Effect of Roasting and Vacuum Microwave Drying Pretreatment on the Yield and Chemical Properties of Black Sesame Seed Oil Extracted by using Screw Press

Pimolpun Lertbuaban[1, *] and Rattana Muangrat[2]

[1]Department of Food Science and Technology, Faculty of Agro-industry, Chiang Mai University, Chiang Mai, Thailand
[2]Department of Food Process Engineering, Faculty of Agro-industry, Chiang Mai University, Chiang Mai, Thailand
[*]Corresponding author, E-mail: pimolpun.army@gmail.com

Abstract

Black sesame oil is a high-quality edible oil that is high in essential fatty acids, which have a variety of medical benefits. The optimal pretreatment process for black sesame preparation prior to sesame oil extraction is critical for its beneficial bioactive compounds. The goals of this study were to determine the effect of roasting temperatures and vacuum microwave power levels on the yield, antioxidant properties, and fatty acid composition of black sesame oil extracted using the screw press technique. Black sesame seeds were dried at different roasting temperatures (80, 100, and 120°C) and vacuum microwave power levels (0.50, 1.50, and 2.25 kW/kg). The oil was extracted from dried black sesame seeds using a single screw press at temperatures of 45, 55, and 65°C. According to the findings, roasting at 80°C and vacuum microwave drying at 2.25 kW/kg using a pressing temperature of 65°C is an appropriate pretreatment process for black sesame preparation prior to oil extraction, indicating a high oil yield and improved chemical properties. The optimal extraction conditions for high crude oil yield were roasting temperature at 80°C and vacuum microwave power at 2.25 kW/kg with pressing temperature at 65°C. Moreover, an increasing trend was observed in the levels of sesamin and sesamolin, as well as the antioxidant activities present in the sample, with an elevation in both the roasting temperature and vacuum microwave drying power. Upon exceeding a roasting temperature of 100°C, the total flavonoid content (TFC) exhibited a decrease. Similarly, an increase in the power of vacuum microwave drying beyond 1.50 kW/kg sample led to a reduction in both the total phenolic content (TPC) and TFC. There were no significant differences in the fatty acid compositions of black sesame oils.

Keywords: *Black Sesame Oil, Roasting, Vacuum Microwave Drying, Screw Press*

1. Introduction

Queen of oilseeds was referred to the sesame seeds. It contains 53% quality edible oil, 42% cake, and 5% moisture (Akinoso, 2006). Sesame oil contains a highly unsaturated edible oil rich in essential fatty acids that has numerous medical benefits such as antioxidant, anti-inflammatory, and immune-boosting properties, as well as a pleasant aroma and flavor (Nam et al., 2014; Zhang et al., 2016). Sesame oil contains oleic acid (35-54%), linoleic acid (39-59%), palmitic acid (10%), and stearic acid (5%) (Bopitiya & Madhujith, 2013). Furthermore, it contains a high concentration of bioactive substances such as phytosterols, tocopherols, and lignans such as sesamin, sesamolin, and sesaminol, which are well known to be important in preventing oil oxidation and promoting antioxidative activity (Kanu et al., 2010; Shahidi et al., 1997).

Currently, there are several extraction methods with varying efficiencies in the oil extraction process. Solvent extraction is a traditional method with a high yield, but the disadvantage is the low quality of the oil extracted (Zhao & Zhang, 2014). The screw press method is widely used for sesame oil extraction, allowing for high-quality oils at a reasonable price (Rabadán et al., 2018). The screw press could recover 75 to 95% of the oil from oilseeds. Its efficiency in producing oilseed is determined by the process used to prepare the raw material, which may include cleaning, conditioning, decorticating, cracking, roasting, heating, and extruding (Martínez et al., 2013). The roasting process is critical in the production of sesame oil because it affects the oil's composition, color, and quality. It influences the antioxidant factors that influence the stability of roasted sesame seeds. As a result, the goal of roasting is to disrupt the microstructure, physical properties, and chemical composition of oilseeds through heat and moisture, encouraging cell damage, oil accumulation, and

enzyme inactivation. This increases the amount of oil extracted during the pressing process as well (Bi, 2005; Ji et al., 2019). There are also other interesting pretreatment processes, such as microwave drying. Food products are heated at a low temperature by its high penetrating power. In general, high-fat and high-moisture foods are quickly cooked or dried in the microwave (Feramuz et al., 2006). Microwave drying was used for heating prior to the oil extraction process. Stress reactions in plant structure or oil seeds may result from microwave pretreatment. It is possible to increase oil extraction yield by using microwave radiation on oil seeds. Furthermore, microwave-treated oil improved oxidative stability, most likely due to an increase in antioxidant compounds (Azadmard-Damirchi et al., 2011).

Because of the current nature of the problem that caused the pandemic, the beneficial biological and medical properties of black sesame oil make it a healthy option for consumers to prepare for pandemic readiness. Therefore, the objective of this research was to determine the effect of various pretreatment methods, such as roasting temperatures and vacuum microwave power levels, affected the yield, antioxidant properties, and fatty acid composition of oil extracted from black sesame seeds using the screw press method.

