samples stored under air-tight dark conditions for 60 days. The initial acid value for flaxseed oil was lower than coconut oil. However, throughout the storage period, the acid value for flaxseed oil was higher than coconut oil. The blends also

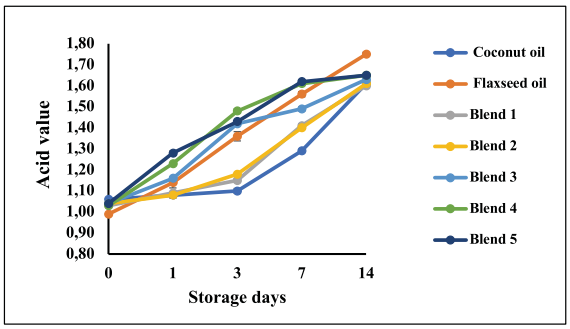


Figure 1a

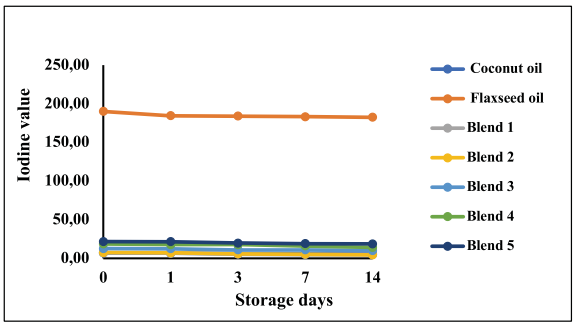


Figure 1b

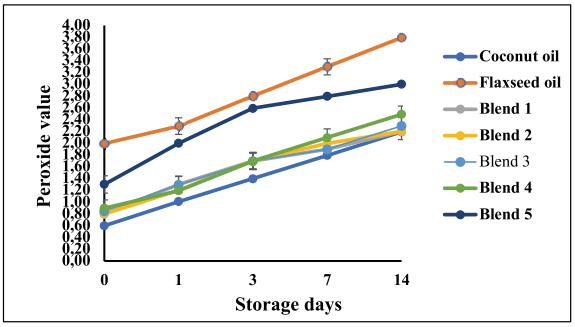


Figure 1c

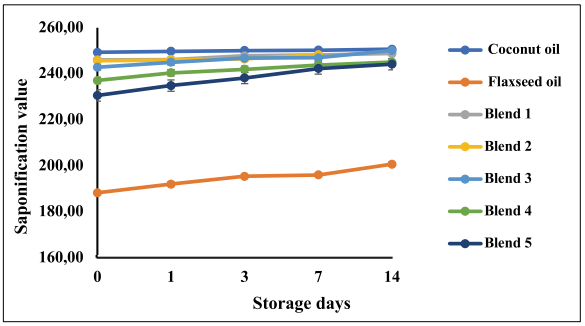


Figure 1d

Figure 1. 1a. Acid value (mg KOH / g of sample), 1b. iodine value, 1c. peroxide value (meq O_2 / kg of sample), and 1d. saponification value (mg KOH/ g of sample) of coconut oil, flaxseed oil and their blends (Blend 1-95:5, Blend 2-90:10, Blend 3- 85:15, Blend 4- 80:20 and Blend 5-75:25, Coconut oil: Flaxseed oil, respectively) under accelerated oven storage at 65 °C. Values are the means ± standard deviation of duplicates. Mean significant differences were tested using DMRT at α level 0.05.

presented increased acid values but were lower than flaxseed oil. This observation could be attributed to the higher degree of unsaturation in flaxseed oil compared to coconut oil. A study evaluated the stability of oil blends, and found that the blend of rice bran oil with sesame oil had lower free fatty acid content than pure sesame oil throughout the twelve-month storage period (Gulla and Waghray, 2011).

