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Effects of Cooking Temperature and Storage Time on the Quality of Macadamia Nut Oil*

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Abstract

The purpose is to study the influence of cooking and storage habits on the quality of macadamia nut oil, so as to provide reference for macadamia nut processing enterprises and consumers. Macadamia oil was treated at 100 ℃, 200 ℃, 300 ℃, microwave heating, 45 ℃ constant temperature storage, natural light for different times, and its acid value, peroxide value, squalene, sterol and fatty acid content were detected according to the national standard method. The results showed that the acid value and peroxide value increased with time. The acid value and peroxide value of macadamia oil cooked at 300 ℃ and stored under natural light were higher than those heated by microwave and stored at 45 ℃, and increased rapidly with the increase of cooking and light time. The acid value was as high as 0.77 mg/g, with an increase of 63.8%, and the peroxide value was as high as 6.18 mg/g, with an increase of 43.7%. As for squalene, it decreased in varying degrees with heating time and storage time. Squalene in macadamia oil cooked at 300 ℃ and stored under natural light were lower than those heated by microwave and stored at 45 ℃ constant temperature, respectively, and decreased rapidly with the increase of cooking and light time, with the reduction ranges of 38.6% and28.4% respectively; Stigmasterol was not detected in macadamia oil. But in macadamia oil the content of β- sitosterol was 0.132 g/100 g, and the content did not change significantly in each treatment group. In the experimental treatment group, the content of fatty acids in macadamia oil had different trends. After treatment at 300 ℃ for 20 minutes, the content of oleic acid decreased by 75.66%, the content of palmitic acid decreased by 75.28%, and the content of palmitic acid decreased by 74.12%. In conclusion, low temperature heating, microwave heating and storage away from light can better preserve the quality of macadamia oil, this study will provide a theoretical basis for the rational utilization of macadamia oil as cooking oil.

Keywords: Macadamia Oil; Cooking Temperature; Storage Time; Quality

1 INTRODUCTION

Macadamia integrifolia Maiden & Betche, also known as macadamia nut or Queensland nut, originates from the subtropical rainforest regions along the eastern coast of southeastern Queensland and northeastern New South Wales in Australia. It belongs to the family Proteaceae and the genus Macadamia [1]. Macadamia nuts are rich in various nutrients, with a fat content of up to 70%, predominantly consisting of unsaturated fatty acids [2]. They are also abundant in 8 essential amino acids, soluble sugars, starch, minerals, and vitamins [3]. In China, macadamia nuts are mainly cultivated in Yunnan, Guangdong, Guangxi, Guizhou, and other regions [4-5]. In December 2021, the Forestry and Grassland Bureau of Yunnan Province released the Development Plan for the Macadamia Industry in Yunnan Province, aiming to achieve a planting area of 4.2 million acres by 2023, accounting for around 70% of the global planting area, and the industry value is projected to reach 12 billion yuan.

Macadamia oil is a natural vegetable oil obtained from the processes of dehusking, drying, cracking, kernel extraction, and oil production of the raw macadamia nuts. It is rich in monounsaturated fatty acids, as well as natural

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antioxidants such as polyphenols, squalene, and phytosterols [6-7]. Studies have shown that macadamia oil possesses various health benefits, including lipid-lowering and antioxidant properties [7]. Macadamia oil has high commercial value and is widely used in industries such as cosmetics, health care, and medicine [3, 8]. With the improvement of people's living standards and the increasing awareness of overall health, consumers have higher demands for the quality of edible oils.

This study investigates the impact of various heating methods and storage conditions, including 100°C, 200°C, 300°C, microwave heating, constant temperature storage at 45°C, and natural light exposure, on the quality of macadamia oil. The oil is derived from macadamia nuts and subjected to different treatment times. Parameters such as acid value, peroxide value, squalene, sterols, and fatty acid content are measured to explore the influence of cooking and storage practices on the quality of macadamia oil. The aim is to provide a theoretical basis for the proper cooking and utilization of macadamia oil.