2. Objectives

1) To investigate the effect of roasting and vacuum microwave drying pretreatment on black sesame seeds on oil extraction using a screw press.

2) To compare the oil yield and chemical properties of roasted and vacuum microwave dried black sesame seed oil obtained from 1) and untreated black sesame oil.

3. Materials and Methods

3.1 Sample

Black Sesame KU 18 samples were supported by the Huay Saew Royal Project Development Center, Chiang Mai, Thailand. Proximate analysis was performed on black sesame seeds, which contained 5.81% moisture, 13.50% protein, 48.52% fat, 11.92% carbohydrate, 4.99% ash, and 15.26% fiber. Prior to the pretreatment process, samples were stored in vacuum-sealed plastic bags at room temperature.

3.2 Pretreatment of Black Sesame Seeds by Roasting and Vacuum Microwave drying Process

Approximately 400 g of black sesame seeds were pretreated using roasting and vacuum microwave drying methods.

The roasting process was carried out using an electric pan (Arachi Model, SF-A21, RSMall Group Co., Ltd., Thailand) and temperature was measured using a digital thermometer (Testo Model, 926, Germany) and different roasting temperatures of 80, 100, and 120°C for 10 min.

The vacuum microwave dryer (March Cool, Thailand) was used in the vacuum microwave drying process. Before vacuum microwave drying, black sesame seed samples were placed in a perforated plastic tank and covered with a white cloth. The vacuum microwave drying process used power levels of 0.50, 1.50, and 2.25 kW/kg for 10 min.

Each roasting and vacuum microwave drying process was repeated three times. After pretreatment, samples of black sesame seeds were allowed to equilibrate to room temperature (25°C). Prior to oil extraction, the roasted and vacuum microwave-dried black sesame seed samples were placed in polyethylene plastic bags and stored at room temperature.

3.3 Oil Extraction by Screw Press

Approximately 400 g of black sesame seeds (both untreated and treated) were extracted for oil using a single screw press (Model FEA-101ss-M-H-Tc-2015) developed by Friend Energy Limited Partnership in Chiang Mai, Thailand. The effect of temperature on press oil was investigated at three different temperatures (45, 55, and 65°C). Crude oil samples from screw press extraction were stored in dark bottles, wrapped in aluminum foil, and kept at 4 °C until analysis. Following that, black sesame crude oil samples were prepared for further analysis by centrifuge for 30 min at 5,500 rpm to separate tiny particles from the crude oil samples.

3.4 Crude oil yield

The percentage of crude oil yield was determined by the following equation.

$$\text{The percentage of crude oil yield (\%)} = \left(\frac{\text{weight of crude oil (g)}}{\text{weight of black sesame seed sample (g)}}\right) \text{x}100$$

3.5 Determination of Sesamin and Sesamolin Content

The sesamin and sesamolin content of extracted black sesame oil samples was determined by modifying the Schwertner and Rios (2012). Each 100 mg extracted oil sample was mixed with 4 mL of methanol, vortexed for 15 minutes, and centrifuged at 5,000 rpm for 2 minutes. The supernatant was transferred to a volumetric flask (10 ml) and the volume was adjusted with methanol. The obtained solution was filtered through 0.45 µm pore size nylon filters. The extracted solutions were separated using a high-performance liquid chromatograph (HPLC) (Agilent 1260, Agilent Technologies, USA) equipped with a diode array detector, a binary pump, and a column oven with temperature control. In this study, stationary phase was used as a reversed-phase Poroshell 120 EC-C18, particle size 4 m, HPLC column (250 mm length, 4.6 mm i.d.). The mobile phase was 70:30 v/v methanol-deionized water added to the column at a flow rate of 0.8 ml/min in an amount of approximately 20 µl. Then, sesamin and sesamolin in the eluent were detected at 290 nm and determined by comparing retention times with standard sesamin and sesamolin compounds. HPLC was used to analyze and quantify sesamin and sesamolin using standard curves of sesamin and sesamolin. To determine the average sesamin or sesamolin content, all samples were repeated three times.

3.6 Determination of Total Phenolic Compounds

Total phenolic compounds (TPC) were determined by modifying the method of Sriyab et al. (2021). Each oil sample (2 g) was dissolved in 1 ml of hexane and extracted with aqueous 80% methanol (2 ml). The solution was centrifuged for 10 min at 5,000 rpm after being vortexed for 15 minutes. The methanol layer (20 µl) was then mixed with 10% Folin-Ciocalteu solution (100 µl) for 4 minutes before being mixed with 7.5% sodium carbonate (80 µl) and kept in the dark at room temperature for 2 hours. The UV absorbance was measured at 750 nm using a Microplate reader (Multimode Detector, Beckman Coulter DTX880, Fullerton, CA, USA). The TPC of mixture samples was calculated using the gallic acid standard curve. TPC results were presented in micrograms of gallic acid equivalents per gram of extracted oil sample (µg GAE/g oil).