3.2.2. Iodine value

The iodine value is the indicator of the degree of unsaturation. Unsaturated fatty acids are more susceptible to oxidation. Therefore, there will be a decrease in the degree of unsaturation with the progress of oxidation. The iodine value for flaxseed oil was higher than coconut oil because of the higher unsaturation of flaxseed oil than coconut oil. The iodine values for oils and their blends decreased with storage time, which was attributed to the oxidation of unsaturated fatty acids. The initial iodine values for coconut oil and flaxseed oil were, 7.08 ± 0.23 and 190.03 ± 0.45, respectively. The initial iodine value for oil blends increased with an increasing proportion of flaxseed oil because of the higher unsaturation of flaxseed oil. However, throughout the storage period, oil blends exhibited a downward trend (Figure 1b). The iodine values for coconut oil, blend 1, and blend 2 were not significantly different ($p > 0.05$) throughout storage, whereas other blends and flaxseed oil showed significantly different ($p < 0.05$) iodine values. Anwar *et al.* (2007) reported that a blend of 0-80% *Moringa oleifera* oil with sunflower oil and soybean oil resulted in decline in the iodine value as a function of storage time. The slow decline in the iodine value of oil blends could be attributed to the induction period where fat is oxidized, slowly demonstrating the initiation of the oxidation reaction. The rapid alterations in the iodine value for oil blends may be due to the propagation of the oxidation process where hydroperoxides are formed from free radicals in fatty acids generated in the initiation stage of the oxidation reaction (Gulla and Waghray, 2011).

3.2.3. Peroxide value

Peroxide value is denoted as an important indicator of oil stability (Bhardwaj *et al*., 2015). Peroxides are the primary oxidation products generated in the early stages of the oxidation of lipids, and they contribute to the successive oxidation reactions to form a range of nonvolatile and volatile secondary oxidative compounds (Shahidi *et al*., 2017). The peroxide values for both oils and their blends increased with an increasing storage period (Figure 1c). There was no significant difference between the peroxide values for blends 1, 2, and 3, whereas blend 4 and blend 5 differed significantly ($p < 0.05$). The results obtained were in accordance with Siddique *et al.* (2010), who reported that peroxide value increased with storage time. Further, after 14 days of accelerated storage, flaxseed oil showed a significantly ($p < 0.05$) higher peroxide value (3.79 ± 0.01 meq O_2/kg) compared to coconut oil (2.19 ± 0.01 meq O_2/kg), and blends obtained lower peroxide values than pure flaxseed oil. The higher peroxide values for flaxseed oil and the blends with a high proportion of flaxseed oil are due to the higher degree of unsaturation of flaxseed oil than coconut oil. A study by Bhardwaj *et al*. (2015) on enhancing the oxidative stability of flaxseed oil by blending it with palm oil revealed that blending flaxseed oil with 60% palm oil was significantly stable throughout the storage period compared to blending flaxseed oil with 40% palm oil because of the oxidative stability of palm oil. A study by Hamed and Abo-Elwafa (2012) reported that blending flaxseed oil with *Nigella* seed oil inhibited hydroperoxide formation by 31.71% (relative to flaxseed oil) compared to that of a blend with sesame oil which showed only 9.75% hydroperoxide formation inhibition. This means blending *Nigella* seed oil with flaxseed oil reduced the peroxide value of flaxseed oil compared to blending with sesame oil.

3.2.4. Saponification value

The saponification value is a measure of the average molecular weight of all the fatty acids present. The higher the saponification value, the shorter the fatty acids on the glycerol backbone (Marina *et al*., 2009). The initial saponification value for coconut oil was 249.33 ± 0.58 mg KOH/g and flaxseed oil was 188.24 ± 0.01 mg KOH/g. This indicates that coconut oil has a higher amount of short chain fatty acids than flaxseed oil. The initial saponification value of oil blends decreased with an increased proportion of flaxseed oil. The saponification value for oils and their blends showed an increasing trend with storage time (Figure 1d). Blends and oil exhibited significant

differences ($p < 0.05$), although no significant differences were found between blends 2 and 3 ($p > 0.05$). An increase in the saponification value of the samples with storage indicates a decrease in the chain length of fatty acids, possibly due to the breakdown of fatty acids during oxidation. The results obtained were in accordance with Siddique *et al.* (2010), who reported that the saponification value for oil samples increased with storage time. This trend explains that with the extended storage of these oils, free fatty acids are formed, which increases the saponification value.

3.3. Oxidative stability of oils and their blends during frying

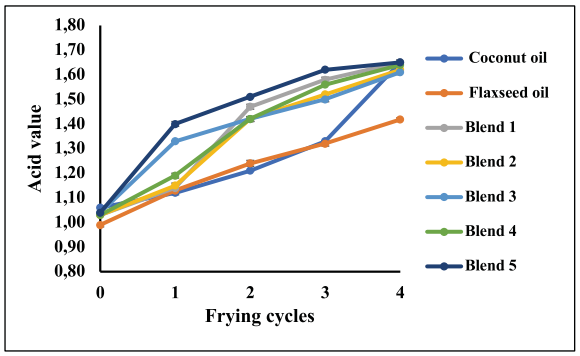
During the frying of pure flaxseed oil, higher foaming was observed. It was difficult to determine frying conditions. However, blend 3 exhibited the lowest foam compared to blends 4 and 5.

