

The effect of replacing red palm stearin with red palm olein in baked potato cookies

J. Xu^a, Y.Y. Liu^b, T.M. Olajide^a, H.A. Liu^b and X.C. Weng^{a,b,✉}

^aSchool of Environmental and Chemical Engineering, Shanghai University, 333, Nanchen Road, Shanghai 200444, China

^bSchool of Life Sciences, Shanghai University, 333, Nanchen Road, Shanghai 200444, China

✉Corresponding author: wxch@staff.shu.edu.cn

Submitted: 8 April 2021; Accepted: 25 May 2021; Published online: 22 June 2022

SUMMARY: Potato cookies were formulated by replacing red palm stearin (RPS) by red palm olein (RPOL) at 0, 17 and 35%, and then baked at 160, 180 and 200 °C for 10, 12 and 15 min. The sensory analysis, using an orthogonal test, showed that a RPS-RPOL ratio of 65:35, baking temperature of 160 °C, and baking time 12 min were the optimal conditions. Cookies made from 65% RPS + 35% RPOL composition exhibited 0.6 times less squalene, but 1.5 times more β-carotene, tocopherols and tocotrienols than the mixture of RPS and RPOL at 100:0. In addition, cookies with superior oxidative stability were obtained at a lower temperature (160 °C) and short baking time (10 min). This study demonstrates that the application of RPOL and RPS blending can positively enhance the nutritional properties and oxidative stability of baked food, and that using potato in the baking processing may be beneficial.

KEYWORDS: Micronutrients; Oxidative stability; Potato; Red palm olein; Red palm stearin

RESUMEN: Efecto de reemplazar estearina por oleína de palma en galletas de papa horneadas. Las galletas de papa fueron formuladas reemplazando estearina de palma roja (RPS) por oleína de palma roja (RPOL) al 0, 17 y 35%, y posteriormente horneadas a 160, 180 y 200°C durante 10, 12 y 15 min. El análisis sensorial utilizando una prueba ortogonal mostró que la relación RPS-RPOL 65:35, la temperatura de horneado 160 °C, y el tiempo de horneado 12 min fueron las condiciones óptimas. Las galletas hechas de 65% RPS + 35% RPOL presentan 0,6 veces menos de escualeno, pero 1,5 veces más β-caroteno, tocoferoles y tocotrienoles que la mezcla de RPS y RPOL en 100:0. Por otra parte, las galletas con mayor estabilidad oxidativa se obtuvieron a menor temperatura (160 °C) y menor tiempo de horneado (10 min). Este estudio demuestra que la mezcla RPOL y RPS puede mejorar positivamente las propiedades nutricionales y la estabilidad oxidativa de los alimentos horneados, y que el uso de papa en el procesamiento de hornear puede ser beneficioso.

PALABRAS CLAVE: Estabilidad oxidativa; Estearina de palma roja; Micronutrientes; Oleína de palma roja; Patata

Citation/Cómo citar este artículo: Xu J, Liu YY, Olajide TM, Liu HA, Weng X. 2022. The effect of replacing red palm stearin with red palm olein in baked potato cookies. *Grasas Aceites* 73 (2), e456. <https://doi.org/10.3989/gya.0441211>

Copyright: ©2022 CSIC. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0) License.

1. INTRODUCTION

The potato, an all-around nutritious food which is rich in protein, vitamins, dietary fiber, minerals, and micronutrients (Singh, 2016) is grown in 149 countries and ranks as the fourth-most important food crop worldwide. This high-yielding, adaptable, nutritional crop has been utilized many times during periods of food shortage. As an economic crop, the value of potato has gradually increased in the past two decades. The international trade of potato has risen considerably because of the growing demand by the food processing industry (Birch *et al.*, 2012). More and more research has been focused on the potato staple food processing and industrial development, such as potato steamed bread, rice noodles, bread and so on (Zhang *et al.*, 2017). The potato could also be a good nutritional additive to foods that are highly desirable in a diet because of their beneficial effects on human health, such as cookies. Using the potato as a raw material for making biscuits and cookies can not only enrich the types of potato and increase consumption, but can also ameliorate the disadvantages of single nutritional components of existing products. This could be of great significance for improving people's nutrition and dietary balance. Nevertheless, studies on potato cookies are still limited. The development of potato cookies can increase the variety of cookies, enhance the living standards of people and contribute to theoretical reference for the development of potato leisure food.

Cookies are a type of convenient baked food which is loved by consumers. It could be made from different dough comprising of majorly wheat flour and/or sugar, milk, egg, salt, and flavor added during production (Oluwamukomi *et al.*, 2010). Extensive efforts have been made to improve the nutritional value of cookies. The lipids applied in cookies and other baking products are mainly animal fats and hydrogenated vegetable oils, which are solid at room temperature and have good processing performance. However, animal oils are expensive. Hydrogenated vegetable oils, on the other hand, are low in price, but contain trans fatty acids which may increase the risk of cardiovascular disease, cancer, diabetes and other diseases (Kong *et al.*, 2011). The low-cost, large-scale production palm oil, with approximately 48% saturated fatty acids, is expected to replace hydrogenated oils (Mba *et al.*, 2015).

In addition, palm oil is the vegetable oil with the largest volume of production, consumption and trade in the world at present. It is cheap and stable. Palm oil is also widely known for its high contents in carotenoids, squalene, tocopherols and tocotrienols. It is processed by advanced technologies such as molecular distillation (Mayamol *et al.*, 2007). While removing impurities in the oil, the product retains most of its nutrients. These nutritional substances are especially good for the eye and skin, protect biological systems against oxidation and prevent various types of cancer and other diseases (Mayamol *et al.*, 2007). Red palm olein (RPOL) and red palm stearin (RPS) are deep red palm oils with different melting points processed by fractionation. RPOL is liquid at room temperature, with poor processing properties but abundant micronutrients. On the contrary, RPS is semi-solid at room temperature, with relatively low nutrient content, but suitable for the processing of cookies. (Nor and Miskandar, 2007). The application of RPOL and RPS blending in baking processes not only gives baked foods an ideal natural color and enhances their nutritional value, but it also expands the application of palm oil and increases the number of consumers.