3.7 Determination of Total Flavonoid Content

Total flavonoid content (TFC) was determined by modifying the method of Sriyab et al. (2021). Each oil sample weighed about 2 g and was dissolved in 1 ml of hexane before being extracted with aqueous 80% methanol (2 ml). The solution was centrifuged for 10 min at 5,000 rpm after being vortexed for 15 minutes. The methanol layer (20 µl) was combined with 80 µl of 0.5% w/v aluminum chloride aqueous solution and 100 µl of 40 mM potassium acetate solution. Following that, the mixture was kept at room temperature in the dark for 30 minutes. The UV absorbance was measured at 415 nm using a Microplate reader (Multimode Detector, Beckman Coulter DTX880, Fullerton, CA, USA). TFC was calculated using the quercetin standard curve, and the results were presented in milligrams of quercetin equivalent per gram of extracted oil sample (mg QE/g oil).

3.8 Determination of Antioxidant Activities by DPPH and ABTS Assays

The DPPH• scavenging activity was determined by modifying the method developed by Yeerong et al. (2021). As a control, Trolox solution was used. The black sesame seed oil sample (0.5 g) was thoroughly mixed with methanol (1.5 ml) and centrifuged at 5,500 rpm for 10 minutes. The methanolic extract (20 µl) was then mixed with 0.167 mM DPPH (180 µl) in methanol and stored at room temperature in the dark for 30 minutes. The mixture was measure at 520 nm with the multimode detector (BMG Labtech, Ortenberg, Germany). The DPPH• scavenging activity was calculated by using Trolox standard curve (Trolox in

methanol at concentration gradients ranging from 5 to 1,000 μM) and expressed as micromoles of Trolox equivalents per gram of extracted oil (μmol TEAC/g oil).

The ABTS•+ scavenging activity was determined according to the method of Yeerong et al. (2021). Trolox solution was used as a control. The black sesame seed oil sample (0.5 g) was thoroughly mixed with methanol (1.5 ml) and centrifuged at 5,500 rpm for 10 min. The ABTS•+ solution was created by combining 7 mM ABTS solution with 2.45 mM potassium persulfate solution in a 2:3 volume ratio and stored at room temperature in the dark for 16 h. After 16 h, the ABTS•+ solution was dissolved in methanol until the solution's absorbance at 750 nm was 0.7 ± 0.02. Subsequently, 20 μl of solution samples was mixed with 180 μl of ABTS•+ solution and kept at room temperature for 5 min. The absorbance of the mixture was measured at 750 nm using a multimode detector (BMG Labtech, Ortenberg, Germany). The ABTS•+ scavenging activity was calculated by using the Trolox standard curve (Trolox in methanol at concentration levels ranging from 5 to 1,000 μM) and expressed as micromoles of Trolox equivalents per gram of extracted oil (μmol TEAC/g oil).

3.9 Fatty Acid Composition Analysis of Black Sesame Seed oil

Fatty acid composition was measured by modifying the method of Muangrat et al. (2020) and Satchithanandam et al. (2001). As an internal standard, tridecanoic acid (C13:0) is used. A 0.1 g sample of black sesame seed oil was mixed with 0.1 ml of tridecanoic acid at a concentration of 10 mg/ml. The mixture was then mixed with 5 ml of 0.5 M sodium hydroxide in methanol and refluxed for 5 min. Then, add 5 ml of boron trifluoride dissolved in methanol (20% w/v) and continue to reflux for 5 minutes. After cooling to room temperature, 10 ml of a saturated sodium chloride solution and 5 ml of hexane were added to separate the layers of fatty acid methyl esters (FAMEs). A 0.45-micron filter was used to filter the top hexane layer. The samples were run through a gas chromatography system (Nexis GC-2030, Shimadzu Co.), equipped with Rt-2560 biscyanopropyl polysiloxane capillary column (100 m × 0.25 mm i.d. × 0.20 μm film thickness, Restek) and flame ionization detector were included (FID). The injector and detector temperatures were set to 250°C and 260°C, respectively. The column temperature was increased from 140°C to 230°C at a rate of 3°C per minute for 45 min. Helium was used as the carrier gas, with a steady flow rate of 1.2 ml/min.

3.10 Statistical analysis

Experimental results were computed and presented as the mean ± standard deviation for triplicate determinations. An analysis of variance was used to analyze the experimental results (ANOVA). The differences in means at the 95% confidence level were compared using Duncan's new multiple range test after analyzing the experimental results with SPSS statistics.

4. Results and Discussion

4.1 Extraction yield

According to Table 1, the highest crude oil yield (approximately 47.73%) was obtained from black sesame seeds when roasted at 80°C and pressed at 65°C. The crude oil yield obtained at roasting temperatures of 80°C was not significantly different and higher than roasting temperatures of 100 and 120°C at different pressing temperatures of 45, 55, and 65°C. Despite the fact that various studies have shown that higher roasting temperatures result in higher extraction yield oil (Elkhaleefa & Shigidi, 2015; Ji et al., 2019). However, this study found that when black sesame seeds were treated at high roasting temperatures above 100°C, the surface was burned and hardened. This result was similar to Muangrat et al. (2020) who demonstrated that raising the roasting temperature too high reduced the efficiency of oil extraction, most likely because the inside structure of the black sesame seeds was damaged and the oil outlet for seed oil was blocked. Furthermore, a high roasting temperature of 100°C and a pressing temperature of 55°C resulted in a low extraction yield (29.23%). The highest crude oil yield for black sesame seed pretreatment using vacuum microwave drying method was about 45.96% achieved by using vacuum microwave power of 2.25 kW/kg and pressing temperature of 65°C, which was not significantly different from that obtained by using roasting temperature of 80°C and pressing temperature of 65°C. In contrast, the vacuum microwave power of 1.50