3.3.1. Acid value

The acid values for oils and their blends were significantly increased throughout frying (Figure 2a). After the 4th frying cycle, except for blends 1 and 3, all other samples showed a significant increase in acid value ($p < 0.05$). During frying, both oxidation and hydrolysis could lead to the formation of free fatty acids. Che and Wan (1998) also found that the acid value increased throughout frying for palm oil and coconut oil blends.

3.3.2. Iodine value

The iodine value for oils and their blends showed a downward trend (Figure 2b). Other than coconut oil and blend 1, the iodine values for all samples differed significantly ($p < 0.05$). This indicates the progress of oxidation and coconut oil and blend 1 showed higher stability than the other blends and flaxseed oil. This is evident from the non-significant changes in the fatty acid profile before and after frying for these two samples. Alireza *et al.* (2010) found a similar decreasing trend in the iodine value for oils and their blends during deep frying and reported that the decrease in the iodine value is due to the decrease in double bonds as oil becomes oxidized. Che and Wan (1998)



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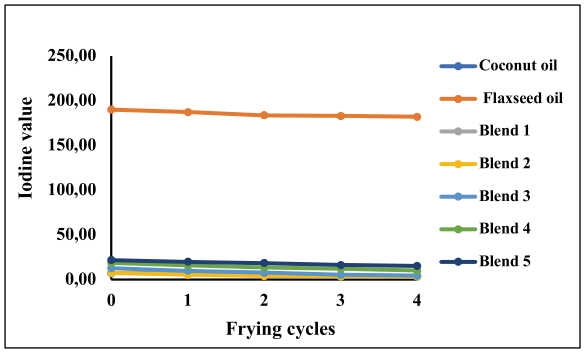

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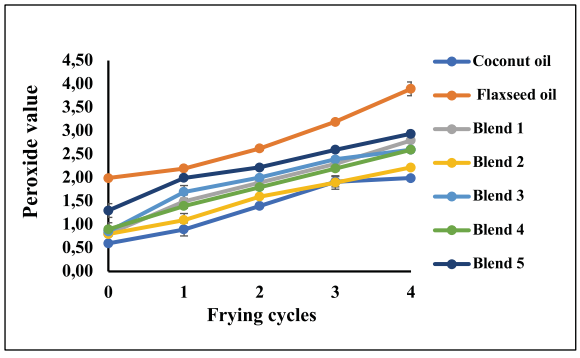

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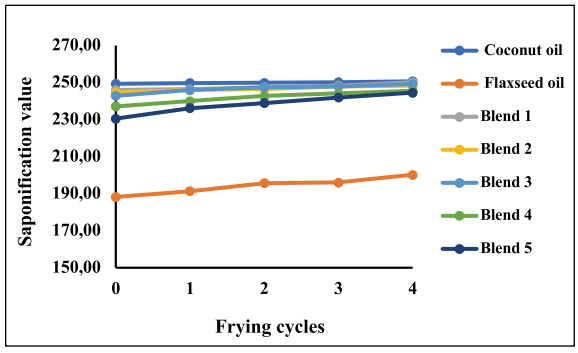

2 d

Figure 2. 2a. Acid value (mg KOH/g of oil); 2b. iodine value; 2c. peroxide value (meq O_2/kg of sample), and 2d. saponification value (mg KOH / g of sample) of coconut oil, flaxseed oil and their blends (Blend 1-95:5, Blend 2-90:10, Blend 3- 85:15, Blend 4- 80:20 and Blend 5-75:25, Coconut oil: Flaxseed oil, respectively) during frying at 180 ± 5 °C. Values are the means of duplicates. Values are the means ± standard deviation of duplicates. Mean significant differences were tested using DMRT at α level 0.05.

also reported the same downward trend in the iodine value for palm oil and coconut oil blends.