Thus, this research is devoted to the development of potato cookies with different RPS-RPOL ratios. The micronutrients, oxidative stability and sensory attributes of the samples were determined. Baking processing parameters such as baking temperature and baking time affect the physicochemical properties of products. To obtain a better understanding of these changes in red palm oil that occur in the baking process in this study, samples were baked at three temperatures (160, 180, 200 °C) for three different durations (10 min, 12 min, 15 min), which are the usual production conditions for baked foods (the cookies were fully cooked but not burnt). This study may provide reference values for the selection of formulae for baking products, the optimization research of baking parameters in industrial production and the prediction of shelf-life.

2. MATERIALS AND METHODS

2.1. Materials

Potato flour (homemade), wheat flour, sugar, and egg yolk were purchased from Wal-Mart supermarket (Shanghai, China). RPS (50 °C) and RPOL

(24 °C) were donated by Palm Oil Research and Technical Service Institute of Malaysian Palm Oil Board (PORTSIM) (Shanghai, China).

2.2. Sample preparation

The pre-optimized recipe for potato cookies was used: potato flour 200 g, wheat flour 300 g, fats (RPS-RPOL) 300 g, sugar 200 g, egg yolk 150 g. Melted RPS (heated at 55 °C) and RPOL were well mixed, followed by the addition of sugar and egg. The mixture of potato flour and wheat flour was added last, and the dough was kneaded and sheeted to a uniform thickness of 5 mm. Then, the dough was cooled at 4 °C for 20 min and cut into the size of 30 mm × 30 mm. Baking was carried out in a SM-522 baking oven (Xinmai machinery Co., Ltd., Wuxi, China). After that, the cookies were cooled at room temperature, then sealed and stored at -20 °C.

The fats in the formula were blended with RPS and RPOL at three different ratios (RPS-RPOL: 100:0, 83:17, and 65:35) (the dough becomes difficult to form and oil flows out when a larger proportion of RPOL is added, hence the ratio of 65:35 was chosen as the maximum). The three levels of baking temperature (160, 180, and 200 °C) and three levels of baking time (10, 12, and 15 min) were used. Under these usual baking conditions, the cookies were fully cooked but not burnt.

2.3. Sensory analysis

In order to simplify the sensory analysis, the L₉ (3³) orthogonal experimental design was adopted. The factors and levels are shown in Table 1. The 9 products were put into randomly numbered containers. Fifteen semi-trained panel members (all from the Food Science Department, Shanghai University, Shanghai, China) evaluated the color, aroma, taste, texture, and overall acceptability of the products through a 7-point hedonic scale, from 1

(strongly dislike) to 7 (strongly like) (Harianti *et al.*, 2018).

2.4. Oil extraction

100 g of cookies were finely ground before extraction and the lipids were extracted by 500 mL petroleum ether in a DK-S12 electric-heated thermostatic water bath (Hualian Medical Equipment Co., Ltd., Shanghai, China) at 65 °C for 20 min. The micronutrients were stored in a deep freezer for further analysis after the rotary evaporation of the solvent at 35 °C.

2.5. β-Carotene

A β-Carotene analysis was performed on UV-1800PC Ultraviolet spectrophotometer (Mapada Instrument Co., Shanghai, China) (Pan *et al.*, 2016). 0.1 g of cookies was accurately weighed, the volume was made constant with n-hexane to 25 mL, and then placed in a colorimetric dish. The absorbance of the sample was measured by UV-1800PC at 446 nm wavelength with a blank as control. The calculation method of carotene was as follows:

$$Co = \frac{383E}{IC} \quad (1)$$

Where *E* represents the sample absorbance, *I* represents the width of the colorimetric dish, *C* represents the content of red palm oil in the sample (g/100mL), *Co* represents the content of β-carotene in red palm oil (mg/kg).

2.6. Squalene

Squalene was analyzed by a LC-20A High Performance Liquid Chromatography (HPLC) coupled with an SPD-M20A UV detector (Shimadzu Co., Japan) (Pan *et al.*, 2016). The unsaponifiables were extracted from 3 g oil samples, then dissolved and diluted to 25 mL with n-hexane. The extracts were filtrated through a 0.22 μm membrane filter and chromatograms were acquired at 204 nm using an injection volume of 25 μL. An Inertsustain C18 column (250 mm × 4 mm, 5 μm; Shimadzu Co., Japan) was equilibrated using acetonitrile/methanol 4:0 (v/v) at a flow rate of 1 mL/min. Squalene was identified and quantified by comparison to the corresponding standards (Aladdin Industrial Co., Shanghai, China) as external standards.

TABLE 1. Orthogonal experimental design (three factors and three levels) for sensory analysis

Levels	Factors		
	A (RPS-RPOL)	B (Temperature/°C)	C (Time/min)
1	100:0	160	10
2	83:17	180	12
3	65:35	200	15

2.7. Tocotrienols and tocopherols

Tocotrienols and tocopherols were analyzed according to a modified procedure of Yui *et al.* (2016) using the external standard (α -, β -, γ -, and δ -isoforms, Solarbio Co., Beijing, China) method on an LC-20A HPLC equipped with a RF-10AXL Fluorescence detector (Shimadzu Co., Japan). 2 g of oil sample were dissolved in methanol and sonicated for 20 min, centrifuged at 500×g for 10 min. Excitation and emission absorbance were set at 290 nm and 330 nm, respectively. Separation was done on an Inertsustain C18 column (250 mm × 4 mm, 5 μ m; Shimadzu Co., Japan) thermostated at 30 °C. The mobile phase comprised a mixture of methanol-water (98:2, v/v) at a flow rate of 1 ml/min (injection volume = 5 μ L).

2.8. Schaal oven test

The Schaal oven test was used for sample pre-treatment to accelerate oxidation (Michotte *et al.*, 2011). The samples were placed in the elec-

tro-thermal blower drying box ($63 \pm 1^\circ\text{C}$) for 40 days to measure the β -carotene content at 3-day intervals. The determination of β -carotene was performed according to the method of Pan *et al.*, (2016).