kW/kg and pressing temperature of 45°C produced the least amount of oil (38.14%). The results showed that higher vacuum microwave power and pressing temperature can increase crude oil yield because they cause more internal stress during drying and material and membrane decomposition (Giri & Prasad, 2007). As a result, sesame seed oil may move from the cell membrane, resulting in a higher crude oil yield when using a screw press (Muangrat et al., 2020). Furthermore, Tian et al. (2012) demonstrated that vacuum microwave drying could produce a high porosity of sesame seeds, resulting in improved oil extraction efficiency.

Table 1 Crude oil yield from roasting and vacuum microwave drying pretreatment, and non-treatment of black sesame seeds extracted using the screw press method.

Pretreatment	Pressing temperature (°C)	Crude oil yield (%)
Roasting temperature (°C)		
80	45	46.37 ± 4.77 ^{ab}
	55	46.32 ± 0.41 ^{ab}
	65	47.73 ± 0.24 ^{a}
100	45	29.23 ± 1.14 ^{i}
	55	31.38 ± 1.14 ^{hi}
	65	44.84 ± 1.67 ^{abcd}
120	45	34.64 ± 2.54 ^{ghi}
	55	37.51 ± 0.46 ^{fg}
	65	41.12 ± 3.28 ^{def}
Vacuum microwave drying power (kW/kg sample)		
0.50	45	42.79 ± 0.95 ^{bcde}
	55	42.60 ± 0.65 ^{bcde}
	65	43.83 ± 0.19 ^{abcde}
1.50	45	38.14 ± 0.97 ^{fg}
	55	40.38 ± 1.47 ^{ef}
	65	41.19 ± 1.59 ^{cde}
2.25	45	43.02 ± 2.19 ^{bcde}
	55	44.96 ± 0.25 ^{abcd}
	65	45.96 ± 2.89 ^{ab}
Non-treatment		
	45	45.64± 2.27 ^{abc}
	55	44.89± 0.54 ^{abcd}
	65	44.15± 0.88 ^{abcde}

Data are means ± standard deviation. Different superscript letters in a column are significantly different ($p \leq 0.05$)

In addition, the extracted crude oil yield of untreated black sesame seeds was determined and is shown in Table 1. The crude oil yield extracted from untreated black sesame seeds at 45, 55, and 65°C pressing temperatures was similar to that extracted from roasted black sesame seeds at 80°C roasting temperature and vacuum microwaved black sesame seeds at power of 2.25 kW/kg pressing temperature of 65°C. According to Table 1, a pressing temperature of 65°C could extract a high content of crude oil from roasted, vacuum microwaved, and untreated black sesame seeds. Thus, crude oil samples were collected from roasted, vacuum microwaved, and untreated black sesame seeds at a pressing temperature of 65°C to determine sesamin, sesamolin, total phenolic compounds, total flavonoids, antioxidant properties (DPPH• and ABTS•+) as shown in Table 2 and fatty acid composition as shown in Table 3.

4.2 Content of Sesamin and Sesamolin

Table 2 shows the content of two major lignans in black sesame seed oil, sesamin and sesamolin, after roasting, vacuum microwave drying, and non-treatment. The content of sesamin and sesamolin in roasted and vacuum microwaved black sesame oil ranged from 4.75 to 6.62 mg/g oil and 3.41 to 4.19 mg/g

oil, respectively. According to the findings, the crude oil extracted from roasted, vacuum microwaved, and untreated black sesame seeds contained more sesamin than sesamolin. These findings were similar to those of Kim et al. (2006) and Lee et al. (2008). Sesamin (6.62 mg/g oil) and sesamolin (4.19 mg/g oil) levels were highest in samples obtained from roasted black sesame seeds at 80°C roasting temperature and vacuum microwaved at 2.25 kW/kg microwave power, respectively. Meanwhile, untreated black sesame oil samples contained 4.90 mg/g oil and 3.44 mg/g oil of sesamin and sesamolin, respectively. The sesamin and sesamolin content of the extracted oil samples was not significantly different when roasted at 80 and 120°C. It was discovered that sesamin and sesamolin levels in samples obtained by roasting sesame seeds at 100°C were not significantly different from untreated sesame seeds. Sesamin and sesamolin are lignans that do not degrade when heated. Sesamin is stable at high temperatures (Andargie et al., 2021).

