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Enhancing oxidative stability and antioxidant retention through synergistic blending of rice bran oil and palm olein during prolonged deep-fat frying

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ABSTRACT

Blending edible oils with complementary properties offers a practical strategy to enhance both frying stability and nutritional quality. This study investigated the oxidative stability, antioxidant retention, and fatty acid composition of rice bran oil (RBO), palm olein oil (POO), and their blends at 80:20 and 70:30 ratios during 30 hours of deep-fat frying at 180°C. A comprehensive analysis was conducted using key indicators such as peroxide value (PV), free fatty acids (FFA), p-anisidine value (p-AV), iodine value (IV), smoke point, tocopherols, tocotrienols, and γ-oryzanol content. The results showed that the 80:20 blend achieved the highest oxidative stability and antioxidant retention, with a 33.84% reduction in PV compared to POO and retention of 28.17 mg/100 g of γ-oryzanol after 30 hours. Both oil blends maintained a favorable SFA:MUFA: PUFA ratio of approximately 1:1.5:1, closely aligning with dietary recommendations for cardiovascular health. Blending effectively delayed lipid oxidation and thermal degradation compared to pure oils, resulting in better preservation of tocopherols and reduced formation of degradation products. These findings demonstrate that blending RBO and POO at appropriate ratios produces frying oils with improved thermal resistance and health-promoting attributes. This approach presents a cost-effective and scientifically grounded solution for industrial and household frying, offering improved product quality, safety, and nutritional value in fried foods.

Contribution/Originality: This study is the first to evaluate the long-term frying stability (30 hours) of rice bran oil–palm olein blends at specific ratios of 80:20 and 70:30, focusing on antioxidant retention and the SFA:MUFA:PUFA balance. It offers an innovative oil formulation with both industrial applicability and health benefits.

1. INTRODUCTION

One of the most common methods of cooking worldwide, frying is very popular in home kitchens and is also employed in the food sector for its ability to improve the texture, taste, and appearance of food. In combination with high temperatures (about 180°C on average) and longer frying times, it causes significant chemical alterations in the fried oils. Oxidation, hydrolysis, polymerization, and thermal degradation produce unwanted chemical compounds such as free fatty acids (FFAs), hydroperoxides, aldehydes, ketones, and total polar compounds (TPC). These chemical changes alter the flavor and sensory characteristics of fried foods and pose health risks due to the production of harmful compounds. Therefore, choosing frying oils with higher thermal stability and a more balanced nutritional

profile is important not only for consumer health safety but also for product quality (Dhyani, Chopra, Singh, & Garg, 2023) but also for maintaining product quality.

Several edible oils are available in the market; while palm olein oil (POO) and rice bran oil (RBO) are commonly used in frying, each with different advantages and disadvantages. RBO is particularly valued for its dietary features, containing a well-structured fatty acid profile with high levels of polyunsaturated fatty acids (PUFAs), as linoleic acid (C18:2) and linolenic acid (C18:3) (Huang et al., 2024). In addition, RBO is enriched with antioxidant molecules such as γ-oryzanol, tocopherols, and tocotrienols, which provide significant protection against free radicals and lipid oxidation (Chotimarkorn, Benjakul, & Silalai, 2008). Potential health benefits associated with these bioactive compounds include protection against cardiovascular diseases, anti-inflammatory properties, and cholesterol reduction. Despite these beneficial nutritional properties, RBO has a high PUFA content, which makes it unstable after prolonged frying due to accelerated oxidative degradation.

On the other hand, POO is a suitable oil for industrial frying purposes due to its excellent thermal stability (Patil, Waghmare, & Annapure, 2023). Its composition has a high content of MUFA, mainly oleic acid (C18:1), and high levels of SFAs, especially palmitic acid (C16:0), which can account for the oil's stability. Tocotrienols, primarily found in palm oil, are a unique form of vitamin E that further boost oxidative stability. However, from a nutritional perspective, POO is less suitable for improving cardiovascular health than oils with a more balanced fatty acid profile, such as RBO. The lower PUFA concentration and higher SFA content in POO are less desirable.

An increasingly popular approach to improving frying performance while maintaining targeted nutritional attributes is to combine oils with complementary characteristics. However, blending enables the preparation of customized oils that merge the nutritional advantages of rice bran oil (RBO) with the oxidative stability of palm olein oil (POO). Rice bran oil protein inhibits oxidative deterioration, improves antioxidant retention, and slows the formation of hazardous oxidized products, making it useful as a natural antioxidant. Additionally, it can help achieve the SFA:MUFA: PUFA ratio close to the ideal ratio of 1:1.5:1 recommended by the World Health Organization (WHO) for cardiovascular health (World Health Organization, 2008). The effectiveness of using oil blends for enhancing fried life and oxidative stability of frying oils has been shown in recent research (Heshmati, Jafarzadeh-Moghaddam, Pezeshki, & Shaddel, 2022; Koohikamali & Alam, 2019), while Long-term changes related to fatty acid composition and antioxidant retention during continuous frying over multiple cycles require further investigation. The oxidative degradation of oils during frying leads to the formation of chemical compounds such as aldehydes, ketones, and polymerized triglycerides, which have been associated with adverse health effects including cytotoxicity, genotoxicity, and inflammation. Therefore, the current work aimed to study frying performance over 30 hours at 180°C, focusing on fatty acid composition and antioxidant retention in RBO, POO, and their blends (80:20 and 70:30). The study monitored several important metrics, including free fatty acid (FFA) concentration, peroxide value (PV), p-anisidine value (p-AV), iodine value (IV), smoke point, absorbance at 420 nm, and total polar compounds (TPC). Fatty acid compositions, including differences among saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA), were analyzed to evaluate thermal behaviors and degradation patterns for each oil. Additionally, the contents of antioxidants mainly tocopherols, tocotrienols, and γ-oryzanol were assessed to understand how these substances influence the oxidative stability of oils throughout the frying process.

The current study provides a deeper interpretation of how the blending of RBO with the use of POO can impact oil stability and frying performance. The findings aim to show consumers and the food industry how to optimize oil compositions for improved thermal functionality, reduced degradation, and enhanced nutritional quality. Ultimately, this study contributes to a better understanding of oil blending as a successful method to reconcile the functional and nutritional properties of edible oils, offering potential solutions for improving the quality of fried foods and minimizing health risks associated with repeated frying. Unlike prior studies focusing on short-term frying stability or individual oil types, this work explores the synergistic potential of RBO and POO blends under extended frying

conditions. This novel blending strategy seeks to enhance both the thermal stability and nutritional profile of frying oils, addressing real-world industrial frying needs.

2. MATERIALS AND METHODS MATERIALS

Commercial suppliers in Thailand supplied refined rice bran oil (RBO) and palm olein oil (POO). Before use in the study, the oils were examined for their physicochemical quality to ensure that every sample met all requirements for edible oil standards. To create the experimental oil blends, RBO and POO were combined in two specific ratios: 80:20 and 70:30 (v/v). Under carefully controlled laboratory conditions, the blending method provided consistency, accuracy, and repeatability across all samples. To achieve the required ratios (80:20 and 70:30, v/v), the oils were meticulously measured using calibrated volumetric equipment. To minimize the possibility of oxidation or deterioration during mixing, the process was conducted in a temperature-regulated environment (25 ± 1°C). To ensure uniform distribution of both oils, an initial magnetic stirrer with a Teflon-coated stirring bar was used at 500 rpm for 30 minutes to break up any immiscible layers. To improve homogeneity and reduce air bubble formation, the mixture was gently mechanically agitated at 100 rpm for 15 minutes following the initial mixing. Visual inspection and refractive index estimation confirmed the blend's consistency and homogeneity. Subsequently, all the combined oils were stored in airtight containers at 4°C until further research could be conducted to maintain their quality and prevent oxidation.