2.9. Statistical analysis

The data obtained from various experiments were statistically analyzed. All assays were carried out in duplicate or triplicate and the data are presented as mean \pm standard deviation (SD). Analysis of variance (ANOVA) was carried out using IBM SPSS 22.0, followed by Duncan's multiple range test ($P < 0.05$).

3. RESULTS AND DISCUSSION

3.1. Sensory characteristics

The effects of different RPS-RPOL ratios, baking times and baking temperatures on the color, aroma, taste, texture and overall acceptability of cookies were studied by L9 (3^3) orthogonal tests (Table 1), and the results of orthogonal tests are shown in Table 2.

TABLE 2. Orthogonal test results for sensory characteristics of potato cookies

Samples	A (RPS-RPOL)	B (Temperature/ $^\circ\text{C}$)	C (Time/min)	Color	Aroma	Taste	Texture	Overall
1	1	1	1	5.1	5.1	5.0	5.9	5.0
2	1	2	2	5.4	5.2	5.8	6.8	6.2
3	1	3	3	1.8	3.6	3.4	5.1	2.3
4	2	1	2	5.3	4.9	5.5	5.8	6.0
5	2	2	3	3.5	4.4	4.5	5.1	4.5
6	2	3	1	5.2	4.9	4.5	4.9	4.1
7	3	1	3	5.7	5.4	5.5	5.3	5.6
8	3	2	1	5.9	5.1	5.6	5.4	5.8
9	3	3	2	3.3	4.3	4.1	4.5	3.2
Color	k ₁	4.1	5.4	5.4				
	k ₂	4.7	5.0	4.7				
	k ₃	5.0	3.4	3.7				
	R	0.9	1.9	1.7				
Aroma	k ₁	4.6	5.1	5.0				
	k ₂	4.7	4.9	4.8				
	k ₃	4.9	4.3	4.5				
	R	0.3	0.8	0.6				
Taste	k ₁	4.7	5.3	5.0				
	k ₂	4.8	5.3	5.1				
	k ₃	5.1	4.0	4.5				
	R	0.3	1.3	0.7				
Texture	k ₁	5.9	5.7	5.4				
	k ₂	5.3	5.8	5.7				
	k ₃	5.1	4.8	5.2				
	R	0.8	0.9	0.5				
Overall	k ₁	4.5	5.6	5.0				
	k ₂	4.9	5.5	5.1				
	k ₃	4.9	3.2	4.2				
	R	0.4	2.3	1.0				

RPS, red palm stearin; RPOL, red palm olein.

According to the R values, the order of importance of the variables on the color, aroma, taste and overall acceptability was as follows: baking temperature (B) > baking time (C) > RPS-RPOL ratio (A), and the optimal condition was A3B1C1 or A3B1C2; that is, the optimal conditions were RPS-RPOL 65:35, baking temperature 160 °C, baking time 10 min or 12 min. However, the factors influencing the cookie texture were as follows: baking temperature (B) > RPS-RPOL ratio (A) > baking time (C) and the optimal condition was A1B2C3. Different from other sensory qualities, the RPS-RPOL ratio had great influence on the texture of cookies. The optimal RPS-RPOL ratio was 100:0, which means that the high content in RPS is beneficial to the crisp texture of cookies. In general, considering the influence of all sensory properties, the most significant factor affecting the quality of cookies was baking temperature (B), followed by baking time (C), and then RPS-RPOL ratio (A). The better sensory evaluation scores for the cookies were obtained when the baking condition was A3B1C2 (RPS-RPOL ratio 65:35, baking temperature 160 °C, and baking time 12 min). These conditions caused evenly-colored cookies, with no incomplete cooking, no charring, and a crisp taste.

3.2. β -Carotene

The contents of β -carotene in RPOL and RPS were 454.735 ± 1.986 mg/kg and 224.401 ± 1.704 mg/kg, respectively. The content in β -carotene in RPOL was 15 times higher than that in carrot and 300 times higher than that in tomato (Radhika *et al.*, 2017). The effects of different RPS-RPOL proportions, baking temperatures and baking times on the content in β -carotene in oil are presented in Table 3. There was a significant effect of different RPS-RPOL ratios and baking conditions on β -carotene

content (mg/kg) in the oil of potato cookies. The content in β -carotene in the oil of potato cookies significantly decreased as the baking time and baking temperature increased ($p < 0.05$). Without adding RPOL, β -carotene was retained the most at 160 °C for 10 min (81.7% of the oil), and the least at 200 °C for 15 min (73.9% of the oil). Siti *et al.* (2018) conducted a deep-frying experiment at 180 °C, and after 10 times of repeated frying, the contents in β -carotene in red palm oil decreased from 294 to 143 mg/kg, and from 119 to 82 mg/kg in yellow palm oil. It can be seen that the content in β -carotene in red palm oil after thermal processing is still higher than that in ordinary yellow palm oil.

Added red palm oil to cookies can effectively increase the β -carotene content in cookies. El-Hadad *et al.* (2010) used 40% shortening and 60% RPOL, and the β -carotene content in cookie samples was 188 mg/kg, 14.8 times higher than in 100% shortening cookies. Researchers have used red palm oil as a substitute fat for a variety of functional food processing, in which the β -carotene can be retained better in red palm oil; the retention in cookies was better than that in bread (Sidhu *et al.*, 2004; Marjan *et al.*, 2016). Thus, the consumption of red palm oil can supplement β -carotene. It was reported that the long-term intake of RPOL as a source of carotenoids, can improve regional population problems (Sobhana *et al.*, 2019), improve the biological characteristics of animal plasma glucose, and cholesterol, and prevent diabetes and cardiovascular diseases. Red palm olein improve the levels of catalase and glutathione peroxidase in red blood cells, which is beneficial to antioxidation (Szulczewska-Remi *et al.*, 2019). In addition, the combined effects of carotene, tocopherols, tocotrienols and other natural antioxidants in red palm olein cannot be underestimated (Yanishlieva *et al.*, 1998).