When the vacuum microwave power was increased for treated black sesame seeds using the vacuum microwave drying method, the content of sesamin and sesamolin in the oil samples increased. It was also shown that sesamin and sesamolin levels in extracted oil samples obtained by vacuum microwave power at 2.25 kW/kg were significantly higher than in untreated sesame seeds. Furthermore, the amount of sesamin and sesamolin in the extracted oil samples did not differ significantly when vacuum microwaved at 0.50 and 1.50 kW/kg. The study revealed that the crude extracted oil sample showed a decrease and increase in sesamin and sesamolin content, respectively, with increasing roasting temperatures from 80°C to 100°C and from 100°C to 120°C, and vacuum microwave drying power from 0.50 to 1.50 kW/kg sample and from 1.50 to 2.25 kW/kg sample, respectively. It is important to consider that the structures of sesamin and sesamolin may become unstable under these thermal processing conditions, as reported by Yoshida and Takagi (1997). It should also be noted that variations in the conditions of roasting and vacuum microwave drying may affect the changes in the levels of sesamin and sesamolin in extracted oil. Hence, further studies are required to gain a comprehensive understanding of the underlying mechanisms responsible for the observed fluctuations.

Table 2 Antioxidant Activities (DPPH• and ABTS•+), sesamin, sesamolin, total phenolic compounds and total flavonoid content of crude oils from roasting and vacuum microwave drying pretreatment of black sesame seeds and extracted using the pressing temperature of 65°C, and from non-treatment of black sesame seeds.

Pretreatment	Antioxidant Activities		Sesamin (mg/g oil)	Sesamolin (mg/g oil)	TPC (µg GAE/g oil)	TFC (mg GAE/g oil)
	DPPH• scavenging activity (µmol TEAC/g oil)	ABTS•+ scavenging activity (µmol TEAC/g oil)				
Roasting temperature (°C)						
80	0.40± 0.03^{c}	0.25± 0.04^{e}	6.62± 0.04^{a}	4.09± 0.01^{ab}	31.52± 2.65^{e}	2.91± 0.09^{c}
100	0.36± 0.00^{d}	0.29± 0.04^{e}	5.52± 0.27^{bc}	3.41± 0.18^{c}	30.52± 1.09^{e}	3.67± 0.06^{b}
120	0.45± 0.01^{a}	0.40± 0.02^{c}	6.07± 0.23^{ab}	3.64± 0.15^{bc}	45.52± 1.32^{c}	3.39± 0.11^{bc}
Vacuum microwave drying power (kW/kg sample)						
0.50	0.41± 0.01^{bc}	0.31± 0.03^{de}	4.75± 0.50^{cd}	2.78± 0.30^{d}	39.24± 1.55^{d}	3.00± 0.07^{c}
1.50	0.44± 0.02^{ab}	0.58± 0.03^{b}	3.90± 0.39^{d}	2.71± 0.21^{d}	61.35± 1.58^{a}	5.34± 0.09^{a}
2.25	0.40± 0.02^{c}	0.75± 0.07^{a}	6.08± 0.70^{ab}	4.19± 0.31^{a}	55.63± 1.27^{b}	2.81± 0.86^{c}
Non-treatment						
	0.32± 0.01^{e}	0.37± 0.04^{cd}	4.90± 1.28^{c}	3.44± 0.08^{c}	53.57± 2.22^{b}	5.72± 1.50^{a}

Data are means ± standard deviation. Different superscript letters in a column are significantly different ($p \leq 0.05$)

4.3 Total Phenolic Compounds

Table 2 shows the TPC of oil samples obtained from roasted, vacuum microwaved, and untreated black sesame seeds. The amount of TPC varied between roasting temperatures and vacuum microwave drying power levels, ranging from 30.52 to 61.35 µg GAE/g oil. TPC content (61.35 µg GAE/g oil) was found to be higher in seed oil samples obtained from vacuum microwaved black sesame seeds at a microwave power of

1.50 kW/kg than in untreated black sesame oils. The higher the roasting temperature, the higher the TPC content of seed oil samples. The TPC content of oil samples increased significantly when the vacuum microwave power was increased to 1.50 kW/kg, and then decreased significantly when the vacuum microwave power was increased to 2.25 kW/kg. Previously, studies showed that plant phenolic compounds in bound form could be separated and released using a high roasting temperature and vacuum microwave drying power (Jannat et al., 2010). The rapid generation of heat by microwave radiation, which resulted in cellular matrix destruction and increased phenolic compound release and antioxidant activity, may contribute to the rapid and effective nature of microwave pretreatment (Chan et al., 2016). However, due to thermal degradation, roasting and vacuum microwave drying pretreatment at high temperatures and microwave power may cause a decrease in TPC content in oil samples (Jannat et al., 2010; Kaseke et al., 2020). As a result, by using appropriate roasting and vacuum microwave drying methods, the TPC content of extracted black sesame oils could be increased.