Purchased from a local supplier, 10 mm thick frozen potato slices were used as the fried product to replicate actual frying conditions. With a 13 L oil capacity, the deep fryer (Model GY-131V) was thermostatically controlled. During testing, the fryer operated at 180 ± 2°C continuously. To ensure stability and consistency, the temperature was monitored with an inbuilt thermostat. With a voltage of 220 V and a power rating of 3 kW, the fryer provided sufficient heating capacity to maintain the desired temperature range without fluctuations. The inside dimensions of the fries compartment, 240 x 300 x 190 mm, ensured consistent heat distribution throughout food preparation. Each fried batch was timed and monitored to guarantee uniform results and consistent quality.

Purchased from Sigma-Aldrich (St. Louis, MO, USA) and Merck (Darmstadt, Germany) were chemicals and reagents for oil analysis, including potassium iodide, chloroform, acetic acid, and p-anisidine. Each reagent used was of analytical grade. Sigma-Aldrich provided standards for tocopherols, tocotrienols, and γ-oryzanol for antioxidant measurements. The reference standard for the identification and quantification of fatty acid methyl esters (FAME) during gas chromatography (GC) analysis was also the Supelco 37 Component FAME Mix (Sigma-Aldrich, St. Louis, MO, USA). These standards ensured accurate and consistent measurements throughout the experiment.

To protect oil samples from light and oxygen exposure, amber glass bottles with airtight screw caps and a volume capacity of 100 mL were used for collection and storage. Effective prevention of damaging UV (UV) and visible light in the 300–500 nm range by the amber color helps to slow oxidative deterioration in oils. The hermetic seal created by the airtight caps reduces moisture absorption and oxygen intrusion. All bottles were thoroughly cleaned, dried, and flushed with nitrogen gas to remove any residual oxygen before use. Until further research, the stored oil samples were kept at −20°C to prevent oxidation and breakdown.

2.1. Frying Procedure

The aim of the research studies was to determine how various oil blends affected the quality of fried potatoes throughout several frying cycles and during oil degradation. Using ratios of 80:20 and 70:30 (v/v), four different types of oils were tested: pure rice bran oil, pure palm olein, and blends of rice bran oil with palm olein. Triplicate testing of each oil type ensured statistical reliability. A constant temperature of 180 ± 2°C was maintained during the frying process, using a thermostatically controlled deep fryer with a 10 L oil capacity. At the start of each trial, 10 L of fresh oil was used. The frying process was conducted over five consecutive days, with six hours of frying each day, totaling thirty hours of frying per oil sample. Frozen 500 g portions of potato slices were fried for six minutes each

day. Each day involved approximately 15 frying cycles, with 4-minute intervals between batches to simulate typical intermittent frying conditions. Every five frying cycles, a thirty-minute break was included to mimic real kitchen operations.

Oil samples (50 mL) were randomly collected from each frying cycle while the oil remained hot. After cooling to about 50°C, the samples were stored in amber glass bottles with airtight seals and maintained at -20°C to reduce oxidative changes before analysis. Four main time points 0 hours (fresh oil), 10 hours, 20 hours, and 30 hours of cumulative frying time were used to gather oil samples. The leftover oil was filtered through a double-layer cheesecloth at the end of each frying day to remove food debris and kept in stainless steel containers with tight lids. Refrigerated at 4°C overnight, the oil was reheated the next day to 180°C for continued use. This process ensured consistent experimental conditions across all trials and modeled commercial frying methods.

2.2. Free Fatty Acids

FFA (% oleic acid) was determined by AOCS (2017b). Oil samples taken at 0, 10, 20, and 30 hours of frying (cooled to room temperature) were mixed with 50 mL ethanol/diethyl ether (1:1, v/v; 5 g sample, phenolphthalein indicator present) and titrated to a 30-second pink endpoint with 0.1 N NaOH. The FFA (% oleic acid) was calculated as (V×N×28.2)/W, where V is the titrant volume (mL), N is its normality, and W is the sample mass (g). Triplicate determinations are reported as mean ± SD.

2.3. Peroxide Value (PV)

PV was measured following AOCS (2017e). In brief, 5 g of oil was dissolved in 30 mL of glacial acetic acid/chloroform (3:2, v/v), treated with 0.5 mL of saturated KI, swirled for 1 minute in the dark, then diluted with 30 mL of water. Liberated I_2 was titrated with 0.01 N $Na_2S_2O_3$ (starch endpoint). PV (meq O_2/kg oil) = [(S − B) × N × 1000]/W, where S and B are titrant volumes (mL), N is normality, and W is the sample mass (g). Determinations were run in triplicate; data are presented as mean ± SD.

2.4. p-Anisidine Value (p-AV)

Secondary oxidation was evaluated according to AOCS (2017d). Oil samples taken at 0–30 hours of frying (2 g) were diluted with 25 mL of isooctane, and their absorbance at 350 nm was recorded (A_1). After adding 1 mL of 0.25% p-anisidine in acetic acid and allowing the mixture to stand for 10 minutes in the dark, the absorbance was re-measured (A_2). The p-AV was calculated as 25 times the difference ($2A_2 - A_1$). Triplicate results are reported as the mean ± standard deviation (SD).

2.5. Iodine Value (IV)

IV was determined by AOCS (2017c). An oil aliquot (0.2–3 g) was dissolved in 20 mL of chloroform, reacted with 25 mL of Wij's reagent, and kept in the dark for 30 minutes. After adding 20 mL of 10% KI and 100 mL of water, liberated I_2 was titrated with 0.1 N $Na_2S_2O_3$ to a starch endpoint. IV (g I_2/100 g oil) = [(B − S) × N × 12.69]/W, where B and S are the blank and sample titrant volumes (mL), N is the normality, and W is the sample mass (g). Triplicate results are reported as the mean ± SD.

2.6. Smoke Point

Thermal stability was assessed according to AOCS (2017g). Oil samples taken at 0–30 hours of frying (50 mL) were heated in an open beaker; temperature was monitored with a digital thermometer, and the smoke point was recorded when continuous smoke appeared. Triplicate measurements are reported as mean ± SD.

2.7. Absorbance at 420 nm

Pigment or oxidation buildup was tracked according to Saguy, Shani, Weinberg, and Garti (1996). Oil samples taken at 0–30 hours of frying (0.1 g) were diluted in 25 mL of isooctane, and absorbance at 420 nm was measured against an isooctane blank using a UV-Vis spectrophotometer. Triplicate results are reported as mean ± SD.

2.8. Total Polar Compounds (TPCs)

TPCs were measured by AOCS (2017f). A 5 g oil sample was dissolved in 50 mL n-hexane and passed through a silica gel column (70–230 mesh, activated at 130 °C for 2 hours). After eluting non-polar lipids with 150 mL n-hexane, polar lipids were collected with 150 mL of ethyl acetate/hexane (1:1, v/v), evaporated at 40 °C under vacuum, and weighed. TPCs (%) = [Weight of polar fraction (g) / Weight of oil sample (g)] × 100. Triplicate determinations are reported as mean ± SD.

2.9. Fatty Acid Composition

Methyl esters were prepared following AOCS (2017a). Oil (50 mg) was saponified with 1 M NaOH/methanol and methylated with 14% BF_3/methanol. FAMEs were analyzed on a Shimadzu GC-17A (DB-WAX, 30 m × 0.25 mm i.d., 0.25 µm; FID); oven temperature was set from 150°C (for 1 min) to 240°C at a rate of 1°C per minute, using helium as the carrier gas at a constant flow. Fatty acids were identified by retention time compared to a 37-component FAME standard (Supelco) and reported as a percentage of total fatty acids. Triplicate determinations are expressed as the mean.

2.10. γ-Oryzanol Content

γ-Oryzanol was quantified by RP-HPLC (Rogers et al. (1993) modified). Oil (100 mg) was dissolved in 1 mL n-propanol, filtered (0.2 µm PTFE), and injected into an Agilent 1100 with Hypersil ODS (4 × 250 mm, 5 µm). Elution: methanol/acetonitrile/dichloromethane/acetic acid (50: 44: 3: 3, v/v/v/v) at 1 mL min^{-1}; UV 330 nm. Concentration was calculated from peak area versus a γ-oryzanol standard curve.