2 MATERIALS AND METHODS

2.1 Experimental Materials

1) Experimental Materials and Equipment

Macadamia oil was provided by Guangzhou Elysia Health Food Technology Co., Ltd. A mixture of 37 fatty acid methyl esters was used as a reference standard (purchased from NU-CHEK Standards, USA). Squalene standard was obtained from the National Centre for Quality Supervision and Inspection of Oil and Fat Products. Analytical grade n-hexane and methanol were purchased from Shanghai Anpu Experimental Technology Co., Ltd. Sodium thiosulfate titration solution and sodium hydroxide titration solution were also obtained from Shanghai Anpu Experimental Technology Co., Ltd. All organic solvents used for separation were domestically produced and of analytical purity.

2) Experimental Equipment

The experimental equipment used in this study included an Agilent 7890A gas chromatograph, an LC-20AT liquid chromatograph, a microwave oven manufactured by Midea Microwave Appliances Co., Ltd. in Shunde District, a temperature controller from Hunan Jinrongyuan Instrument Equipment Co., Ltd., a JA3103 precision electronic balance from Shanghai Precision Scientific Instrument Co., Ltd., and a TGL-15B centrifuge from Shanghai Anting Scientific Instrument Factory.

2.2 Methods

1) Sample Processing Conditions

Blank Control Group: The crude oil was stored at room temperature in the dark as a blank control. Two parallel samples were prepared, with each sample weighing 50 g.

High Temperature Cooking Group: The samples were heated at cooking temperatures of 100°C, 200°C, and 300°C for 5 minutes, 10 minutes, 15 minutes, and 20 minutes, respectively. A total of 12 sample points were collected, with each sample prepared in parallel and weighing 50 g.

Microwave Heating Group: The samples were heated in a microwave oven operating at 50 Hz with an output power of 700 W for 5 minutes, 10 minutes, 15 minutes, and 20 minutes, respectively. A total of 4 sample points were collected, with each sample prepared in parallel and weighing 50 g.

Storage Group: The samples were stored either in a constant temperature incubator at 45°C or under natural light for durations of 14 days, 28 days, and 42 days. The bottles were shaken once a day, and a total of 6 sample points were collected. Each sample was prepared in parallel with two replicates, with each replicate weighing 50 g.

2) Determination of Acid Value (AV) [9]

The collected samples were subjected to the determination of acid value following the guidelines outlined in the "GB 5009.229-2016 National Food Safety Standard - Determination of Acid Value in Food". Cold solvent indicator titration method was employed for the analysis.

3) Determination of Peroxide Value (POV) [10]

The collected samples were analyzed for peroxide value using the titration method as specified in the "GB 5009.227-2016 National Food Safety Standard - Determination of Peroxide Value in Food". The measurement was conducted in a shaded area to prevent direct sunlight exposure and efforts were made to minimize air exposure during the analysis.

4) Determination of Fatty Acid (FA) Types and Content

(1) Fatty Acid Methylation

The reference method[11] was followed with optimization. 100.00 mg of the sample was weighed into a 20.00 mL centrifuge tube (with a screw cap). Then, 10.00 mL of n-hexane was added to dissolve the sample. Subsequently, 100.00 μL of potassium hydroxide methanol solution (prepared by adding 11.20 g KOH to 100.00 mL methanol) was added. The screw cap was closed, and the mixture was vortexed for 1 min. After centrifugation at 5000 rpm for 5 min, 1.00 mL of the supernatant was taken for analysis.

(2) Chromatographic Conditions

The detector used was a Flame Ionization Detector (FID). The chromatographic column was comprised of polyethylene glycol (PEG) stationary phase. The injector temperature was set at 270℃, while the detector temperature was set at 280℃. The temperature program for the chromatographic analysis was as follows: initial temperature of 100℃ held for 13 minutes, followed by a ramp from 100℃ to 180℃ at a rate of 10℃/min and held for 6 minutes, then a ramp from 180℃ to 200℃ at a rate of 1℃/min and held for 20 minutes, and finally a ramp from 200℃ to 230℃ at a rate of 4℃/min and held for 10.5 minutes. Nitrogen gas was used as the carrier gas with a split ratio of 100:1. The injection volume was 1.00 μL.

(3) Analytical Method

The collected samples were analyzed using gas chromatography based on the ester standard curve method for the determination of 37 types of fatty acids, following the guidelines outlined in the "GB 5009.168-2016 National Food Safety Standard - Determination of Fatty Acids in Food" using the external standard method.