4.4 Total Flavonoid Content

Table 2 shows the TFC of oil samples obtained from roasted, vacuum microwaved, and untreated black sesame seeds. The amount of TFC in different roasting temperatures and vacuum microwave drying power levels ranged from 2.81 to 5.34 mg QE/g oil. TFC levels were highest in seed oil samples from vacuum microwaved black sesame seeds at 1.50 kW/kg vacuum microwave power. The TFC of oil samples increased significantly when the roasting temperature and vacuum microwave drying power were increased to 100°C and 1.50 kW/kg, respectively, and then decreased to 120°C and 2.25 kW/kg, respectively. It could be the result of an excessively high roasting temperature and high vacuum microwave power, which causes total flavonoids to degrade (Chaaban et al., 2017). Furthermore, high microwave power may cause excessive product temperature rise, reducing extraction yield through product deterioration and compound decomposition (Winny & Valérie, 2012). Furthermore, the TFC of untreated black sesame oil samples was not significantly different from vacuum microwaved black sesame oil samples using 1.5 kW/kg microwave power, but it was higher than roasted black sesame oil samples.

4.5 Antioxidant Activities

Table 2 shows the DPPH• and ABTS•+ scavenging activity of crude oil samples obtained from roasted, vacuum microwaved, and untreated black sesame seeds. The significantly highest activity (0.45 µmol TEAC/g oil) for DPPH• scavenging activity was observed in seed oil sample from roasted black sesame seeds at roasting temperature of 120°C. The significantly highest activity (0.75 µmol TEAC/g oil) for ABTS•+ scavenging activity was observed in seed oil samples from vacuum microwaved black sesame seeds at a microwave power of 2.25 kW/kg. DPPH• and ABTS•+ scavenging activity were higher in the extracted oil derived from roasted and vacuum microwaved black sesame seeds than in the untreated black sesame seeds. When the roasting temperature was raised, the DPPH• and ABTS•+ scavenging activity increased. It was similar to previous research that concluded that increasing the roasting temperature and vacuum microwave power increased the antioxidant activity of crude oil samples (Muangrat et al., 2020). TPC and TFC were discovered to be involved in radical scavenging activity in crude oil samples.

4.6 Fatty Acid Composition

Table 3 shows the fatty acid composition of non-treated, roasted, and vacuum microwaved black sesame seed oils. Saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) are all found in black sesame seed oil. It is mostly made up of oleic acid, linoleic acid, palmitic acid, steric acid, and arachidic acid, which are the main fatty acids found in sesame seed oil (Huang et al., 2023; Ji et al., 2019). Linoleic acid and oleic acid were found in the highest concentrations in extracted black sesame oil, accounting for 40.25-46.16% and 36.38-39.72%, respectively. There were no significant differences in palmitic acid and oleic acid in sesame oils prepared from roasted, vacuum microwaved non-treated seeds, but there was a slight effect on steric acid, arachidic acid, and linoleic acid. These findings were similar to those of Ji et al. (2019) who discovered no significant differences in the fatty acid composition of

sesame oils pretreated from roasted seeds. However, because PUFA are sensitive to lipid oxidation, the percentage of PUFA decreased as the vacuum microwave drying power increased. Thermal pretreatment (roasting and vacuum microwave drying) reduced the content of unsaturated fatty acids (Huang et al., 2023). Furthermore, high microwave power may cause the product temperature to rise too quickly, resulting in product damage or compound decomposition (Winny & Valérie, 2012).

Table 3 Fatty acid composition of crude oils from roasting and vacuum microwave drying pretreatment of black sesame seeds and extracted using the pressing temperature of 65°C, and from non-treatment of black sesame seeds.

Pretreatment	Saturated fatty acid (%)			Monounsaturated fatty acid (%)	Polyunsaturated fatty acid (%)
	Palmitic acid (C16:0)^{ns}	Stearic acid (C18:0)	Arachidic acid (C20:0)	Oleic acid (C18:1n9c)^{ns}	Linoleic acid (C18:2 n6c)
Roasting temperature (°C)					
80	8.73 ± 0.56	5.06 ± 0.46^{ab}	1.19 ± 0.11^{a}	39.72 ± 1.78	46.16 ± 0.62^{a}
100	8.27 ± 0.60	4.71 ± 0.33^{ab}	1.16 ± 0.03^{a}	37.11± 1.85	45.45 ± 1.53^{a}
120	8.45 ± 0.47	4.78 ± 0.30^{ab}	1.2 2± 0.15^{a}	38.24 ± 0.81	45.54 ± 0.45^{a}
Vacuum microwave drying power (kW/kg sample)					
0.50	8.55 ± 0.40	5.37 ± 0.33^{a}	1.33 ± 0.04^{a}	38.83 ± 2.21	44.80 ± 2.63^{a}
1.50	7.43 ± 0.76	4.38 ± 0.20^{b}	1.24 ± 0.99^{a}	36.38± 0.33	41.05 ± 0.53^{bc}
2.25	7.95 ± 0.42	4.54 ± 0.18^{b}	1.39 ± 0.57^{a}	36.77 ± 1.32	40.25 ± 0.60^{c}
Non-treatment					
	8.43 ± 0.04	5.01 ± 0.07^{ab}	0.85 ± 0.22^{b}	38.94 ± 0.62	43.93 ± 1.63^{ab}

Data are means ± standard deviation. Different superscript letters in a column are significantly different ($p \leq 0.05$)