2.11. Total Tocopherol and Tocopherol Isomer Contents

Total and individual (α-, β-, γ-, δ-) tocopherols were quantified by RP-HPLC (Xu, Hua, & Godber, 2001). Oil (100 mg) was dissolved in 1 mL n-propanol, filtered (0.2 µm PTFE), and injected into an Agilent 1100 fitted with a Mightysil RP-18 GP column (250 × 4.6 mm, 3 µm) and FLD (290 nm ex/330 nm em). Elution: methanol/acetonitrile/dichloromethane (50: 44: 6, v/v/v) at 1 mL min^{-1}. Isomers were identified by retention time versus standards; concentrations were calculated from peak areas and summed for total tocopherols. Triplicate determinations are reported as mean ± SD.

2.12. Statistical Analysis

Data are means ± SD of triplicate determinations. One-way ANOVA was conducted using SPSS v XX, and Tukey's test ($p < 0.05$) identified significant differences among means.

3. RESULTS AND DISCUSSION

3.1. Physicochemical Properties of Frying Oil Prior to Frying

The physicochemical properties of rice bran oil (RBO), palm olein oil (POO), and their blends (80:20 and 70:30) were initially determined to evaluate their stability and suitability for frying. As shown in Table 1, there were significant differences ($p < 0.05$) in values of FFA, PV, p-AV, IV, smoke point, absorbance at 450 nm, and TPC.

FFA was consistently low (0.15%–0.17%) in all samples, indicating hydrolytic rancidity and demonstrating the initial high quality of the oils. FFA content was highest in POO (0.17%) and showed no significant difference between

the blends and RBO, indicating that blending does not affect the FFA levels. The suitability of these oils and blends for frying was assessed based on their physicochemical properties.

The PV, which indicates the degree of initial oxidation, was higher in RBO (1.23 meq O_2/kg), possibly because of its higher proportion of polyunsaturated fatty acids (PUFAs) (Farhoosh, Esmaeilzadeh Kenari, & Poorazrang, 2009; Yang & Chiang, 2017). POO showed the lowest PV (1.14 meq O_2/kg), indicating the highest oxidative stability. p-AV, which indicates secondary oxidation products such as aldehydes, followed a similar trend, with the highest value (1.88) observed in RBO and the lowest (1.76) in POO. However, the 80:20 p-AV level (1.86) and the 70:30 p-AV level (1.84) showed intermediate p-AV values.

Table 1. Physicochemical properties of frying oil before frying, using rice bran oil (RBO), palm olein oil (POO), and their blends at 80:20 and 70:30 ratios.

Parameters	Type of oil (Treatment)			
	RBO	POO	80:20	70:30
FFA (%)	0.15±0.01	0.17±0.01	0.15±0.01	0.16±0.01
PV (meqO_2/kg oil)	1.23±0.09	1.14±0.11	1.21±0.09	1.20±0.10
p-AV	1.88±0.12	1.76±0.08	1.86±0.07	1.84±0.10
IV (g I_2/100 g oil)	98.60 ± 3.95^{c}	52.20 ± 2.85^{a}	89.62 ± 3.78^{b}	84.68 ± 2.71^{b}
Smoke point (°C)	238.00 ± 2.50^{c}	226.00 ± 3.25^{a}	235.50 ± 3.55^{b}	234.00 ± 3.00^{b}
Absorbance at 420 nm	0.22 ± 0.02^{a}	0.28 ± 0.03^{b}	0.23 ± 0.02^{a}	0.24 ± 0.02^{ab}
TPC (%)	3.15±0.26	2.85±0.19	2.94±0.22	2.78±0.18
α-tocopherol (mg/100g)	18.88 ± 0.94^{b}	15.64 ± 0.78^{a}	18.23 ± 0.77^{b}	17.91 ± 0.71^{b}
γ-tocopherol (mg/100g)	32.64 ± 1.14^{c}	23.17 ± 1.98^{a}	30.75 ± 1.45^{b}	29.80 ± 1.28^{b}
α-tocotrienol (mg/100g)	2.32 ± 0.12^{a}	26.71 ± 1.13^{d}	7.20 ± 0.43^{b}	9.64 ± 0.56^{c}
γ -tocotrienol (mg/100g)	41.26 ± 2.37^{b}	31.45 ± 1.68^{a}	39.30 ± 1.93^{b}	38.32 ± 1.74^{b}
Total vitamin E (mg/100 g)	95.10±3.24	96.97±2.99	95.48±2.44	95.67±2.65
γ -oryzanol (mg/ 100 g)	$1{,}250.75\pm45.58^{d}$	0^{a}	$1{,}002.45\pm41.21^{c}$	883.98 ± 28.19^{b}

Note: Each value represents the mean ± standard deviation (SD) from three independent replicates. Means within each row with different superscripts are significantly different ($p < 0.05$).

The most notable difference between POO and RBO was the degree of unsaturation, as indicated by the iodine value (IV). RBO had a significantly higher IV (98.60 g I_2/100 g) compared to POO (52.20 g I_2/100 g), reflecting its higher unsaturated fatty acid content. The blends showed intermediate values, indicating a balanced fatty acid composition derived from the combination of the two oils. The thermal stability, as indicated by the smoke point, was also high for RBO (238°C) and approximately 234°C for blended oils, confirming their suitability for frying applications.

POO had the highest absorbance at 420 nm, indicating a higher content of pigments and initial oxidation products compared to RBO and the blends. The TPC levels among all samples were relatively close (2.78%–3.15%), indicating acceptable initial quality before frying of the oils, as also observed by others (Hampikyan, Çolak, Akhan, & Turgay 2011; Kittipongpittaya, Panya, Prasomsri, & Sueaphet, 2020).

The observed differences in physicochemical properties can be attributed to variations in fatty acid composition and natural antioxidant content. POO with high saturated fatty acid (SFA) content is believed to have high oxidative stability, while RBO, with high unsaturated fatty acid content, is more susceptible to oxidation due to a higher lipid index (IV). Blends incorporating RBO and POO appear to balance nutritional benefits and frying stability based on their intermediate values. This makes these blends suitable for both domestic and industrial frying applications, offering an optimal combination of heat resistance and oxidative stability.

3.2. Tocopherols, Tocotrienols, and γ-Oryzanol Content in Frying Oils Before Frying

Various blends of RBO and POO at 80:20 and 70:30 ratios were analyzed for their tocopherol, tocotrienol, and γ-oryzanol content. The study also evaluated their antioxidant capacity and effect on oxidative stability. Table 1 shows data with significant differences ($p < 0.05$) in antioxidant composition among types of oils. Total vitamin E

content ranged from 95 to 97 mg/100 g across all samples, with blending having no significant effect. The highest concentration of α-tocopherol and γ-tocopherol, with high radical-scavenging capacity, was measured in RBO. According to Mishra and Sharma (2014), γ-tocopherol is a key contributor to RBO's antioxidant capacity, significantly delaying lipid oxidation. These differences highlight the unique antioxidant compositions between RBO and POO.

The concentration of γ-Oryzanol, the most abundant unique antioxidant contained in RBO (1,250 mg/100 g), significantly contributed to the overall antioxidant potential of RBO. Although γ-oryzanol content decreased in the blends, substantial amounts remained (approximately 1,000 mg/100 g in the 80:20 blend), maintaining high antioxidative capacity. It is also in accordance with earlier studies, Maszewska, Florowska, Matysiak, Marciniak-Łukasiak, and Dłużewska (2018) and Wu et al. (2019), indicating that γ-oryzanol was more stable than tocopherols and tocotrienols at high frying temperature. The differences in antioxidant profiles are due to the intrinsic composition of each oil. Higher unsaturated fatty acid ratios result in an increased proportion of tocopherols found in RBO, while tocotrienols are typical in tropical oils such as POO. γ-Oryzanol also contributes to the oxidative stability of RBO by preventing free radical formation and stabilizing the oil during elevated temperatures. Blending RBO and POO results in oil formulations that retain a balanced profile of tocopherols, tocotrienols, and γ-oryzanol. This improves frying stability while enhancing nutritional value.