TABLE 3. The effects of different RPS-RPOL ratios, baking times and baking temperatures on β -carotene content (mg/kg) in the oil of potato cookies

RPS-RPOL	160 °C			180 °C			200 °C		
	10 min	12 min	15 min	10 min	12 min	15 min	10 min	12 min	15 min
100:0	183.2±1.9 ^{aC}	170.9±2.5 ^{bcC}	169.8±0.5 ^{cdC}	175.0±2.2 ^{bc}	165.6±5.7 ^d	166.7±1.9 ^{cdC}	171.6±0.8 ^{bcC}	165.7±0.4 ^{dC}	165.6±0.9 ^{dC}
83:17	229.0±2.3 ^{aB}	226.3±2.7 ^{abB}	213.8±4.0 ^{cb}	227.5±4.1 ^{abB}	221.3±1.9 ^{bb}	203.5±5.1 ^{deB}	223.4±1.9 ^{abB}	208.9±2.0 ^{cdB}	198.2±3.1 ^{eB}
65:35	281.1±4.5 ^{aA}	263.5±8.9 ^{bcA}	255.5±3.4 ^{cdA}	274.9±5.6 ^{abA}	255.4±7.0 ^{cdA}	245.4±8.0 ^{deA}	268.7±5.0 ^{bA}	238.4±3.1 ^{cdA}	233.6±0.1 ^{fA}

*Results are expressed as mean \pm standard deviation (n=3).

*Labelled with the same letter did not differ significantly ($p \leq 0.05$) according to Duncan's test.

3.3. Squalene

The squalene content in RPOL and RPS were 185.7 mg/kg and 233.3 mg/kg, respectively. The squalene content in RPS was higher than in RPOL, which is the opposite of β -carotene. Kumar and Krishna (2014) carried out the dry fractionation of crude red palm olein, and obtained the squalene contents of crude red palm olein and crude red palm stearin as 360 mg/kg and 16.4 mg/kg, which were inconsistent with the results of this paper, and may be related to the special processing technology of the oil. Another research showed that the processing method of palm oil can affect the micronutrient content in the oil (Mayamol *et al.*, 2007).

There is a significant ($p < 0.05$) influence of different RPS-RPOL ratios, baking times and baking temperatures on squalene content (mg/kg) in the oil of potato cookies (Table 4). The squalene content (mg/kg) in the oil of potato cookies was found to vary significantly under different baking conditions and showed a decreasing trend ($p < 0.05$). The content in squalene descended with the elevation of baking temperature and extended time and the decreased trend observed in the amount of squalene under different baking conditions was the same as that of β -carotene. Without the addition of RPOL, most squalene was retained at 160 °C for 10 min, accounting for 95.7% of the oil content. At 200 °C for 15 min, the retention rate of squalene was the lowest at 58.7%. With the addition of RPOL, the amount of squalene in the oil decreased accordingly. Applying red palm oil as a squalene source may increase the amount of squalene for humans as squalene in food can be well absorbed (the absorption amount reaches 60-85%). Therefore, food with red palm oil as the source of squalene is expected to improve the content in human squalene after intake. Squalene

has strong antioxidant effects, which can quench free radical oxygen, prevent lipid peroxidation, promote anti-aging and improve immunity. It can also protect normal cells, inhibit the growth of tumor cells and reduce the risk of breast cancer, colon cancer, pancreatic cancer and other cancers. Squalene can promote metabolism of the body, and protect the heart, liver, kidney and other organs (Reddy and Couvreur, 2009).

3.4. Tocotrienols and tocopherols

The data pertaining to tocotrienol and tocopherol contents (ppm) in the oil of potato cookies is presented in Table 4. The total amounts of tocopherols and tocotrienols in RPOL and RPS were 664.3 mg/kg and 254.7 mg/kg, respectively. In addition, different RPS-RPOL ratios and different baking conditions showed significant differences in tocotrienol and tocopherol contents (ppm) in the oil of potato cookies ($p < 0.05$). The content in tocotrienols was higher than that of tocopherols, and the β/γ - isomer was higher than of other isomers. The most serious losses were presented in β/γ -tocotrienol, in agreement with the report for baking, deep-frying, and other thermal processing (Rossi *et al.*, 2007).

The retention of tocotrienols and tocopherols was under the influence of process parameters. It was obvious that the δ -, β/γ -tocotrienol, δ -, β/γ -tocopherol and total tocotrienol, tocopherol tendencies resembled β -carotene. The loss in vitamin E was minimum at a low temperature for a short time (160 °C, 10 min). The thermal degradation of vitamin E in oils may have been aggravated by the increases in temperature and time, as clarified by Hamid *et al.* (2014).

What's more, the results from sample baking under the same conditions but with different RPS-RPOL proportions showed that the content in vitamin E in cookies could be increased by adding

TABLE 4. The effects of different RPS-RPOL ratios, baking times and baking temperatures on squalene content (mg/kg) in the oil of potato cookies

RPS-RPOL	160 °C			180 °C			200 °C		
	10 min	12 min	15 min	10 min	12 min	15 min	10 min	12 min	15 min
100:0	223.9±2.4 ^{aA}	196.8±5.3 ^{bA}	194.1±2.2 ^{cA}	159.7±1.4 ^{cA}	133.7±3.0 ^{dB}	133.1±1.2 ^{cA}	147.9±1.0 ^{dA}	135.2±4.2 ^{cA}	131.2±1.4 ^{cA}
83:17	151.3±3.9 ^{aB}	140.5±4.1 ^{bB}	128.7±1.6 ^{cB}	143.9±5.5 ^{abB}	138.2±7.1 ^{bA}	122.7±2.0 ^{dB}	139.9±2.1 ^{bB}	130.0±4.4 ^{bB}	126.8±0.8 ^{bB}
65:35	135.2±1.7 ^{aC}	127.8±2.2 ^{bC}	115.6±4.3 ^{cC}	122.7±2.4 ^{bC}	108.6±0.3 ^{dC}	99.1±4.3 ^{dB}	114.3±2.5 ^{cC}	105.7±2.5 ^{deC}	101.2±1.6 ^{deC}

*Results are expressed as mean \pm standard deviation (n = 3).