5. Conclusion

In this study, the roasting and vacuum microwave drying pretreatment had an effect on oil yield and bioactive compounds, particularly sesamin and sesamolin. The highest oil yield was obtained from roasted black sesame seeds at an oven temperature of 80°C and vacuum microwaved black sesame seeds at a power of 2.25 kW/kg, respectively. Furthermore, the roasting temperature and vacuum microwave drying power may increase the content of sesamin and sesamolin in the crude oil. The increased TPC and TFC content of the seed oil samples was caused by the higher roasting temperature. The TPC and TFC content of oil samples increased during vacuum microwave drying pretreatment but decreased at higher vacuum microwave power. Furthermore, because of the high content of TPC, sesamin, and sesamolin and higher than untreated black sesame seed oil, the higher roasting temperature and vacuum microwave drying power resulted in higher DPPH and ABTS antioxidant activities. There were no significant differences in fatty acid compositions in sesame oils prepared from roasted, vacuum microwaved, and untreated seeds. Thus, roasting at 80°C and vacuum microwave drying at 2.25 kW/kg with a pressing temperature of 65°C is an appropriate pretreatment process for black sesame preparation prior to oil extraction, indicating a high oil yield and improved chemical properties. This study can be applied to the edible oil extraction industry to produce food products or health supplements containing black sesame oil.

6. Acknowledgements

Authors gratefully acknowledge to Agro-Industry, Chiang Mai University, Thailand for laboratory, facilities and in-kind assistance. Also, the authors would like to thank Huay Saew Royal Project Development Center, Chiang Mai, Thailand for providing us the black sesame seed samples.

7. References

Akinoso, R. (2006). Effects of moisture content, roasting duration and temperature on yield and quality of palm kernel (Elaeis guineensis) and sesame (sesamum indicum) oils. *A PhD Thesis, the University of Ibadan, Nigeria*.

Andargie, M., Vinas, M., Rathgeb, A., Möller, E., & Karlovsky, P. (2021). Lignans of sesame (Sesamum indicum L.): A comprehensive review. *Molecules*, *26*(4), 883. https://doi.org/https://doi.org/10.3390/molecules26040883

Azadmard-Damirchi, S., Alirezalu, K., & Achachlouei, B. F. (2011). Microwave pretreatment of seeds to extract high quality vegetable oil. *World Acad Sci Eng Technol*, *57*, 72-75.

Bi, Y. (2005). Oil chemistry. In: Chemical industry press.

Bopitiya, D., & Madhujith, T. (2013). Antioxidant activity and total phenolic content of sesame (Sesamum indicum L.) seed oil.

Chaaban, H., Ioannou, I., Chebil, L., Slimane, M., Gérardin, C., Paris, C., Charbonnel, C., Chekir, L., & Ghoul, M. (2017). Effect of heat processing on thermal stability and antioxidant activity of six flavonoids. *Journal of Food Processing and Preservation*, *41*(5), e13203.

Chan, C.-H., Yeoh, H. K., Yusoff, R., & Ngoh, G. C. (2016). A first-principles model for plant cell rupture in microwave-assisted extraction of bioactive compounds. *Journal of Food Engineering*, *188*, 98-107.

Elkhaleefa, A., & Shigidi, I. (2015). Optimization of sesame oil extraction process conditions. *Advances in Chemical Engineering and Science*, *5*(03), 305.

Feramuz, Ö., Muharrem, G., & Mustafa, E. (2006). Influence of Different Microwave Seed Roasting Processes on the Changes in Quality and Fatty Acid Composition of Tehina (Sesame Butter) Oil. *AKDENİZ ÜNİVERSİTESİ ZİRAAT FAKÜLTESİ DERGİSİ*, *19*(2), 207-216.

Giri, S. K., & Prasad, S. (2007). Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms. *Journal of Food Engineering*, *78*(2), 512-521. https://doi.org/https://doi.org/10.1016/j.jfoodeng.2005.10.021

Huang, Y., Liu, C., Ge, Z., Huang, F., Tang, H., Zhou, Q., Liu, R., Huang, J., & Zheng, C. (2023). Influence of different thermal treatment methods on the processing qualities of sesame seeds and cold-pressed oil. *Food Chemistry*, *404*, 134683. https://doi.org/https://doi.org/10.1016/j.foodchem.2022.134683

Jannat, B., Oveisi, M., Sadeghi, N., Hajimahmoodi, M., Behzad, M., Choopankari, E., & Behfar, A. (2010). Effects of roasting temperature and time on healthy nutraceuticals of antioxidants and total phenolic content in Iranian sesame seeds (Sesamum indicum L.). *Journal of Environmental Health Science & Engineering*, *7*(1), 97-102.

Ji, J., Liu, Y., Shi, L., Wang, N., & Wang, X. (2019). Effect of roasting treatment on the chemical composition of sesame oil. *LWT*, *101*, 191-200. https://doi.org/https://doi.org/10.1016/j.lwt.2018.11.008

Kanu, P. J., Bahsoon, J. Z., Kanu, J. B., & Kandeh, J. (2010). Nutraceutical importance of sesame seed and oil: a review of the contribution of their lignans. *Sierra Leone Journal of Biomedical Research*, *2*(1), 4-16.