These results highlight the key role of antioxidants in modulating the oxidative stability and nutritional quality of frying oils. Tocopherols primarily function as radical scavengers, tocotrienols prevent lipid peroxidation, and γ-oryzanol provides protection under conditions of extreme frying. Thus, blending is a practical strategy to improve the oxidative stability of frying oils while maintaining health benefits. Further studies on the degradation kinetics of these antioxidants can also be conducted during repeated frying cycles to provide a more thorough understanding of their long-term stability and performance.

3.3. Fatty Acid Composition of Frying Oil Before Frying

Measurement of fatty acid composition of RBO and POO at 80:20 and 70:30 ratios (RBO: POO) was conducted to assess their suitability as frying oils. As shown in Table 2, the fatty acid profiles of the oils differed significantly ($p < 0.05$). Palmitic acid (C16:0), the most common saturated fatty acid (SFA), ranged from 17% in refined bleached oil (RBO) to 40% in palm oil (POO). The levels of palmitic acid in the blended oils (25%–27%) reflected the contribution of POO in enhancing oxidative stability (Farhoosh et al., 2009; Maszewska et al., 2018).

Table 2. Fatty acid composition of frying oil before frying, using rice bran oil (RBO), palm olein oil (POO), and their blends at 80:20 and 70:30 ratios.

Fatty acid	Type of oil (Treatment)			
	RBO	**POO**	**80:20**	**70:30**
Palmitic Acid, C16:0	17.52±0.85^{a}	39.61±1.02^{c}	25.15±0.58^{b}	26.93±0.42^{b}
Stearic Acid, C18:0	1.85±0.05^{a}	4.28±0.12^{c}	3.16±0.14^{b}	3.31±0.07^{b}
Oleic Acid, C18:1, n-9	42.16±1.14^{ab}	44.16±1.23^{b}	40.11±1.35^{a}	40.89±1.11^{a}
Linoleic Acid, C18:2, n-6	35.68±1.07^{d}	10.47±0.66^{a}	29.73±0.35^{c}	26.01±0.42^{b}
Linolenic Acid, C18:3, n-3	1.15±0.02^{c}	0.24±0.01^{a}	0.81±0.02^{b}	1.61±0.03^{c}
Others	1.64±0.02^{d}	1.24±0.03^{b}	1.04±0.03^{a}	1.25±0.04^{b}
SFAs	19.37±0.95^{a}	43.89±1.22^{c}	28.31±1.00^{b}	30.24±0.99^{b}
MUFAs	42.16±1.66	44.16±1.56	40.11±1.82	40.62±1.68
PUFAs	36.83±0.86^{d}	10.71±0.65^{a}	30.54±0.86^{c}	27.62±0.56^{b}
SFA: MUFA: PUFA	1.0: 2.2: 1.9	1.0: 1.1: 0.2	1.0: 1.4: 1.1	1.0: 1.3: 0.9

Note: Each value represents the mean ± standard deviation (SD) from three independent replicates. Means within each row with different superscripts are significantly different ($p < 0.05$).

Oleic acid (C18:1), the primary MUFA, remained relatively consistent across all samples (40%– 44%). MUFAs are known for their oxidative stability and cardiovascular benefits. According to Moreno et al. (2008), MUFA-rich oils reduce LDL cholesterol while offering greater oxidative stability than PUFA-rich oils.

The PUFA content varied significantly among the oils, with linoleic acid (C18:2, n-6) constituting the majority. RBO had the highest PUFA content (36%), while POO had the lowest (10%). These blended oils exhibited moderate PUFA levels (26%–30%), which are suggested to balance thermal stability with healthful properties. Only traces of linolenic acid (C18:3, n-3), an essential omega-3 fatty acid, were detected, with higher concentrations in the 70:30 blend (1.6%), corresponding to the increased RBO content.

The differences in fatty acid composition reflect the intrinsic characteristics of each oil. POO is rich in SFA, consistent with the characteristics of tropical fats, which offer better thermal stability. In contrast, the high PUFA content in RBO provides essential fatty acids but increases susceptibility to oxidation. The SFA: MUFA: PUFA ratio in the blended oils offers an optimal balance between oxidative stability and nutritional quality, making them suitable for high-temperature frying applications.

These results are consistent with well-known principles of lipid oxidation and indicate that higher levels of SFA and MUFA in frying fats increase frying stability without compromising important nutrients. The blended oils of POO and RBO enhance the advantageous properties of POO and the nutritional properties of RBO to provide an acceptable composition. These findings demonstrate that oil blending can be a promising approach to develop formulations that meet consumer demand for healthier and more stable frying oils. Investigating their lipid degradation and antioxidant performance after multiple frying cycles can offer valuable guidance for further improving the long-term stability and performance of blended oils.

3.4. SFA: MUFA: PUFA Ratios of Frying Oils

Table 2: Fatty acid composition of RBO, POO, and RBO: POO blends (80:20 and 70:30) were studied to assess nutritional properties and oxidative stability. The highest content of SFA was in POO (44%) compared to 19% in RBO, but intermediate amounts of SFA were found in blended oils (28%–30%), contributing to thermal stability (Frankel & Huang, 1994; Jadhav, Gogate, Waghmare, & Annapure, 2022). All samples contained a similar amount of MUFA (40%–44%), with oleic acid (C18:1) contributing to oxidative stability (Schwingshackl & Hoffmann, 2012) and cardioprotective effects (Desjardins et al., 2024).

PUFA content was highly variable, with 37% in RBO and 10% in POO. The PUFA was lowered to 26%–30% (blended oils), while maintaining the essential fatty acids, and showed resistance to frying temperatures. Linoleic acid (C18:2) was the predominant PUFA, and linolenic acid (C18:3) was detected in trace amounts (1.6%) in the 70:30 blend. The ratios of SFA:MUFA: PUFA indicate the intrinsic features of the oils: RBO (1.0:2.2:1.9), POO (1.0:1.1:0.2), and blends (1.0:1.4:1.1 for 80:20), which are significant considering that WHO and AHA recommend ratios of 1:1.5:1.

These findings emphasize the role of SFA and MUFA in frying stability and PUFA in nutritional balance. The combination of RBO and POO results in an effective method to address frying performance with health benefits. They cater to consumer demand for healthier and more stable oils and have marketable formulations for commercial and household use. Further studies on fatty acid breakdown during frying cycles will improve long-term stability and performance.

3.5. Changes in Free Fatty Acid (FFA) Content During Frying

The free fatty acid (FFA) content of RBO, POO, and their blends (80:20 and 70:30) was monitored during 30 hours of frying to determine hydrolytic degradation (Table 3). At the initial stage (0 hours), all oils contained low FFA (0.15%–0.17%), indicating their high quality and suitability for frying. The accumulation of FFA differed significantly ($p < 0.05$) during frying. POO had a higher FFA increase than RBO within a short time period, consistent with Emebu et al. (2022), who reported that palm-based oils tend to accumulate FFA faster as a result of moisture absorption during frying.

POO showed the significantly ($p<0.05$) highest levels of FFA at 20 hours while RBO showed the highest resistance to hydrolysis. Such resistance probably results from the higher antioxidant contents (γ-oryzanol and

tocopherols) in RBO, which can inhibit hydrolytic degradation. The intermediate FFA levels in blended oils suggest that the antioxidant protection of RBO and the thermal stability of POO work together to enhance frying stability.

Table 3. Changes in the physicochemical properties of frying oil during frying at 180°C using rice bran oil (RBO), palm olein oil (POO), and their blends at 80:20 and 70:30 ratios.