3.3.3. Peroxide value

The peroxide value was increased with frying cycles (Figure 2c). The values for blends 1 and 4 were not significantly different ($p > 0.05$). However, other samples were significantly differed ($p < 0.05$). After the 4th cycle of frying, flaxseed oil exhibited the highest peroxide value (3.90 ± 0.15 meq O_2/kg), while coconut oil had a peroxide value of 1.99 ± 0.001 meq O_2/kg. Blend 1 exhibited a higher peroxide value (2.80 ± 0.00 meq O_2/kg) than that of blend 2 (2.22 ± 0.03 meq O_2/kg). However, blend 5 obtained the highest peroxide value (2.94 ± 0.07 meq O_2/kg) among all the blends studied. Blends 3 and 4 manifested similar peroxide values after the 4th frying cycle. This observation also can be explained based on the degree of unsaturation. Flaxseed oil and blend 5, which consisted of a high amount of flaxseed oil, presented more extensive oxidation than the other samples. Farhoosh *et al*. (2009) observed a similar increasing trend in peroxide value for canola, olive, palm olein, and corn oils, and the blending of these four oils showed a lower peroxide value compared to pure oils. Che and Wan (1998) also found the same scenario in the peroxide value pattern and stated the same fact.

3.3.4. Saponification value

The saponification value also increased throughout frying (Figure 2d). However, the values for blends 2 and 3 were not significantly different ($p > 0.05$). Flaxseed oil showed a higher increment compared to coconut oil (from 188.71 ± 0.66 mg KOH/g to 200.22± 0.19 mg KOH/g) and showed a significant increase in saponification value ($p < 0.05$). An increase in the saponification value indicates the formation of short-chain fatty acids due to the oxidative degradation of fatty acids. Goburdhun and Jhurree (1995) observed an increasing trend in the saponification value of soybean oil blended with palm kernel olein.

3.4. Fatty acids composition of oils and their blends before and after frying

The SFA: MUFA: PUFA (Saturated fatty acids: Monounsaturated fatty acid: Polyunsaturated fatty acids) ratios of coconut oil and flaxseed oil were 20.3:1:0 and 1:1.6:5.6, respectively. The blends showed a modification in the SFA: MUFA: PUFA ratio (Joshi *et al*., 2023). In particular, blend 5 showed 7.3:1:1.5, and blend 4 showed 7.8:1:1, respectively (Table 2). The WHO recommends that a reduction in the intake of SFA has been associated with a significant reduction in coronary heart disease when replaced with PUFA (WHO, 2018).

The blends showed an increase in alpha-linolenic acid contents (omega-3 fatty acid). The alpha-linolenic acid content in blends 1, 2, 3, 4, and 5 were 3.47 ± 0.02, 5.26 ± 0.03, 5.41 ± 0.01, 6.95 ± 0.01, and 11.12 ± 0.01%, respectively. The results obtained were in accordance with Faiza *et al.* (2016), where the blending of coconut oil and flaxseed oil blends of 70:30, respectively, increased the linolenic acid content. Among the blends, blend 5 exhibited a favorable omega-3 and omega-6 fatty acid composition, it showed 11.12 ± 0.01% omega-3 fatty acid and 5.01 ± 0.01% omega-6 fatty acid (Table 1).

After 4 hours of continuous frying, a change in fatty acid composition was observed. Alpha-linolenic acid (C18:3) contents were significantly decreased in flaxseed oil, blends 1, 2, 3 and 5, ($p < 0.05$); whereas the Alpha-linolenic acid content in blend 4 was not changed ($p > 0.05$). Linoleic acid (C18:2) content also significantly decreased in the original flaxseed oil and all blends. These results were in accordance with Che and Wan (1998). Linoleic acid content was reduced by 1% in flaxseed oil and by 56, 41, 45, 24, and 19% in blends 1, 2, 3, 4 and 5, respectively. The alpha-linolenic acid content was reduced by 32, 67, 56, 36, and 31% in flaxseed oil in blends 1, 2, 3, and 5, respectively.

Alpha-linolenic acid (C18:3) is a polyunsaturated fatty acid and is more susceptible to oxidation and cis-trans isomerization (Szabo *et al*., 2022). The multiple double bonds make alpha-linolenic acid highly susceptible to oxidative and thermal degradation, leading to the formation of lipid peroxides, aldehydes, and ketones. High temperatures exacerbate this process by breaking the carbon-carbon double bonds and generating free radicals, which propagate further degradation. The degradation of alpha-linolenic acid during the thermal treatment of edible oils is reported in the literature (Mao *et al.,* 2020; Szabo *et al*., 2022).