5) Determination of Squalene

Accurately weighing 2 g (to a precision of 0.0001 g) of macadamia nut oil, it was transferred to a 250 mL conical flask. Then, 50 mL of 1 mol/L potassium hydroxide-ethanol solution was added. The flask was placed in a constant-temperature water bath at 80℃, and the mixture was refluxed for 50 minutes for saponification. After cooling to room temperature, the saponification solution was transferred to a 250 mL separating funnel. Addition of n-hexane followed, and the mixture was vigorously shaken for 2 minutes, followed by a 10-minute settling period. After the solution separated into two layers, the upper organic phase was transferred to another 250 mL separating funnel. The lower saponification solution was subjected to two additional extractions with 30 mL and 20 mL of n-hexane, respectively. The organic extract from the three extractions was combined in the same separating funnel. Each time, 30 mL of 10% ethanol solution was added to wash the organic phase to neutral, followed by dehydration using anhydrous sodium sulfate. The solvent was evaporated to near-dryness in a 40℃ water bath, and the residue was dissolved in n-hexane and diluted to a final volume of 10 mL. The solution was filtered through a 0.45 μm organic membrane and analyzed by gas chromatography.

6) Determination of Sterols

Precisely weighing 2 g (to a precision of 0.0001 g) of macadamia nut oil, it was transferred to a 50 mL volumetric flask. Then, 20 mL of methanol was accurately added. The mixture was subjected to 40 minutes of ultrasonic treatment and cooled to room temperature. The flask was filled to volume with methanol, followed by filtration through a 0.22 μm membrane filter. The determination was conducted using high-performance liquid chromatography (HPLC).

3 RESULTS AND ANALYSIS

3.1 Influence of Different Temperatures and Storage Conditions on the Acid Value of Macadamia Nut Oil

Temperature has a significant impact on the acid value[12]. In this study, macadamia nut oil was subjected to different heating conditions at temperatures of 100℃, 200℃, and 300℃ using a microwave oven with a frequency of 50 Hz and an output power of 700 W. The samples were heated for varying durations, and the changes in acid value were obtained as shown in Figure 1A. The initial acid value of macadamia nut oil was 0.47 mg/g. With increasing temperatures, the acid value exhibited different degrees of increase, and the trend was more pronounced at higher temperatures. Heating at 100℃ showed no significant change in acid value, while both 200℃ and microwave heating resulted in a slight increase. When the temperature reached 300℃, the acid value of macadamia nut oil increased with longer heating time. At a heating time of 20 minutes, the acid value rose from 0.47 mg/g to 0.77 mg/g, representing an increase of 63.8%.

Storage conditions also have a certain impact on the quality of the oil[13]. Macadamia nut oil was subjected to storage at a constant temperature of 45℃ in a CO_2 incubator with natural light exposure, and the changes in acid value were observed, as shown in Figure 1B. Under long-term storage at a constant temperature of 45℃, there was no significant change in the acid value. In contrast, storage under natural light exposure resulted in a noticeable increase in the acid value. After 42 days of storage, the acid value increased from 0.47 mg/g to 0.62 mg/g, representing an increase of 31.9%. Sun et al. [14] found that in the process of storage, the main causes of increased acid value in Guangdong sausage were the presence of lipase and phospholipase in the raw meat. However, further research is needed to determine the specific reasons for the increase in acid value in macadamia nut oil under natural light exposure during storage.