Time (hr.)	FFA (%)			
	RBO	**POO**	**80:20**	**70:30**
0	0.15±0.01	0.17±0.01	0.15±0.01	0.16±0.01
10	0.21±0.01^{a}	0.28±0.01^{b}	0.24±0.02^{a}	0.23±0.02^{a}
20	0.42±0.02^{a}	0.59±0.03^{b}	0.45±0.02^{a}	0.47±0.03^{a}
30	0.85±0.03^{a}	0.97±0.03^{b}	0.87±0.03^{a}	0.89±0.03^{a}
	PV (meqO_2/kg oil)			
	RBO	POO	80:20	70:30
0	1.23±0.09	1.14±0.11	1.21±0.09	1.20±0.10
10	8.25±0.55^{c}	6.73±0.64^{b}	5.69±0.54^{ab}	5.02±0.49^{a}
20	18.24±1.14^{c}	14.79±1.16^{b}	12.38±1.17^{ab}	10.66±1.21^{a}
30	16.78±1.16^{b}	17.56±1.24^{b}	13.12±1.14^{a}	12.58±1.23^{a}
	p-AV			
	RBO	POO	80:20	70:30
0	1.88±0.12	1.76±0.08	1.86±0.07	1.84±0.10
10	5.48±0.24^{b}	4.69±0.28^{a}	5.38±0.19^{b}	5.13±0.022^{ab}
20	16.84±1.12^{b}	14.42±0.72^{a}	16.01±0.89^{ab}	15.78±1.17^{ab}
30	24.35±1.28	22.58±1.34	23.42±1.29	22.82±1.35
	IV (g I_2/100 g oil)			
	RBO	POO	80:20	70:30
0	98.60±3.95^{c}	52.20±2.85^{a}	89.62±3.78^{b}	84.68±2.71^{b}
10	88.38±2.68^{c}	50.41±2.55^{a}	81.56±3.17^{b}	77.65±2.88^{b}
20	79.21±2.54^{c}	48.66±3.38^{a}	74.31±2.98^{b}	71.32±2.63^{b}
30	70.99±2.62^{b}	46.98±3.42^{a}	67.26±2.74^{b}	65.54±2.57^{b}
	Smoke point (°C)			
	RBO	POO	80:20	70:30
0	238.00±2.50^{b}	226.00±3.25^{a}	235.50±3.55^{b}	234.00±3.00^{b}
10	215.50±2.55^{a}	218.00±2.55^{a}	214.50±2.65^{b}	216.50±2.05^{b}
20	201.00±2.65^{a}	210.00±2.50^{b}	212.50±2.15^{b}	210.00±2.95^{b}
30	190.50±3.50^{a}	205.50±2.35^{b}	203.00±2.55^{b}	200.00±2.05^{b}
	Absorbance at 420 nm			
	RBO	POO	80:20	70:30
0	0.22±0.02^{a}	0.28±0.03^{b}	0.23±0.02^{a}	0.24±0.02^{ab}
10	0.38±0.03^{b}	0.32±0.02^{a}	0.37±0.04^{ab}	0.36±0.02^{ab}
20	0.88±0.04^{c}	0.48±0.06^{a}	0.81±0.03^{bc}	0.76±0.05^{b}
30	1.34±0.08^{b}	0.96±0.12^{a}	1.26±0.07^{b}	1.23±0.11^{b}
	TPC (%)			
	RBO	POO	80:20	70:30
0	3.15±0.26	2.85±0.19	2.94±0.22	2.78±0.18
10	11.26±0.36^{b}	9.83±0.24^{a}	10.64±0.27^{ab}	10.07±0.19^{a}
20	18.67±0.43^{c}	13.39±0.38^{a}	15.99±0.35^{b}	15.53±0.33^{b}
30	28.54±0.52^{d}	18.64±0.63^{a}	22.84±0.58^{c}	20.35±0.61^{b}

Note: Each value represents the mean ± standard deviation (SD) from three independent replicates. Means within each row with different superscripts are significantly different ($p < 0.05$).

The observed differences can be attributed to variations in the lipid structures and antioxidant composition. POO, being a high-SFA oil, tends to undergo hydrolytic degradation more than RBO, which has a high-PUFA content but does possess natural antioxidants that counteract hydrolysis. This trend correlates with proposed theories of lipid degradation, which note that antioxidants mitigate hydrolytic intermediates, leading to a reduction in FFA (Aydeniz & Yilmaz, 2016). These results indicate that hydrolytic degradation is influenced by both fatty acid composition and

antioxidant presence. Blended oils offer functional and nutritional benefits for both commercial and household frying by moderating FFA accumulation and improving oxidative stability.

3.6. Changes in Peroxide Value (PV) During Frying

Primary oxidation was monitored using peroxide value (PV), with values for RBO, POO, and their blends (80:20 and 70:30) monitored over 30 hours (Table 3). At the initial stage (0 hours), the PVs were low (1.14–1.23 meq O_2/kg), indicating freshness. RBO's higher PUFA content makes it more susceptible to oxidation, resulting in a slightly higher initial PV. The PVs of the blended oils were intermediate, reflecting the combined oxidative characteristics of RBO and POO.

After 10 hours, due to hydroperoxide formation, PVs increased in all samples. The PV increase of RBO was quicker than that of POO, consistent with Kittipongpittaya et al. (2020), who observed rapid peroxide formation in PUFA-rich oils. The slower increase of PV in blended oils indicated protection provided by tocopherols and γ-oryzanol derived from RBO. RBO's PV peaked at 20 hours and declined at 30 hours due to hydroperoxide decomposition into secondary oxidation products. In comparison, POO's PV continued rising at 30 hours, indicating ongoing peroxidation. The blended oils consistently showed lower PVs, confirming their enhanced oxidative stability.

This is related to the fatty acids composition and antioxidant contents. PUFA-rich RBO is susceptible to peroxidation, whereas higher SFA content in POO enhances oxidative stability. Blended oils contain POO, which increases stability, and RBO reduces peroxide formation due to its antioxidant properties (Dhyani, Chopra, Singh, & Garg, 2023; Yang & Chiang, 2017). According to Codex Alimentarius and EFSA, maintaining PVs below 10–15 meq O_2/kg ensures acceptable sensory and nutritional quality during frying.

3.7. Changes in p-Anisidine Value (p-AV) During Frying

The p-anisidine value (p-AV) measures degradation products such as aldehydes and ketones, which reduce oil quality. Table 3 shows that significant differences ($p < 0.05$) exist in p-AV among RBO, POO, and their blends after 30 hours of frying. At 0 h, p-AVs were low (1.76–1.88), indicating slight secondary oxidation. Among the four oils, RBO exhibited the highest initial p-AV due to its PUFA concentration, whereas POO showed the lowest p-AV and thus the greatest oxidative stability. Intermediate values were found for blended oils, indicating that there were no significant changes in oxidation levels after blending.

During frying, p-AV increased in all samples. At 10 hours, RBO had a higher p-AV than POO, consistent with Koohikamali and Alam (2019), who reported faster secondary oxidation in PUFA-rich oils compared to SFA- and MUFA-rich oils (Tompkins & Perkins, 1999). Such a stabilizing effect of POO resulted in a slower increase in p-AV values for blended oils. RBO reached its peak, while POO and blended oils showed a more gradual increase in p-AV. Blended oils reduced aldehyde and ketone formation by delaying oxidation. These trends mirror the fatty acid profiles of the oils: PUFA-rich RBO is more susceptible to oxidation, whereas POO is more stable due to its higher SFA and MUFA contents. Antioxidants in RBO, such as tocopherols and γ-oryzanol, may help control secondary oxidation in blends.

According to Mishra and Sharma (2014), blending high-PUFA oils with more stable oils reduces the potential for secondary oxidation. For acceptable sensory quality, all international regulators, including Codex Alimentarius and AOCS, have recommended a p-AV below 20. POO and blended oils remained within the limit until 30 hours, while RBO exceeded the limit, reinforcing the fact that blending offers benefits in maintaining frying oil quality.

3.8. Changes in Iodine Value (IV) During Frying

Iodine value (IV) reflects the degree of unsaturation of oils and is one of the most important markers of oxidative degradation. For RBO, POO, and their blends (80:20 and 70:30), the IV significantly varied ($p < 0.05$) over 30 hours

of frying, as illustrated in Table 3. The IV progressively decreased in all samples, indicating increased saturation due to thermal oxidation and polymerization.

RBO had the highest IV among oils at 0 hours due to its high PUFA content, while POO had the lowest IV, consistent with its high SFA and MUFA content. Blended oils exhibited intermediate IVs, reflecting a compromise between oxidative stability and fatty acid profile. Similar findings were reported by Chotimarkorn and Silalai (2008) and Mishra and Sharma (2014), indicating that polyunsaturated fatty acids (PUFA) oils are more perishable and undergo rapid degradation during frying. The IV in RBO decreased rapidly with frying time.