*Labelled with the same letter did not differ significantly ($p \leq 0.05$) according to Duncan's test.

RPOL, which contains higher vitamin E content. RPOL and RPS are not only rich in natural antioxidant vitamin E, but have also been applied in the production of sugar-snap cookies and bread with good sensory characteristics and consumer acceptability (Al-Saquer *et al.*, 2004). The presence of tocotrienols and tocopherols retards oil autoxidation greatly and protects fatty foods from off-flavors. In addition, these compounds possess gene regulatory functions (α -tocopherol), anti-inflammatory, antitumor activities (γ -tocopherol), neuroprotective properties, preventive effect on cholesterol biosynthesis, and anticancer effects (Kamaleldin and Appelqvist, 1996). In short, considerable retention of tocotrienols and tocopherols in food is beneficial to both food storage and human health.

3.5. Schaal oven test

To characterize the oxidative stability of the products, the change in trends of β -carotene content during the oven test are presented in Figure 1. Generally, combined with the ordinates of Figure 1a, 1b, 1c, samples with a higher ratio of RPOL showed superior properties in the oven test since the β -carotene concentration in RPOL was higher than that in RPS. Besides, the β -carotene contents increased, then decreased and became steady at last with the prolongation of oxidation time, indicating that the oxidation of oil proceeded continuously. The concentration of β -carotene increased from day 0 to day 3, decreased slowly from day 3 to day 12, decreased rapidly from day 12 to day 20, and remained unchanged after day 33. Lee (1986) reported a slight increase followed

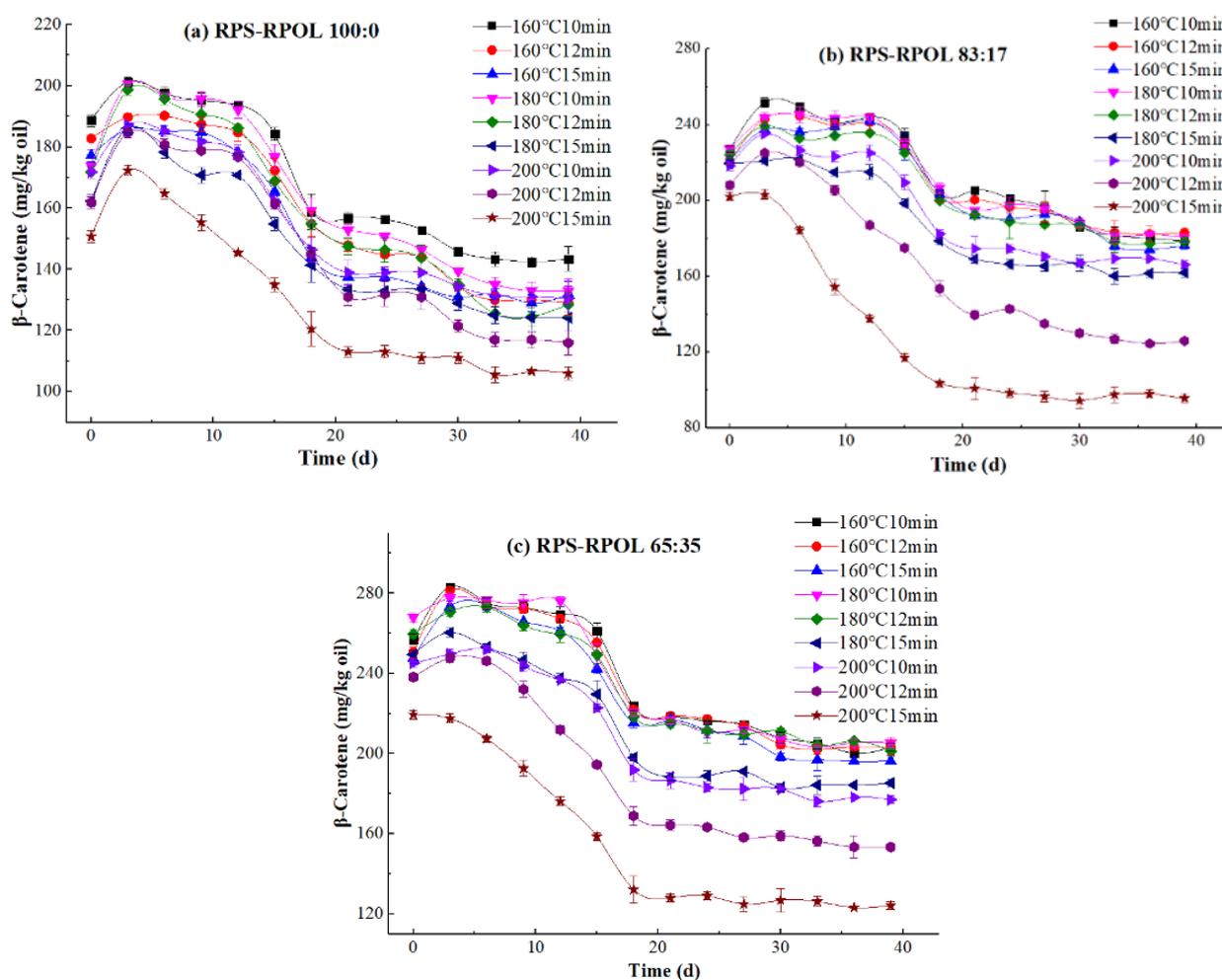


FIGURE 1. The β -carotene contents in the oils extracted from potato cookies during the oven test at 63 °C for 39 days. The results are expressed as mean \pm standard deviation ($n = 3$). (a. RPS-RPOL, 100:0; b. RPS-RPOL, 83:17; c. RPS-RPOL, 65:35).