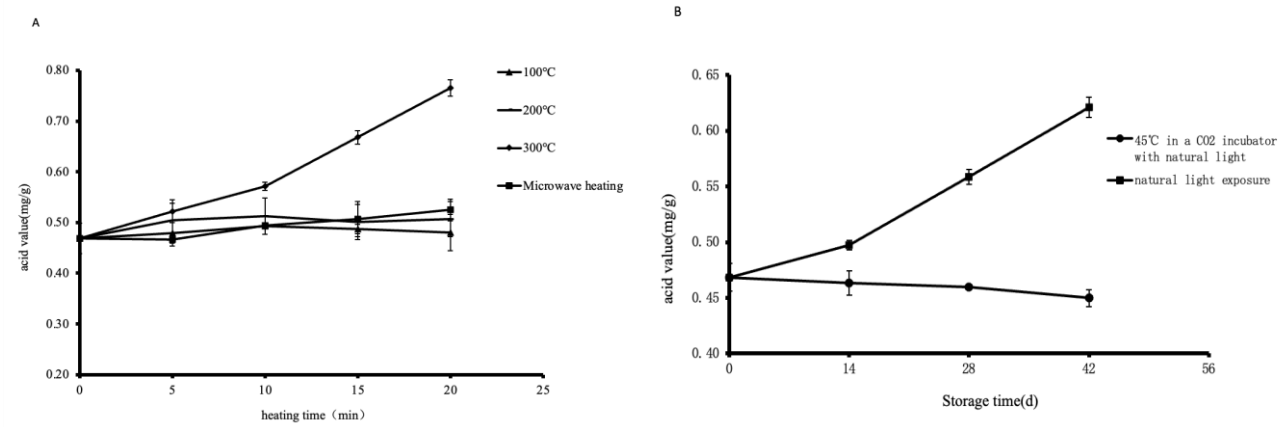

FIG.1 EFFECTS OF DIFFERENT TEMPERATURES AND STORAGE TIME ON THE ACID VALUE OF MACADAMIA OIL

3.2 The Influence of Different Temperatures and Storage Conditions on Peroxide Value of Macadamia Nut Oil

The oxidation of fats is highly influenced by the storage temperature [15]. Macadamia nut oil was subjected to various heating durations under different temperature conditions, including 100℃, 200℃, and 300℃ using a microwave oven with a frequency of 50 Hz and an output power of 700 W. The changes in peroxide value were observed and are shown in Figure 2A. The initial peroxide value of macadamia nut oil was 4.30 mmol/g. With increasing temperatures, the peroxide value exhibited varying degrees of increase, with a more pronounced trend at higher temperatures. No significant change in peroxide value was observed after treatments at 100℃, 200℃, and microwave heating. However, as the temperature reached 300℃, the peroxide value of macadamia nut oil increased with longer heating time. At a heating time of 20 minutes, the peroxide value rose from 4.30 mmol/g to 6.18 mmol/g, representing an increase of 43.7%.

Placing macadamia nut oil at a constant temperature of 45°C in an incubator with natural light exposure, the changes in peroxide value over the storage period are shown in Figure 2B. Under long-term storage at a constant temperature of 45°C, there was no significant change in the peroxide value. However, under storage conditions with natural light exposure, the peroxide value of macadamia nut oil initially increased significantly and then decreased. After 28 days of natural light exposure storage, the peroxide value rose from 4.30 mmol/g to 12.97 mmol/g, representing an increase of 201.6%. However, after 42 days of natural light exposure storage, the peroxide value decreased from 12.97 mmol/g to 6.28 mmol/g.

Xiaodong Xu et al.[16] investigated the effect of higher ambient temperatures on the accelerated oxidation and faster increase in peroxide value of peanut oil, and the results indicated a good linear relationship between peroxide value changes and different storage times. This is consistent with the observed data patterns in this study. Zhenjie Wang et al. [17] examined the impact of different heat treatments and storage conditions on the quality of blended oils. They found that during storage under natural light exposure, the trend of peroxide value changes was initially increasing and then decreasing. Possible reasons for this trend may include: (1) the possibility of fatty acids undergoing polymerization reactions to form large molecular polymers with carbon-carbon and carbon-oxygen-carbon bonds, which reduces the substrate of hydroperoxides and consequently decreases their generation; (2) hydroperoxides are unstable and prone to further oxidation and decomposition, resulting in the production of aldehydes, ketones, acids, and other secondary oxidation products. This decomposition reaction accelerates the breakdown of hydroperoxides, making the rate of hydroperoxide generation lower than its decomposition rate, thereby reducing the amount of hydroperoxides formed[18, 19].