The slower IV decrease in POO content reflects its natural oxidative stability, and blended oils showed moderate differences, indicating the mitigating effect of mixing oils with varying stabilities on the deterioration of unsaturated fatty acids. RBO antioxidants, such as tocopherols andγ-oryzanol, probably slowed oxidation of blended oils, thereby leading to a more stable IV profile.

These findings align with those of Farhoosh et al. (2009) and Ben Hammouda, Triki, Matthäus, and Bouaziz (2018), demonstrating that mixing high-PUFA oils with stable oils enhances oxidative stability and preserves essential fatty acids. The IV of the blended oils was less variable, indicating their potential suitability for prolonged frying applications.

3.9. Changes in Smoke Point During Frying

The smoke point is an essential criterion for the thermal stability of frying oil, indicating the temperature at which degradation occurs, releasing volatile compounds and visible smoke. Table 3 shows the smoke points of RBO, POO, and their blends (80:20 and 70:30) during 30 hours of frying. RBO had the highest (238°C) and POO the lowest (226°C) smoke points, demonstrating better thermal stability initially. The intermediate values obtained for the 80:20 and 70:30 blends (235.5°C and 234.0°C, respectively) suggest increased stability due to blending.

At 10 hours, smoke points decreased due to degradation products such as free fatty acids. POO decreased to 218°C and RBO to 215.5°C, while blended oils showed more gradual reductions and higher smoke points (80:20 at 214.5°C, 70:30 at 216.5°C), suggesting RBO delayed degradation. After 30 hours, RBO had a smoke point of 190.5°C, POO had fallen significantly to 205.5°C, and the 80:20 blend still provided the highest value (203°C), indicating that blending significantly improves thermal stability.

The slower decline in RBO may be due to its natural antioxidants, including γ-oryzanol and tocopherols. Both RBO antioxidants and the high saturated and monounsaturated fatty acid levels found in POO provide benefits to the blended oils. According to Farhoosh et al. (2009) and Ben Hammouda et al. (2018), mixing PUFA-rich oils with more stable oils slows the degradation of the smoke point. Zribi et al. (2014) and Ben Hammouda et al. (2018) notably underscored the use of blending to improve thin frying stability.

The high smoke point preserves the oil's quality and safety. Commercial and domestic frying applications are best performed with an 80:20 blend, providing stability without sacrificing nutritional value.

3.10. Changes in Absorbance at 420 nm During Frying

Absorbance at 420 nm is an essential indicator of oil degradation, reflecting the accumulation of pigments and oxidation products. Table 3 shows significant differences ($p < 0.05$) among RBO, POO, and blends (80:20 and 70:30) after 30 hours of frying. Absorbance ranged from 0.22 to 0.28 at 0 hours, with POO exhibiting the highest value (0.28), possibly due to carotenoids, and RBO showing the lowest value (0.22), indicating lighter coloration. For blended oils, intermediate values were observed, reflecting their stability and antioxidant properties resulting from their combination.

After 10 hours, the absorbance increased considerably due to oxidation. RBO increased to 0.38, POO to 0.32, and the 80:20 and 70:30 blends were 0.37 and 0.36, respectively, suggesting that blending helped retain quality early on. RBO's absorbance increased to 0.88 after 20 hours ($p < 0.05$), indicating advanced oxidation, while POO maintained

0.48. Blended oils showed a moderate increase, with 0.81 for the 80:20 blend and 0.76 for the 70:30 blend, indicating that blending slows degradation.

RBO reached 1.34 at 30 hours, followed by 1.26 for the 80:20 blend and 1.23 for the 70:30 blend. Due to its highest thermal stability, POO had the lowest absorbance (0.96). In RBO, the increase in absorbance is attributed to its high PUFA content, and the stability of POO can be attributed to its higher content of saturated and monounsaturated fatty acids. In the case of blending, the rate of absorbance increase was reduced, and the oil's clarity and frying stability were thus improved.

3.11. Changes in Total Polar Compounds (TPC) During Frying

Total polar compounds (TPC) are a good measure of oil degradation resulting from oxidation and the accumulation of polymerization products. The TPC of RBO, POO, and their blends (80:20 and 70:30) during 30 hours of frying were evaluated in this study (Table 3). The TPC levels for all oils were low during initial testing. RBO's higher baseline was due to its unsaponifiable matter and natural polar components such as tocopherols and sterols.

At 10 h, the differences in TPC were significant. Because RBO has a high PUFA content, it was shown to have higher TPC compared to POO, since PUFA is more susceptible to oxidation. Intermediate values were obtained with blended oils (10.07–10.64%), supporting the idea that blending lowers oxidizable PUFAs, leading to a delay in degradation.

RBO alone exceeded the 25% TPC limit established by Codex Alimentarius at both 20 and 30 hours, while POO and blends were far below this cutoff, demonstrating their superior stability. The results are consistent with studies reporting that PUFA-rich oils (e.g., sunflower or soybean oils) accumulate polar compounds more rapidly than MUFA-rich oils (Ben Hammouda et al., 2018; Kittipongpittaya et al., 2020). Similarly, Pan et al. (2020) reported that mixing oils enhances oxidative stability when frying.

The RBO's rapidly increasing TPC value is likely due to linoleic and linolenic acids being prone to oxidation, forming hydroperoxides that decompose into secondary polar products. Conversely, the high oleic acid content in POO provides better oxidative stability. Blending POO with RBO reduces the degradation rate of RBO, balancing stability and nutrition.

These findings also have important implications for the food industry; in particular, blending RBO with POO can produce high-performance frying oils that optimize health benefits and oxidative stability in the food industry.

3.12. Changes in α-Tocopherol and γ-Tocopherol Content During Frying

The content of α-tocopherol and γ-tocopherol in RBO, POO, and their blends (80:20 and 70:30) was monitored during 30 hours of frying at 180°C (Table 4). Tocopherols are natural antioxidants; however, prolonged frying reduces their levels and diminishes oil stability. As a more thermolabile compound, α-tocopherol significantly decreased ($p < 0.05$) in all samples, with POO showing the most rapid depletion. RBO contained the highest amount of α-tocopherol (18.88 mg/100 g), while POO had the lowest (15.64 mg/100 g). The blends exhibited intermediate tocopherol levels, indicating that they slowed tocopherol depletion by diluting the reactive PUFAs from RBO with the more stable monounsaturated fatty acids from POO.

The degradation of γ-tocopherol was slower compared to α-tocopherol, which aligns with the higher thermal stability of γ-tocopherol (Athanasiadis et al., 2023). RBO and its blends, which have higher initial γ-tocopherol content (32.64 mg/100 g), were the most effective in providing prolonged protection against oxidation ($p < 0.05$).This is consistent with multiple findings by Wang et al. (2024), which demonstrate that mixing antioxidant-rich oils enhances frying stability.

Table 4. Changes in vitamin E and γ-oryzanol in frying oil during frying at 180°C using rice bran oil (RBO), palm olein oil (POO), and their blends at 80:20 and 70:30 ratios.