Kaseke, T., Opara, U. L., & Fawole, O. A. (2020). Effect of microwave pretreatment of seeds on the quality and antioxidant capacity of pomegranate seed oil. *Foods*, *9*(9), 1287.

Kim, K.-S., Lee, J.-R., & Lee, J.-S. (2006). Determination of Sesamin and Sesamolin in Sesame (Sesamum indicum L.) Seeds Using UV Spectrophotometer and HPLC. *Korean Journal of Crop Science*, *51*(1), 95-100.

Lee, J., Lee, Y., & Choe, E. (2008). Effects of sesamol, sesamin, and sesamolin extracted from roasted sesame oil on the thermal oxidation of methyl linoleate. *LWT - Food Science and Technology*, *41*(10), 1871-1875. https://doi.org/https://doi.org/10.1016/j.lwt.2007.11.019

Martínez, M. L., Penci, M. C., Marin, M. A., Ribotta, P. D., & Maestri, D. M. (2013). Screw press extraction of almond (Prunus dulcis (Miller) D.A. Webb): Oil recovery and oxidative stability. *Journal of Food Engineering*, *119*(1), 40-45. https://doi.org/https://doi.org/10.1016/j.jfoodeng.2013.05.010

Muangrat, R., Chalermchat, Y., Pannasai, S., & Osiriphun, S. (2020). Effect of Roasting and Vacuum Microwave Treatments on Physicochemical and Antioxidant Properties of Oil Extracted from Black Sesame Seeds. *Current Research in Nutrition and Food Science Journal*, *8*(3), 798-814.

Nam, Y. S., Noh, K.-C., Roh, E. J., Keum, G., Lee, Y., & Lee, K.-B. (2014). Determination of edible vegetable oil adulterants in sesame oil using 1H nuclear magnetic resonance spectroscopy. *Analytical Letters*, *47*(7), 1190-1200.

Rabadán, A., Pardo, J. E., Gómez, R., & Álvarez-Ortí, M. (2018). Influence of temperature in the extraction of nut oils by means of screw pressing. *LWT*, *93*, 354-361. https://doi.org/https://doi.org/10.1016/j.lwt.2018.03.061

Satchithanandam, S., Fritsche, J., & Rader, J. I. (2001). Extension of AOAC official method 996.01 to the analysis of standard reference material (SRM) 1846 and infant formulas. *Journal of AOAC International*, *84*(3), 805-814.

Schwertner, H. A., & Rios, D. C. (2012). Analysis of sesamin, asarinin, and sesamolin by HPLC with photodiode and fluorescent detection and by GC/MS: Application to sesame oil and serum samples. *Journal of the American Oil Chemists' Society*, *89*(11), 1943-1950.

Shahidi, F., Wanasundara, P., & Wanasundara, U. (1997). Changes in edible fats and oils during processing. *Journal of Food Lipids*, *4*(3), 199-231.

Sriyab, S., Laosirisathian, N., Punyoyai, C., Anuchapreeda, S., Tima, S., Chiampanichayakul, S., & Chaiyana, W. (2021). Nutricosmetic effects of Asparagus officinalis: a potent matrix metalloproteinase-1 inhibitor. *Sci Rep*, *11*(1), 8772. https://doi.org/10.1038/s41598-021-88340-2

Tian, Y., Zhang, Y., Zeng, S., Zheng, Y., Chen, F., Guo, Z., Lin, Y., & Zheng, B. (2012). Optimization of microwave vacuum drying of lotus (Nelumbo nucifera Gaertn.) seeds by response surface methodology. *Food Science and Technology International*, *18*(5), 477-488.

Winny, R., & Valérie, O. (2012). Microwave-Assisted Extraction of Flavonoids: A Review. *Food Bioprocess Technol*, *5*, 409–424. https://doi.org/10.1007/s11947-011-0573-z

Yeerong, K., Sriyab, S., Somwongin, S., Punyoyai, C., Chantawannakul, P., Anuchapreeda, S., Prommaban, A., & Chaiyana, W. (2021). Skin irritation and potential antioxidant, anti-collagenase, and anti-elastase activities of edible insect extracts. *Sci Rep*, *11*(1), 22954. https://doi.org/10.1038/s41598-021-02382-0

Yoshida, H., & Takagi, S. (1997). Effects of seed roasting temperature and time on the quality characteristics of sesame (Sesamum indicum) oil. *Journal of the Science of Food and Agriculture*, *75*(1), 19-26.

Zhang, L., Shuai, Q., Li, P., Zhang, Q., Ma, F., Zhang, W., & Ding, X. (2016). Ion mobility spectrometry fingerprints: A rapid detection technology for adulteration of sesame oil. *Food Chemistry*, *192*, 60-66.

Zhao, S., & Zhang, D. (2014). Supercritical CO2 extraction of Eucalyptus leaves oil and comparison with Soxhlet extraction and hydro-distillation methods. *Separation and Purification Technology*, *133*, 443-451. https://doi.org/https://doi.org/10.1016/j.seppur.2014.07.018