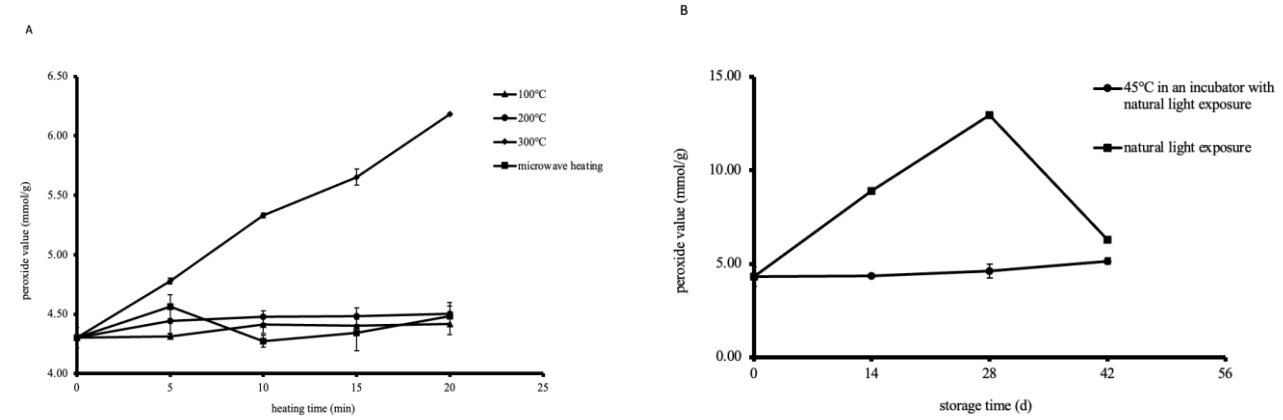

FIG.2 EFFECTS OF DIFFERENT TEMPERATURES AND STORAGE TIME ON THE PEROXIDE VALUE OF MACADAMIA OIL

3.3 The Influence of Different Temperatures and Storage Conditions on Fatty Acid Content of Macadamia Nut Oil

Sixteen types of fatty acids, including oleic acid, palmitoleic acid, and palmitic acid, were detected in the samples (Table 1). The main fatty acids found in the original oil were oleic acid, accounting for 34.6% of the total, and palmitoleic acid, accounting for 10.4% of the total.

The Influence of Different Temperatures and Storage Conditions on Fatty Acids also has certain effects [20]. Studies have shown that both temperature and light significantly affect unsaturated fatty acids [21]. According to Table 2, the fatty acid content showed no significant changes after microwave heating, which is consistent with previous research. Hu Aipeng et al. [22] found that microwave pretreatment does not significantly affect the fatty acid composition and content levels in rapeseed and rapeseed oil. As shown in Tables 3-5, high-temperature heating led to varying degrees of decrease in fatty acid content, with a more significant trend at higher temperatures. Under heating at 100°C, the content of oleic acid decreased from 34.6% to 18.3%, palmitoleic acid decreased from 10.4% to 5.57%, and palmitic acid decreased from 5.14% to 2.76%. Under heating at 200°C, the content of oleic acid decreased from 34.6% to 8.51%, palmitoleic acid decreased from 10.4% to 2.58%, and palmitic acid decreased from 5.14% to 1.29%. Under heating at 300°C, the content of oleic acid decreased from 34.6% to 8.42%, palmitoleic acid decreased from 10.4%

to 2.57%, and palmitic acid decreased from 5.14% to 1.33%. Other fatty acids also showed varying degrees of decrease. Zhang Jing et al. [23] found that low temperatures favor the accumulation of fatty acid content by studying the changes in the components of the epidermal layer in Wenzhou honey tangerines during refrigeration.

The Influence of Different Storage Conditions on Fatty Acid Content can be seen in Table 6. Under long-term storage at a constant temperature of 45℃, the content of oleic acid decreased from 34.6% to 7.38%, palmitoleic acid decreased from 10.4% to 2.25%, and palmitic acid decreased from 5.14% to 1.13%. Other fatty acids also showed varying degrees of decrease. However, under storage conditions with natural light exposure, the changes in fatty acid content were more complex, generally exhibiting a trend of initial decrease followed by an increase, similar to the pattern observed in peroxide value changes. The content of oleic acid decreased from 34.6% to 4.31%, and after 42 days, it increased to 16.9%. The content of palmitoleic acid decreased from 10.4% to 1.32%, and after 42 days, it increased to 5.14%.

The reasonable ratio of fatty acids is not only an important indicator for evaluating food nutrition and health but also a determining factor for the quality of oils and fats [24-25]. Zhang Qing et al.[26] investigated the influence of pasteurization temperature on the oxidation and quality of halogenated egg fat. It was found that with increasing pasteurization temperature, there was no significant change in the total content of saturated fatty acids ($P>0.05$). The total content of monounsaturated fatty acids showed an increasing trend, while the total content of polyunsaturated fatty acids significantly decreased with increasing pasteurization temperature ($P<0.05$).