In the case of coconut oil, some new fatty acids were observed after frying, such as gondonic acid

Table 1. Fatty acid composition of oils and their blends before and after frying

	Raw coconut oil		Raw flaxseed oil		Blend 1	
	Before frying	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**
Caprylic acid (C 8:0)	8.26 ± 0.01[a]	7.83 ± 0.02[b]	ND	ND	6.82 ± 0.02[a]	6.29 ± 0.01[b]
Capric acid (C10:0)	5.30± 0.07[a]	4.95 ± 0.02[a]	ND	ND	5.21 ± 0.01[a]	5.5 ± 0.03[a]
Lauric acid (C12:0)	42.880 ± 0.01[a]	42.145 ± 0.02[a]	ND	ND	42.26 ± 0.01[a]	42.08 ± 0.03[a]
Myristic acid (C14:0)	16.77 ± 0.03[b]	19.22 ± 0.04[a]	ND	ND	17.06 ± 0.01[b]	18.31 ± 0.02[a]
Palmitic acid (C16:0)	17.72 ± 0.01[a]	11.23 ± 0.02[b]	6.70 ± 0.03[a]	6.295 ± 0.07[b]	10.25 ± 0.01[b]	11.39 ± 0.03[a]
Palmitoleic acid (16:1)	ND	ND	ND	0.13 ± 0.03	ND	ND
Stearic acid (C18:0)	3.21 ± 0.01[a]	1.14 ± 0.03[b]	5.52 ± 0.01[a]	5.66 ± 0.05[a]	2.74 ± 0.01[a]	2.92 ± 0.09[a]
Oleic acid (C18:1)	4.66 ± 0.02[a]	4.11± 0.02[a]	18.465 ± 0.01[a]	16.964± 0.06[b]	9.54 ± 0.03[a]	9.61 ± 0.01[a]
Linoleic acid (C18:2)	ND	ND	11.525 ± 0.05[a]	10.960 ± 0.06[a]	3.30± 0.014[a]	1.68 ± 0.00[b]
Heptadecenoic acid (C17:1)	ND	ND	ND	ND	ND	0.006 ± 0.00
Alpha-linolenic acid (C18:3)	ND	ND	53.96 ± 0.01[a]	51.24 ± 0.04[b]	3.47 ± 0.02[a]	1.14 ± 0.03[b]

Table 1 continued

Fatty aids	**Blend 2**		**Blend 3**		**Blend 4**		**Blend 5**	
	Before frying	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**
Caprylic acid (C 8:0)	6.79 ± 0.02[a]	6.42 ± 0.04[a]	6.75 ± 0.04[a]	6.47 ± 0.02[a]	6.90 ± 0.02[a]	6.25 ± 0.01[a]	6.24 ± 0.03[a]	5.56 ± 0.02[b]
Capric acid (C10:0)	5.09 ± 0.01[a]	5.36 ± 0.02[a]	5.22 ± 0.03[a]	4.88 ± 0.01[b]	4.96 ± 0.08[a]	4.70 ± 0.02[a]	4.73 ± 0.04[a]	4.23 ± 0.03[a]
Lauric acid (C12:0)	41.25 ± 0.01[a]	41.03 ± 0.03[a]	40.65 ± 0.03[a]	38.03 ± 0.03[b]	38.21 ± 0.03[a]	36.32 ± 0.03[b]	36.68 ± 0.02[a]	32.77 ± 0.02[b]
Myristic acid (C14:0)	16.05 ± 0.04[b]	17.53 ± 0.03[a]	17.32 ± 0.02[a]	16.19 ± 0.03[b]	16.33 ± 0.03[a]	15.56 ± 0.03[b]	15.8 ± 0.01[a]	14.00 ± 0.03[b]
Palmitic acid (C16:0)	10.13 ± 0.01[a]	10.89 ± 0.03[a]	10.67 ± 0.03[a]	10.72 ± 0.03[a]	10.21 ± 0.02[a]	10.65 ± 0.03[a]	10.76 ± 0.01[a]	10.25 ± 0.03[a]
Palmitoleic acid (16:1)	ND	ND	ND	0.1 ± 0.01	ND	0.09 ± 0.01[b]	ND	0.14 ± 0.01[a]
Stearic acid (C18:0)	3.14 ± 0.01[b]	3.36 ± 0.02[a]	3.14 ± 0.02[a]	3.59 ± 0.03[a]	3.42 ± 0.01[a]	3.93 ± 0.03[a]	3.40 ± 0.02[a]	4.00 ±0.03[a]
Oleic acid (C18:1)	9.67 ± 0.02[b]	9.85 ± 0.01[a]	9.68 ± 0.03[b]	10.54 ± 0.03[a]	10.14 ± 0.02[b]	11.61 ± 0.02[a]	10.51 ± 0.02[b]	12.45 ± 0.01[a]
Linoleic acid (C18:2)	3.83 ± 0.02[a]	2.26 ± 0.02[b]	3.89 ± 0.01[a]	2.13 ± 0.01[b]	4.10 ± 0.02[a]	3.13 ± 0.01[b]	5.01 ± 0.01[a]	4.04 ± 0.02[b]
Heptadecenoic acid (C17:1)	ND	0.07 ±0.01[a]	ND	0.08 ± 0.01[a]	ND	0.09 ± 0.01[a]	ND	ND
Alpha-linolenic acid (C18:3)	5.26 ± 0.03[a]	2.3 ± 0.03[b]	5.41 ± 0.01[a]	3.45 ± 0.21[b]	6.95 ± 0.01[a]	6.48 ± 0.03[a]	11.12 ± 0.01[a]	7.62 ± 0.03[b]