Time (hr.)	α-tocopherol (mg/100 g)			
	RBO	**POO**	**80:20**	**70:30**
0	18.88±0.94^{b}	15.64±0.78^{a}	18.23±0.77^{b}	17.91±0.71^{b}
10	5.45±0.14^{d}	3.32±0.12^{a}	4.28±0.13^{c}	3.73±0.21^{b}
20	1.57±0.08^{d}	0.86±0.08^{a}	1.22±0.07^{c}	1.04±0.06^{b}
30	0.46±0.03^{d}	0.04±0.01^{a}	0.17±0.02^{c}	0.31±0.02^{b}
	γ-tocopherol (mg/100 g)			
	RBO	POO	80:20	70:30
0	32.64±1.14^{c}	23.17±1.98^{a}	30.75±1.45^{b}	29.80±1.28^{b}
10	14.48±1.02^{c}	8.52±0.72^{a}	11.32±0.98^{b}	9.84±0.62^{ab}
20	6.43±0.27^{d}	3.11±0.12^{a}	4.87±0.33^{c}	4.14±0.34^{b}
30	2.85±0.13^{c}	1.11±0.12^{a}	2.15±0.16^{b}	1.82±0.26^{b}
	α-tocotrienol (mg/100 g)			
	RBO	POO	80:20	70:30
0	2.32±0.12^{a}	26.71±1.13^{d}	7.20±0.43^{b}	9.64±0.56^{c}
10	0.05±0.01^{a}	9.06±0.31^{d}	2.04±0.11^{b}	4.05±0.21^{c}
20	0	0	0	0
30	0	0	0	0
	γ -tocotrienol (mg/100 g)			
	RBO	POO	80:20	70:30
0	41.26±2.37^{b}	31.45±1.68^{a}	39.30±1.93^{b}	38.32±1.74^{b}
10	4.71±0.24^{c}	2.17±0.12^{a}	3.12±0.11^{b}	2.82±0.23^{b}
20	0.18±0.02^{b}	0.10±0.01^{a}	0.14±0.02^{b}	0.11±0.01^{ab}
30	0	0	0	0
	Total vitamin E (mg/100 g)			
	RBO	POO	80:20	70:30
0	95.10±3.24	96.97±2.99	95.48±2.44	95.67±2.65
10	24.69±1.12^{c}	14.07±1.11^{a}	18.76±2.11^{b}	16.44±2.09^{ab}
20	8.81±0.49^{c}	4.07±0.31^{a}	6.23±0.54^{b}	5.29±0.43^{b}
30	3.31±0.12^{c}	1.15±0.12^{a}	2.32±0.13^{b}	2.13±0.11^{b}
	γ -oryzanol (mg/100 g)			
	RBO	POO	80:20	70:30
0	1,250.75±45.58^{d}	0^{a}	1,002.45±41.21^{c}	883.98±28.19^{b}
10	409.62±22.23^{d}	0^{a}	262.73±11.87^{c}	191.31±12.34^{b}
20	134.25±46.66^{d}	0^{a}	86.11±6.24^{c}	66.48±4.44^{b}
30	44.15±3.21^{d}	0^{a}	28.17±0.95^{c}	21.75±1.36^{b}

Note: Each value represents the mean ± standard deviation (SD) from three independent replicates. Means within each row with different superscripts are significantly different ($p < 0.05$).

The relative stability of tocopherols is attributable to differences in their chemical structure, and γ-oryzanol in RBO probably contributes to protecting tocopherols from thermal degradation. POO with RBO exhibits improved oil performance as it has high antioxidant capacity and oxidative stability. High retention of tocopherols was observed in 80:20 and 70:30 blends, suggesting that blending can be considered a viable option to extend frying lifetime without compromising oil quality and nutritional value.

3.13. Changes in α-Tocotrienol and γ-Tocotrienol Content During Frying

Table 4 summarizes the changes in α-tocotrienol and γ-tocotrienol content after 30 hours of frying at 180°C in RBO, POO, and their blends (80:20 and 70:30). Tocotrienols, which have better antioxidant properties, are extremely thermally sensitive and degrade quickly at higher temperatures (Ogan, Dumont, & Ngadi, 2017). α-tocotrienol was significantly decreased in all samples, being most abundant in POO (26.71 mg/100 g) and least in RBO (2.32 mg/100 g). At 20 hours, α-tocotrienol was completely exhausted in all samples.

As the initial amount of γ-tocotrienol was larger, its degradation was slow, allowing for prolonged antioxidant protection. The initial γ-tocotrienol content was highest in RBO (41.26 mg/100 g) and lowest in POO (31.45 mg/100 g). The synergistic protection provided by γ-oryzanol and other natural antioxidants accounts for the higher

retention in RBO. However, by 20 hours, γ-tocotrienol levels had reduced to negligible levels in all samples, consistent with reports by Ogan et al. (2017), which indicated that tocotrienols degrade at a faster rate than tocopherols.

In this case, blended oils, especially at an 80:20 ratio, contained more γ-tocotrienol than POO, indicating that blending can delay the degradation of γ-tocotrienol by reducing oxidative stress through other antioxidants like γ-oryzanol.

Blending improves oil stability and extends frying life. Their retention during oil use is important for maintaining the quality and nutrition of oils and is practical for reducing oil replacement rates in the food industry. Combining tocotrienols with γ-oryzanol can further enhance frying performance and thermal stability.

3.14. Changes in Total Vitamin E and γ-Oryzanol Content During Frying

The effects on total vitamin E (tocopherols and tocotrienols) and γ-oryzanol levels are presented in Table 4, after 30 hours of frying at 180°C in RBO, POO, and their blends (80:20 and 70:30). These antioxidants protect oils against oxidative degradation, but prolonged frying significantly decreased their concentrations. Overall, the samples initially had relatively high levels of total vitamin E. POO decomposed the fastest, as it lacks γ-oryzanol, which enhances RBO's stability. Regarding retained vitamin E, the blended oils exhibited higher vitamin E stability than POO alone, with the 80:20 blend performing better than the 70:30 blend.

Vitamin E in POO was almost depleted after 30 hours, whereas it had measurable amounts in RBO and the blends. This agrees with Zade et al. (2024), which showed that oils high in tocopherols and tocotrienols are degraded less under thermal stress. Since γ-Oryzanol is only present in RBO and its blends and has great oxidative stability, it is expected that RBO preserves it at higher levels. Although it decreased markedly by 20 hours, γ-oryzanol was present for longer periods than vitamin E.

The more rapid deterioration of vitamin E in POO highlights the protective effect of γ-oryzanol. This observation aligns with Waseif et al. (2022), confirming the role of γ-oryzanol in enhancing oil stability. The 80:20 blend displayed better retention of both vitamin E and γ-oryzanol, indicating that it is the most suitable for commercial frying, balancing nutrients and stability.

3.15. Changes in Fatty Acid Composition During Frying

Table 5 summarizes the oleic and linoleic acid contents of RBO, POO, and their blends (80:20 and 70:30) after frying at 180°C for 30 hours. Palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3) were selected as targets for assessing frying stability. Palmitic acid and SFAs increased over time as a result of PUFA degradation. At 0 hours, the palmitic acid content was highest in POO, and all samples showed elevated levels after 30 hours.

Oleic acid (C18:1) is a MUFA that, in all samples, was relatively stable. Linoleic acid (C18:2) declined significantly due to its high propensity for oxidation, and RBO showed the greatest decrease. All the samples experienced complete degradation of Linolenic acid (C18:3) after 10 hours, similar to the findings reported by Hénon, Kemény, Recseg, Zwobada, and Kövári (1997), which demonstrated its extreme sensitivity to heat and oxidation.

These findings indicate the combined impact of oxidative moisture and heat degradation. The loss of PUFAs and the retention of oleic acid suggest the thermal resilience of MUFAs (Petersen, Jahreis, Busch-Stockfisch, & Fritsche, 2013).

The 80:20 blend provided higher retention of PUFA than the 70:30 blend, offering a balance between oxidative stability and nutritional quality. Blends with complementary fatty acid profiles enhanced frying stability and oil lifespan (Ben Hammouda et al., 2018; Zhou et al., 2022) as supported by previous studies.

Table 5. Fatty acid composition changes in frying oil during frying at 180°C using rice bran oil (RBO), palm olein oil (POO), and their blends at 80:20 and 70:30 ratios.