TABLE 1 TYPES AND NAMES OF FATTY ACIDS IN THE SAMPLE

Fatty Acid Abbreviation	Colloquially
C12:0	Lauric acid
C14:0	Myristate
C16:0	Palmitic acid
C16:1n7	Palmitoleic acid
C17:1n7	-
C18:0	Stearic acid
C18:1n9c	Oleic acid
C18:2n6c	Linoleic acid
C20:0	Arachidic acid
C20:1	-
C18:3n3	Alpha-linoleic acid
C22:0	Behenoleic acid
C20:4n6	Arachidonic acid
C20:5n3	EPA

TABLE 2 EFFECTS OF DIFFERENT HEATING TIME ON FATTY ACID CONTENT UNDER MICROWAVE HEATING

Fatty Acid Abbreviation	Blank Control	Microwave Heating			
		5 Min	10 Min	15 Min	20 Min
C12:0	0.035±0.00	0.030±0.00**	0.029±0.00**	0.034±0.00	0.035±0.00
C14:0	0.352±0.01	0.304±0.00**	0.293±0.00**	0.358±0.00	0.362±0.02
C16:0	5.135±0.020	4.433±0.03**	4.274±0.03**	5.240±0.02	5.289±0.35
C16:1n7	10.441±0.40	9.013±0.06**	8.676±0.06**	10.601±0.03	10.678±0.71
C17:1n7	0.038±0.00	0.033±0.00**	0.032±0.00**	0.040±0.00*	0.040±0.00*
C18:0	2.096±0.08	1.805±0.01**	1.739±0.00**	2.139±0.01	2.160±0.14

C18:1n9c	34.572±0.13	29.746±0.24**	28.605±0.00**	35.075±0.12	35.371±2.30
C18:2n6c	1.260±0.05	1.088±0.01**	1.038±0.00**	1.244±0.00	1.249±0.10
C20:0	1.583±0.06	1.359±0.01**	1.309±0.00**	1.615±0.00	1.634±0.10
C18:3n6	0.00	0.00	0.00	0.00	0.00
C20:1	0.073±0.00	0.063±0.00**	0.059±0.00**	0.070±0.00*	0.068±0.00**
C18:3n3	1.411±0.06	1.212±0.01**	1.164±0.00**	1.431±0.00	1.444±0.10
C22:0	0.458±0.02	0.392±0.00**	0.378±0.00**	0.468±0.00	0.473±0.03
C20:4n6	0.140±0.01	0.119±0.00**	0.115±0.00**	0.144±0.00	0.144±0.01
C20:5n3	0.174±0.01	0.141±0.00	0.141±0.01	0.177±0.00*	0.180±0.01*

** Significant at 0.01 level, * significant at 0.05 level.

TABLE 3 EFFECTS OF DIFFERENT HEATING TIME ON FATTY ACID CONTENT UNDER HEATING CONDITION OF 100℃

Fatty Aid Abbreviation	**Blank Control**	**100℃**			
		5 Min	**10 Min**	**15 Min**	**20 Min**
C12:0	0.035±0.00	0.02±0.00**	0.02±0.00**	0.02±0.00**	0.02±0.00**
C14:0	0.352±0.01	0.23±0.02**	0.23±0.00**	0.19±0.00**	0.19±0.00 **
C16:0	5.135±0.020	3.34±0.26**	3.36±0.09**	2.77±0.11**	2.76 ±0.06**
C16:1n7	10.441±0.40	6.75±0.52**	6.80±0.18**	5.59±0.23**	5.57±0.13**
C17:1n7	0.038±0.00	0.00	0.00	0.00	0.00
C18:0	2.096±0.08	1.36±0.10**	1.37±0.03**	1.13±0.05**	1.12±0.03**
C18:1n9c	34.572±0.13	21.31±0.44**	22.34±0.58**	18.36±0.75**	18.27±0.42**
C18:2n6c	1.260±0.05	0.00	0.00	0.00	0.00
C20:0	1.583±0.06	0.00	0.00	0.00	0.00
C18:3n6	0.00	1.08±0.09**	1.13±0.10**	0.89±0.04**	0.89±0.02 **
C20:1	0.073±0.00	0.05±0.00**	0.00	0.00	0.00
C18:3n3	1.411±0.06	0.91±0.07**	0.92±0.02**	0.75±0.03**	0.75±0.02**
C22:0	0.458±0.02	0.00	0.00	0.00	0.00
C20:3n6	0.00	0.31 ±0.03	0.30 ±0.01	0.24 ±0.01	0.24±0.01
C20:4n6	0.140±0.01	0.00	0.00	0.00	0.00
C20:5n3	0.174±0.01	0.00	0.00	0.00	0.00