TABLE 5. Effect of different RPS-RPOL ratios, baking times and baking temperatures on tocotrienol and tocopherol contents (ppm) in the oil of potato cookies

RPS-RPOL	Temperature	Time	δ -T ₃	β/γ -T ₃	α -T ₃	δ -T	β/γ -T	α -T	Total
100:0	160 °C	10 min	33.4±1.1 ^{cde}	98.0±2.8 ^{fai}	15.7±0.9 ^{ij}	20.8±1.6 ^{cd}	41.1±2.2 ^{def}	16.0±0.4 ⁿ	225.0±9.0 ^{def}
		12 min	29.9±0.7 ^{efghi}	93.8±4.1 ^{fghi}	23.3±2.2 ^{fgh}	18.5±1.4 ^{def}	34.2±2.8 ^{ghij}	24.2±1.3 ^{ghij}	223.9±12.5 ^{def}
		15 min	27.9±0.5 ^{ghij}	89.9±2.6 ^{ghij}	22.9±1.8 ^{fgh}	19.6±1.6 ^{cde}	34.7±1.5 ^{ghi}	26.7±1.9 ^{fgh}	221.7±9.9 ^{defg}
	180 °C	10 min	32.0±0.1 ^{defg}	90.6±5.8 ^{ghij}	20.9±1.5 ^h	20.9±0.8 ^c	36.1±3.3 ^{fgh}	18.1±1.9 ^{lmn}	218.6±13.4 ^{defgh}
		12 min	25.2±1.2 ^{ijkl}	84.5±4.4 ^{ij}	23.9±1.0 ^{fgh}	17.0±0.5 ^{fghi}	30.1±1.0 ^{ijkl}	21.8±2.2 ^{ijkl}	202.5±9.3 ^{efghi}
		15 min	25.9±1.3 ^{ijkl}	85.9±8.2 ^{hij}	22.3±0.5 ^{sh}	16.9±0.3 ^{fghi}	29.5±0.7 ^{ijkl}	21.0±1.2 ^{ijklm}	201.5±12.2 ^{efghi}
	200 °C	10 min	23.4±1.2 ^{klm}	82.0±4.6 ^j	19.8±1.2 ^{hi}	15.0±1.0 ^j	28.9±0.1 ^{ijkl}	21.1±1.7 ^{klm}	190.2±9.8 ^{hij}
		12 min	22.5±4.8 ^{lmn}	71.2±6.1 ^k	20.3±3.8 ^h	16.0±2.4 ^{ghi}	25.4±2.2 ^{lm}	18.5±1.5 ^{lmn}	173.9±20.8 ^{ij}
		15 min	19.5±0.1 ⁿ	60.4±5.1 ^l	14.0±1.3 ^j	11.8±0.8 ^j	22.8±1.7 ^m	17.0±3.0 ^{lmn}	145.5±12.0 ^k
83:17	160 °C	10 min	36.7±1.7 ^{bc}	130.5±8.9 ^{bc}	36.8±3.0 ^c	23.6±1.8 ^b	54.1±3.5 ^c	33.2±3.0 ^{bcd}	314.9±21.9 ^b
		12 min	32.1±1.9 ^{def}	116.0±3.7 ^{de}	30.3±2.8 ^{de}	19.4±0.8 ^{cde}	38.2±2.9 ^{defg}	30.0±2.0 ^{def}	266.0±14.1 ^c
		15 min	30.3±1.2 ^{fgh}	112.5±2.4 ^e	27.1±3.2 ^{def}	17.7±0.3 ^{fghi}	35.1±3.1 ^{ghi}	24.9±2.4 ^{ghij}	247.6±13.6 ^{cd}
	180 °C	10 min	36.2±2.2 ^{bc}	126.8±1.1 ^c	37.6±1.7 ^c	20.4±2.1 ^{cd}	43.5±0.2 ^d	29.9±1.0 ^{def}	294.4±14.1 ^b
		12 min	30.9±3.0 ^{defg}	111.8±7.4 ^c	31.6±0.5 ^d	19.7±0.8 ^{cde}	41.9±5.4 ^{de}	31.6±1.2 ^{cde}	267.5±21.7 ^c
		15 min	26.7±2.8 ^{hijk}	99.7±2.4 ^{fg}	29.1±0.7 ^{de}	17.4±1.1 ^{fghi}	36.9±2.1 ^{efg}	28.4±0.3 ^{efg}	238.2±9.4 ^d
	200 °C	10 min	29.2±5.0 ^{fghi}	101.2±1.9 ^f	26.2±2.8 ^{efg}	16.6±1.0 ^{fghi}	33.0±3.4 ^{ghijk}	23.3±3.0 ^{hijk}	229.5±17.1 ^{de}
		12 min	24.6±2.4 ^{ikl}	84.3±4.2 ^{ij}	23.7±2.0 ^{fgh}	16.7±2.6 ^{fghi}	30.6±4.1 ^{hijkl}	24.7±1.3 ^{ghij}	204.6±19.7 ^{efgh}
		15 min	22.3±0.3 ^{lmn}	81.9±6.9 ^j	21.2±1.4 ^h	15.4±0.4 ^{hi}	27.7±4.9 ^{klm}	25.6±2.8 ^{ghi}	194.1±19.7 ^{ghij}
65:35	160 °C	10 min	41.4±0.6 ^a	153.6±8.6 ^a	48.9±3.2 ^a	29.0±0.6 ^a	66.9±5.8 ^a	33.2±0.3 ^{bcd}	373.0±19.1 ^a
		12 min	37.8±3.0 ^b	136.9±5.0 ^b	44.6±5.9 ^b	27.9±0.5 ^a	61.9±3.2 ^b	45.0±6.5 ^a	354.1±24.1 ^a
		15 min	31.8±3.4 ^{defg}	123.5±3.5 ^{cd}	39.6±0.7 ^c	24.2±1.3 ^b	55.6±1.7 ^c	35.3±2.6 ^{bc}	310.0±13.1 ^b
	180 °C	10 min	34.6±2.1 ^{bcd}	129.8±5.4 ^{bc}	40.9±3.0 ^{bc}	25.1±0.6 ^b	55.7±4.9 ^c	35.8±1.2 ^{bc}	321.9±17.2 ^b
		12 min	32.2±0.7 ^{def}	122.8±2.9 ^{cd}	39.1±0.4 ^c	25.2±1.5 ^b	56.0±2.6 ^c	36.7±3.7 ^b	311.9±11.8 ^b
		15 min	22.4±0.9 ^{lmn}	82.6±7.9 ^j	24.2±0.9 ^{fgh}	17.9±0.7 ^{efg}	36.5±2.5 ^{efg}	11.9±0.3 ^o	195.6±14.2 ^{fghij}
	200 °C	10 min	29.9±2.8 ^{efghi}	116.5±9.2 ^{de}	36.9±5.2 ^c	24.4±0.2 ^b	54.2±1.7 ^c	34.8±2.8 ^{bc}	296.7±21.9 ^b
		12 min	24.6±0.2 ^{ijkl}	94.4±2.3 ^{fgh}	29.1±3.7 ^{de}	18.9±1.4 ^{def}	43.0±2.4 ^d	27.6±0.9 ^{efgh}	237.6±12.9 ^d
		15 min	19.0±1.5 ⁿ	65.6±2.7 ^{kl}	20.6±1.4 ^h	14.8±0.8 ⁱ	30.0±0.6 ^{ijkl}	19.7±1.6 ^{klmn}	169.8±10.6