Time (hr.)	Palmitic Acid, C16:0			
	RBO	**POO**	**80:20**	**70:30**
0	17.52±0.85^{a}	39.61±1.02^{c}	25.15±0.58^{b}	26.93±0.42^{b}
10	18.64±0.66^{a}	40.38±1.01^{c}	25.99±0.63^{b}	27.16±0.39^{b}
20	19.71±0.72^{a}	42.91±0.89^{d}	26.35±0.71^{b}	30.67±0.87^{c}
30	22.57±0.59^{a}	44.19±0.98^{d}	27.89±0.54^{b}	31.06±0.75^{c}
	Stearic Acid, C18:0			
	RBO	POO	80:20	70:30
0	1.85±0.05^{a}	4.28±0.12^{c}	3.16±0.14^{b}	3.31±0.07^{b}
10	2.53±0.08^{a}	4.29±0.11^{d}	3.25±0.10^{b}	3.66±0.09^{c}
20	3.83±0.07^{a}	4.21±0.09^{b}	3.91±0.08^{a}	3.94±0.13^{a}
30	4.38±0.09	4.42±0.08	4.39±0.12	4.39±0.11
	Oleic Acid, C18:1, n-9			
	RBO	POO	80:20	70:30
0	42.16±1.14^{ab}	44.16±1.23^{b}	40.11±1.35^{a}	40.89±1.11^{a}
10	43.21±1.33^{ab}	43.73±1.09^{b}	40.62±1.28^{a}	41.37±1.03^{a}
20	43.72±1.52^{b}	42.99±1.07^{b}	42.67±1.06^{ab}	40.55±1.25^{a}
30	42.32±1.55	41.95±1.23	42.05±1.23	40.01±1.33
	Linoleic Acid, C18:2, n-6			
	RBO	POO	80:20	70:30
0	35.68±1.07^{d}	10.47±0.66^{a}	29.73±0.35^{c}	26.01±0.42^{b}
10	33.23±0.99^{d}	9.64±0.52^{a}	28.51±0.31^{c}	26.15±0.30^{b}
20	30.12±1.15^{d}	8.16±0.47^{a}	25.37±0.28^{c}	23.13±0.45^{b}
30	28.31±0.87^{d}	7.23±0.44^{a}	24.09±0.19^{c}	21.99±0.51^{b}
	Linolenic Acid, C18:3, n-3			
	RBO	POO	80:20	70:30
0	1.15±0.02^{c}	0.24±0.01^{a}	0.81±0.02^{b}	1.61±0.03^{c}
10	0	0	0	0
20	0	0	0	0
30	0	0	0	0
	Others			
	RBO	POO	80:20	70:30
0	1.64±0.02^{d}	1.24±0.03^{b}	1.04±0.03^{a}	1.25±0.04^{b}
10	2.39±0.04^{c}	1.96±0.02^{b}	1.35±0.04^{a}	1.26±0.02^{a}
20	2.62±0.05^{c}	1.73±0.03^{b}	1.44±0.02^{a}	1.35±0.02^{a}
30	2.42±0.04^{c}	2.21±0.04^{b}	1.38±0.02^{a}	2.26±0.03^{b}

Note: Each value represents the mean ± standard deviation (SD) from three independent replicates. Means within each row with different superscripts are significantly different ($p < 0.05$).

3.16. Changes in SFAs, MUFAs, PUFAs, and SFA: MUFA: PUFA Ratios During Frying

As represented in Table 6, the fatty acid composition of RBO, POO, and their blends (80:20 and 70:30) was significantly altered after 30 hours of frying at 180°C. Thermal oxidation caused the degradation of PUFAs, leading to an increase in SFAs. At the beginning of the experimental period, POO contained the most SFA, while RBO contained the least. After 30 hours, SFA levels increased in all samples, with moderate increases in the blends. This is consistent with the concentration effect from PUFA breakdown.

MUFAs, especially oleic acid, appear to be stable during frying and confer high resistance to oxidation (Petersen et al., 2013). PUFAs, especially linoleic (C18:2) and linolenic acid (C18:3), degrade rapidly during frying. Linolenic acid was completely lost in 10 hours; however, linoleic acid showed more degradation, especially in refined bleached oil (RBO). Thus, the 80:20 blend preserved more PUFAs than the 70:30 blend, which was better balanced regarding stability and nutritional quality.

Table 6. Changes in SFAs, MUFAs, PUFAs, and the ratio of SFA: MUFA: PUFA in frying oil during frying at 180°C using rice bran oil (RBO), palm olein oil (POO), and their blends at 80:20 and 70:30.

Time (hr.)	SFAs			
	RBO	**POO**	**80:20**	**70:30**
0	19.37±0.95^{a}	43.89±1.22^{c}	28.31±1.00^{b}	30.24±0.99^{b}
10	21.17±0.88^{a}	44.67±1.32^{c}	29.24±0.85^{b}	30.82±0.78^{b}
20	23.54±0.87^{a}	44.12±1.55^{d}	30.26±0.65^{b}	34.61±0.82^{c}
30	26.98±0.78^{a}	48.61±1.68^{d}	32.28±1.23^{b}	35.45±0.94^{c}
	MUFAs			
	RBO	POO	80:20	70:30
0	42.16±1.66	44.16±1.56	40.11±1.82	40.62±1.68
10	43.21±1.54	43.73±1.32	40.62±1.68	41.37±1.88
20	43.72±1.86	42.99±1.63	42.67±1.74	40.55±1.64
30	42.32±1.72	41.95±1.84	42.05±1.58	40.01±1.53
	PUFAs			
	RBO	POO	80:20	70:30
0	36.83±0.86^{d}	10.71±0.65^{a}	30.54±0.86^{c}	27.62±0.56^{b}
10	33.23±0.79^{d}	9.64±0.85^{a}	28.51±0.96^{c}	26.15±0.69^{b}
20	30.12±0.96^{d}	8.16±0.95^{a}	25.37±0.75^{c}	23.13±0.75^{b}
30	28.31±0.67^{d}	7.23±0.78^{a}	24.09±0.69^{c}	21.99±0.68^{b}
	SFA: MUFA: PUFA			
	RBO	POO	80:20	70:30
0	1.0: 2.2: 1.9	1.0: 1.1: 0.2	1.0: 1.4: 1.1	1.0: 1.3: 0.9
10	1.0: 2.0: 1.6	1.0: 1.0: 0.2	1.0: 1.4: 1.0	1.0: 1.3: 0.8
20	1.0: 1.7: 1.3	1.0: 0.9: 0.2	1.0: 1.3: 0.8	1.0: 1.2: 0.7
30	1.0: 1.6: 1.1	1.0: 0.9: 0.1	1.0: 1.3: 0.7	1.0: 1.1: 0.6

Note: Each value represents the mean ± standard deviation (SD) from three independent replicates. Means within each row with different superscripts are significantly different ($p < 0.05$).

The elevation in the SFA: MUFA: PUFA ratio indicates oxidative stress experienced by the oils. RBO had a well-balanced profile, but a greater amount of PUFAs was lost after frying. POO, which had a high content of SFA, was more stable with minimal changes over time since it was more oxidatively stable. The blended oils showed more balanced ratios, with the 80:20 blend being closer to the World Health Organization-recommended ratio (1:1.5:1) for cardiovascular health. The results are consistent with previous research (Ben Hammouda et al., 2018; Petersen et al., 2013) as mixing oils high in PUFA with oils rich in SFA improves frying stability without sacrificing nutritional quality.

4. CONCLUSION

With a focus on fatty acid content, antioxidant retention, and thermal stability, this study evaluated the stability of RBO, POO, and their blends (80:20, 70:30) during 30 hours of frying at 180°C. Although POO's high SFA and tocotrienol levels offered improved thermal resistance, RBO's high PUFA and γ-oryzanol content provided superior nutrition but reduced oxidative stability.

With the 80:20 mix exhibiting the optimal retention of antioxidants and fatty acids, blended oils balanced stability and nutritional quality. Due to oxidation, PUFA content decreased in all samples, whereas SFA levels increased. Retaining more vitamin E and γ-oryzanol than POO, the 80:20 mix improved fried performance and health benefits.

Emphasizing their potential as better fried substitutes, the SFA: MUFA: PUFA ratio of the blended oils approximates the advised 1:1.5:1 ratio for cardiovascular health. These findings highlight the sensible benefits of combining oils to maximize stability and nutrition. Given the health risks associated with oxidized lipids, this study supports a practical approach to controlling chemical hazards in frying systems by modifying the oil blend composition. Importantly, the extended frying time (30 h) and the specific 80:20 RBO: POO blend ratio explored in this work have not been extensively studied before. This approach demonstrates a balanced trade-off between oxidative stability and nutritional value, offering direct applicability to commercial frying practices.

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