** significant at 0.01 level, * significant at 0.05 level.

TABLE 4 EFFECTS OF DIFFERENT HEATING TIME ON FATTY ACID CONTENT UNDER HEATING CONDITION OF 200℃

Fatty Acid Abbreviation	**Blank Control**	**200℃**			
		5Min	**10Min**	**15Min**	**20Min**
C12:0	0.035±0.00	0.00	0.00	0.01±0.00**	0.000
C14:0	0.352±0.01	0.12±0.00**	0.10±0.00**	0.15±0.00**	0.087±0.00**
C16:0	5.135±0.020	1.76±0.07**	1.46±0.00**	2.25±0.00**	1.285±0.00**
C16:1n7	10.441±0.40	3.54±0.14**	2.93±0.02**	4.53±0.00**	2.576±0.02**
C17:1n7	0.038±0.00	0.00	0.00	0.00	0.000
C18:0	2.096±0.08	0.72±0.03**	0.59±0.00**	0.92±0.00**	0.524±0.00**
C18:1n9c	34.572±0.13	11.63±0.44**	9.62±0.06**	14.94±0.01**	8.511±0.07**

C18:2n6c	1.260±0.05	0.00	0.00	0.00	0.00
C20:0	1.583±0.06	0.54±0.02**	0.45±0.00**	0.69 ±0.00**	0.393±0.00**
C18:3n6	0.00	0.00	0.00	0.00	0.00
C20:1	0.073±0.00	0.00	0.00	0.00	0.00
C18:3n3	1.411±0.06	0.48±0.02**	0.40±0.00**	0.61±0.00**	0.350±0.00**
C22:0	0.458±0.02	0.15±0.00**	0.12 ±0.00**	0.20±0.00**	0.106±0.00**
C20:3n6	0.00	0.00	0.00	0.00	0.00
C20:4n6	0.140±0.01	0.00	0.00	0.00	0.00
C20:5n3	0.174±0.01	0.00	0.00	0.00	0.00

** significant at 0.01 level, * significant at 0.05 level.

TABLE 5 EFFECTS OF DIFFERENT HEATING TIME ON FATTY ACID CONTENT UNDER HEATING CONDITION OF 300℃

Fatty Acid Abbreviation	Blank Control	300℃			
		5 Min	10 Min	15 Min	20 Min
C12:0	0.035±0.00	0.02±0.00**	0.02±0.00**	0.00	0.00
C14:0	0.352±0.01	0.18±0.00**	0.26±0.00**	0.09±0.00**	0.09±0.00**
C16:0	5.135±0.020	2.67±0.02**	3.76±0.11**	1.34 ±0.03**	1.33±0.01**
C16:1n7	10.441±0.40	5.37±0.04**	7.57±0.18**	2.63 ±0.06**	2.57±0.01**
C17:1n7	0.038±0.00	0.00	0.00	0.00	0.00
C18:0	2.096±0.08	1.08±0.01**	1.53±0.04**	0.54±0.01**	0.54±0.01**
C18:1n9c	34.572±0.13	17.59±0.13**	24.74±0.71**	8.65±0.19**	8.42±0.08**
C18:2n6c	1.260±0.05	0.00	0.00	0.00	0.00
C20:0	1.583±0.06	0.80±0.01**	1.15±0.04**	0.41±0.01**	0.40±0.00**
C18:3n6	0.00	0.00	0.00	0.00	0.00
C20:1	0.073±0.00	0.00	0.05±0.00**	0.00	0.00
C18:3n3	1.411±0.06	0.72±0.00**	1.01±0.03**	0.36±0.01**	0.35±0.00**
C22:0	0.458±0.02	0.23±0.00**	0.33±0.00**	0.12±0.00**	0.11±0.00**
C20:3n6	0.00	0.00	0.00	0.00	0.00
C20:4n6	0.140±0.01	0.00	0.00	0.00	0.00
C20:5n3	0.174±0.01	0.00	0.00	0.00	0.00