*Results are expressed as mean ± standard deviation (n = 3). The isomers of tocotrienols and tocopherols are shown as δ , β/γ , α .

*Labelled with the same letter did not differ significantly ($p \leq 0.05$) according to Duncan's test.

by a decrease in β -carotene content during the storage of fresh carrots. This phenomenon may relate to processing methods, the influence of lipoproteins on the separation of carotenoids, and the distribution of different carotenoids during storage. However, it is difficult to ascribe the reason for the increase in β -carotene to only one of them. Research showed that carotene was almost completely lost under high-temperature accelerated oxidation, but tended to be stable in this study because the egg lecithin in cookie formula had a protective effect on carotene at 60 °C (Yanishlieva *et al.*, 1998).

When RPS-RPOL was 100:0 (Figure 1a), the β -carotene content in the samples at 200 °C for 15 min decreased rapidly from day 3, and it was significantly lower than that of the samples under other conditions and after dozens of days. Such a phenomenon revealed that the samples under this condition (200 °C, 15 min) were the most unstable. In addition,

as shown in Figures 1b and 1c (RPS-RPOL were 83:17, 65:35), β -carotene concentration in samples baked at 200 °C (10 min, 12 min, 15 min) and 180 °C (15 min) were significantly lower than that of other samples, however, there was no visible difference in the samples at 160 °C. The results illustrated that temperature was the dominant factor that affected oxidative stability negatively at temperatures above 200 °C. In addition, long baking time played a more decisive role when temperature was less than or equal to 180 °C.

4. CONCLUSIONS

In this study, cookies with better sensory properties were obtained when the baking conditions were RPS-RPOL ratio 65:35, baking temperature 160 °C, and baking time 12 min. Formulated cookies with an RPS-RPOL ratio of 65:35 exhibited 0.6 times

less squalene, but 1.5 times more β -carotene, and tocopherols and tocotrienols than the mixture of RPS and RPOL at 100:0 ratio. In addition, the results indicated that products with high micronutrients and oxidative stability can be obtained with low temperature and short baking time (160 °C, 10 min). Baking time played a more decisive role in oxidative stability when the temperature was below 180 °C. However, temperature was the dominant factor that affected the oxidative stability at temperatures above 200 °C. The total properties as measured in this research is important for formulating, investigating baking conditions, and predicting the shelf-life of red palm oil-potato containing functional baked food. Red palm oil has high nutritional value, which can be used as a healthy food oil and health care product, and can also be used as a substitute for pigment and a supplementary food for some nutritional functional components, thus having a high development and utilization prospect. The development of potato cookies with red palm oil can not only enrich the variety of cookies, make up for the defects of single raw materials and insufficient varieties of baked food, but also have important practical significance for improving the utilization rate of potatoes and meeting the market demand for convenient leisure food.

ACKNOWLEDGEMENTS

The authors thank the Palm Oil Research and Technical Service Institute of Malaysian Palm Oil Board (PORTSIM) for financial support (PORTSIM 054/2017) and for providing red palm oil.

REFERENCES

- Al-Saqer JM, Sidhu JS, Al-Hooti SN, Al-Amiri HA, Al-Othman A, Al-Haji L, Ahmed N, Mansour IB, Minal J. 2004. Developing functional foods using red palm olein. IV. Tocopherols and tocotrienols. *Food Chem.* **85** (4), 579-583. <https://doi.org/10.1016/j.foodchem.2003.08.003>
- Birch PRJ, Bryan G, Fenton B, Gilroy EM., Hein I, Jones JT, Toth IK. 2012. Crops that feed the world 8: Potato: Are the trends of increased global production sustainable? *Food Secur.* **4**, 477-508. <https://doi.org/10.1007/s12571-012-0220-1>
- El-Hadad N, Abou-Gharbia HA, Abd El-Aal MH, Youssef MM. 2010. Red palm olein: Characterization and utilization in formulating novel functional biscuits. *J. Am. Oil Chem. Soc.* **87**, 295-304. <https://doi.org/10.1007/s11746-009-1497-x>
- Hamid AA, Dek MSP, Tan CP. 2014. Changes of major antioxidant compounds and radical scavenging activity of palm oil and rice bran oil during deep-frying. *Antioxidants* **3** (3), 502-515. <https://doi.org/10.3390/antiox3030502>
- Harianti R, Marliyati SA, Rimbawan, Sukandar D. 2018. Development of high antioxidant red palm oil cake as a potential functional food. *J. Gizi Pangan.* **13** (2), 63-70. <https://doi.org/10.25182/jgp.2018.13.2.63-70>
- Kamaleldin A, Appelqvist LA. 1996. The chemistry and antioxidant properties of tocopherols and tocotrienols. *Lipids* **31** (7), 671-701. <https://doi.org/10.1007/bf02522884>
- Kong J, Perkins LB, Dougherty MP, Camire ME. 2011. Control of lipid oxidation in extruded salmon jerky snacks. *J. Food Sci.* **76** (1), C8-C13. <https://doi.org/10.1111/j.1750-3841.2010.01896.x>
- Kumar PKP, Krishna AGG. 2014. Physico-chemical characteristics and nutraceutical distribution of crude palm oil and its fractions. *Grasas Aceites* **65** (2), 26-41. <http://doi.org/10.3989/gya.097413>
- Lee CY. 1986. Changes in carotenoid content of carrots during growth and post-harvest storage. *Food Chem.* **20**, 285-293. [http://doi.org/10.1016/0308-8146\(86\)90097-x](http://doi.org/10.1016/0308-8146(86)90097-x)
- Marjan AQ, Marliyati A, Ekayanti I. 2016. Development of food product with red palm oil substitution as an alternative functional food high in beta carotene. *J. Gizi Pangan.* **11** (2), 91-98. <https://doi.org/10.25182/jgp.2016.11.2.91-98>
- Mayamol PN, Balachandran C, Samuel T. 2007. Process technology for the production of micronutrient rich red palm olein. *J. Am. Oil Chem. Soc.* **84** (6), 587-596. <https://doi.org/10.1007/s11746-007-1078-9>
- Mba OI, Dumont MJ, Ngadi M. 2015. Palm oil: Processing, characterization and utilization in the food industry-A review. *Food Biosci.* **10**, 26-41. <https://doi.org/10.1016/j.fbio.2015.01.003>
- Michotte D, Rogez H, Chirinos R, Mignolet E, Campos D, Larondelle Y. 2011. Linseed oil stabilisation with pure natural phenolic compounds. *Food Chem.* **129**, 1228-1231. <https://doi.org/10.1016/j.foodchem.2011.05.108>
- Nor AI, Miskandar MS. 2007. Utilization of palm oil and palm oil products in shortenings and marga-