Blend 1-95:5, Blend 2-90:10, Blend 3- 85:15, Blend 4- 80:20 and Blend 5-75:25, Coconut oil: Flaxseed oil, respectively. Values are the means ± standard deviation of duplicates. Mean significant differences were tested using DMRT at α level 0.05. The means with the same letters in the same row are not significantly different.

Table 2. SFA: MUFA: PUFA ratio of oils and their blends (%)

Fatty acids	**Coconut oil**		**Flaxseed oil**		**Blend 1**		**Blend 2**		**Blend 3**		**Blend 4**		**Blend 5**	
	Before frying	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**	**Before frying**	**After frying**
SFA	95.26	92.52	12	12.49	84.38	86.58	82.37	84.58	83.69	79.81	79.29	77.43	77.34	71.34
MUFA	4.67	4.09	20.37	21.38	9.53	9.61	9.65	9.83	9.66	10.56	10.15	11.62	10.49	12.44
PUFA	-	-	67.63	65.85	6.69	2.59	9.08	4.54	9.28	5.58	11.07	9.62	16.22	11.89
SFA: MUFA: PUFA	20.3:1:0	22.6:1:0	1:1.6:5.6	1:1.7:5.2	12.6:1.4:1	33.4:4.1:1	9:1:1	18.6:2.1:1	9:1:1	14.3:1.8:1	7.8:1:1	8:1.2:1	7.3:1:1.5	5.9:1:1

Blend 1-95:5, Blend 2-90:10, Blend 3-85:15, Blend 4-80:20 and Blend 5-75:25, Coconut oil: Flaxseed oil, respectively. The values are calculated based on the values given in Table 1.SFA – Saturated Fatty Acids, MUFA – Monounsaturated Fatty Acids and PUFA – Polyunsaturated Fatty Acid

(C20:1), heneicoisylic acid (C21:0) and behenic acid (C22:0). There were no new fatty acids generated in the flaxseed oil or all the blends. The blending of flaxseed oil with coconut oil evidently increased the fatty acids profile of coconut oil and improved the oxidative stability of flaxseed oil. Blending improved the SFA: MUFA:PUFA ratio as well.

4. CONCLUSIONS

All the blends showed acceptable oxidative stability under both storage and frying conditions. Blends 1, 2, and 3 exhibited higher oxidative stability than blends 4 and 5. The acid value of the prepared blends was lower than that of flaxseed oil, although higher than coconut oil. Moreover, the acid value and peroxide value of all blends fell within the acceptable range recommended by Codex Alimentarius. The saponification value increased with storage and after frying; whereas the iodine value decreased throughout storage and after frying. As all the blends exhibited acceptable oxidative stability (Codex Alimentarius, 2021) under both storage and frying conditions, all the blends can be stored for up to 14 months and utilized as a frying medium. Blending can be used to improve the nutritional quality in terms of fatty acid profile. This study also found that combining coconut oil and flaxseed oil at a ratio of 80:20 (coconut oil: flaxseed oil) can boost the contents of omega-3 fatty acids and omega-6 fatty acids and that it can be kept for up to 14 months and utilized as a frying medium.

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DECLARATION OF COMPETING INTEREST

There is no conflict of interest.

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AUTHORSHIP CONTRIBUTION STATEMENT

R. Nivetha: Writing – original draft, Methodology, Investigation, Formal analysis. S. Simmaky: Writing – review & editing, Project administration. S. Sivakanthan: Writing – review & editing, Supervision, Project administration, Conceptualization.

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