- rine. *Eur. J. Lipid Sci. Tech.* **109**, 422-432. <https://doi.org/10.1002/ejlt.200600232>
- Oluwamukomi MO, Oluwalana IB, Akinbowale OF. 2010. Physicochemical and sensory properties of wheat-cassava composite biscuit enriched with soy flour. *Afr. J. Food Sci.* **5** (2), 50-56. <https://doi.org/10.5897/AJFS.9000233>
- Pan KL, Ji M, Hu MM, OOI C. 2016. Analysis of nutritional components for red palm oil. *Chinese cereals oils* **29** (12), 79-81.
- Radhika L, Kanthimathi MS, Ammu KR, Yuen-May C, Kim-Tiu T. 2017. Health-promoting effects of red palm oil: Evidence from animal and human studies. *Nutr Rev.* **75** (2), 98-113. <https://doi.org/10.1093/nutrit/nuw054>
- Reddy LH, Couvreur P. 2009. Squalene: A natural triterpene for use in disease management and therapy. *Adv. Drug Delivery Rev.* **61** (15), 1412-1426. <https://doi.org/10.1016/j.addr.2009.09.005>
- Rossi M, Alamprese C, Ratti S. 2007. Tocopherols and tocotrienols as free radical-scavengers in refined vegetable oils and their stability during deep-fat frying. *Food Chem.* **102** (3), 812-817. <https://doi.org/10.1016/j.foodchem.2006.06.016>
- Sidhu JS, Al-Hooti SN, Al-Saqer JM., Al-Amiri HA., Al-Foudari M, Al-Othman A, Ahmad A, Al-Haji L, Ahmed N, Mansor IB, Minal J. 2004. Developing functional foods using red palm olein: Pilot-scale studies. *Int. J. Food Prop.* **7** (1), 1-13. <https://doi.org/10.1081/JFP-120022491>
- Singh JKL. 2016. Potato Starch and Its Modification. *Adv. Potato Chem. Technol.* 195-247. <https://doi.org/10.1016/b978-0-12-800002-1.00008-x>
- Siti AK, Jinap S, Sukor R. 2018. Effect of fat-soluble anti-oxidants in vegetable oils on acrylamide concentrations during deep-fat frying of French fries. *Malays J. Med. Sci.* **25** (5), 128-139. <https://doi.org/10.21315/mjms2018.25.5.12>
- Sobhana R, Santosh JP, Som NS. 2019. Impact of crude palm oil fortified cookies supplementation on anthropometry, vitamin a and hematological status of school children in India. *Int. J. Vitam. Nutr. Res.* **89** (5-6), 1-10. <https://doi.org/10.1024/0300-9831/a000478>
- Szulczewska-Remi A, Nogala-Kalucka M, Nowak KW. 2019. Study on the influence of palm oil on blood and liver biochemical parameters, beta-carotene and tocochromanols content as well as antioxidant activity in rats. *J. Food Biochem.* **43** (2), e12707. <https://doi.org/10.1111/jfbc.12707>
- Yanishlieva NV, Aitzetmuller K, Raneva VG. 1998. Beta-carotene and lipid oxidation. *Fett-lipid* **100** (10), 444-462. [https://doi.org/10.1002/\(SICI\)1521-4133\(199810\)100:10<444::AID-LIPI444>3.0.CO;2-A](https://doi.org/10.1002/(SICI)1521-4133(199810)100:10<444::AID-LIPI444>3.0.CO;2-A)
- Yui Y, Miyazaki S, Ma Y, Ohira M, Fiehn O, Ikegami T, McCalley DV, Tanaka N. 2016. Distinction of synthetic dl- α -tocopherol from natural vitamin E (d- α -tocopherol) by reversed-phase liquid chromatography. Enhanced selectivity of a polymeric C18 stationary phase at low temperature and/or at high pressure. *J. Chromatogr. A.* **1450**, 45-52. <https://doi.org/10.1016/j.chroma.2016.04.076>
- Zhang H, Xu F, Wu Y, Hu HH, Dai XF. 2017. Progress of potato staple food research and industry development in China. *J. Integr. Agric.* **16** (12), 2924-2932. [https://doi.org/10.1016/S2095-3119\(17\)61736-2](https://doi.org/10.1016/S2095-3119(17)61736-2)