** significant at 0.01 level, * significant at 0.05 level.

TABLE 6 EFFECT OF STORAGE TIME ON FATTY ACID CONTENT

Fatty Acid Abbreviation	Blank Control	45℃ in a CO_2 Incubator			Natural Light Exposure		
		14 d	28 d	42 d	14 d	28 d	42 d
C12:0	0.035±0.00	0.01±0.00**	0.00	0.00	0.00	0.00	0.02±0.00**
C14:0	0.352±0.01	0.16±0.00**	0.10±0.02**	0.08±0.00**	0.08±0.00**	0.05±0.00**	0.17±0.00**
C16:0	5.135±0.020	2.31±0.06**	1.53±0.01**	1.13±0.02**	1.22±0.01**	0.67±0.02**	2.56±0.03**
C16:1n7	10.441±0.40	4.65±0.12**	3.07±0.01**	2.25±0.04**	2.43±0.02**	1.32±0.03**	5.14±0.07**
C17:1n7	0.038±0.00	0.00	0.00	0.00	0.00	0.00	0.00
C18:0	2.096±0.08	0.93±0.02**	0.62±0.00**	0.43±0.05**	0.49±0.00**	0.27±0.01**	1.04±0.01**
C18:1n9c	34.572±0.13	15.23±0.44	10.07±0.03	7.38±0.13	7.98±0.06	4.31±0.10	16.86±0.24

C18:2n6c	1.260±0.05	0.00	0.00	0.00	0.00	0.00	0.00
C20:0	1.583±0.06	0.70±0.02**	0.46±0.00**	0.34±0.00**	0.37±0.00**	0.20±0.01**	0.00
C18:3n6	0.00	0.00	0.00	0.00	0.00	0.00	0.82 ±0.14**
C20:1	0.073±0.00	0.00	0.00	0.00	0.00	0.00	0.00
C18:3n3	1.411±0.06	0.62±0.02	0.41±0.00	0.30±0.01	0.33±0.00	0.18±0.00	0.69 ±0.01
C22:0	0.458±0.02	0.00	0.00	0.00	0.00	0.00	0.00
C20:3n6	0.00	0.21±0.01	0.06±0.09	0.00	0.00	0.00	0.21±0.00
C20:4n6	0.140±0.01	0.00	0.00	0.00	0.00	0.00	0.00
C20:5n3	0.174±0.01	0.00	0.00	0.00	0.00	0.00	0.00

Note: ** significant at 0.01 level, * significant at 0.05 level.

3.4 The Influence of Different Temperatures and Storage Conditions on the Content of Squalene in Macadamia Nut Oil

Squalene is a nutritional co-component found in plant oils and plays an important role in disease prevention. It is widely used in the development of functional foods and pharmaceutical products [27-28]. In this study, Macadamia nut oil was subjected to different heating times under conditions of 100℃, 200℃, 300℃, as well as microwave heating at 50 Hz with an output power of 700 W. The changes in squalene content are shown in Figure 3A. The initial content of squalene in the original oil was 36.3 mg/100 g. After high-temperature heating, the squalene content exhibited varying degrees of decrease, with a more significant trend observed at higher temperatures. Neither significant change in squalene content was observed with heating at 100℃ or microwave heating. When the temperature was raised to 200℃ with a heating time of 20 minutes, the squalene content decreased from 36.3 mg/100 g to 32.6 mg/100 g, representing a decrease of 10.2%. With a temperature of 300℃ and a heating time of 20 minutes, the squalene content continuously decreased from 36.3 mg/100 g to 22.3 mg/100 g, representing a decrease of 38.6%. It can be seen that the higher the heating temperature and the longer the heating time, the greater the decline in squalene content. Microwave heating, on the other hand, had little impact on the squalene content.

The changes in squalene content over time were studied by storing Macadamia nut oil at a constant temperature of 45℃ in a CO_2 incubator and under natural light exposure, as shown in Figure 3B. Under long-term storage at a constant temperature of 45℃, there was no significant change in squalene content. In contrast, under storage conditions with natural light exposure, a pronounced decrease in squalene content was observed. After storage for forty-two days, the squalene content decreased continuously from 36.3 mg/100 g to 26.0 mg/100 g, representing a decrease of 28.4%. This indicates that light exposure may lead to the decomposition or loss of squalene, which is detrimental to the storage of squalene.

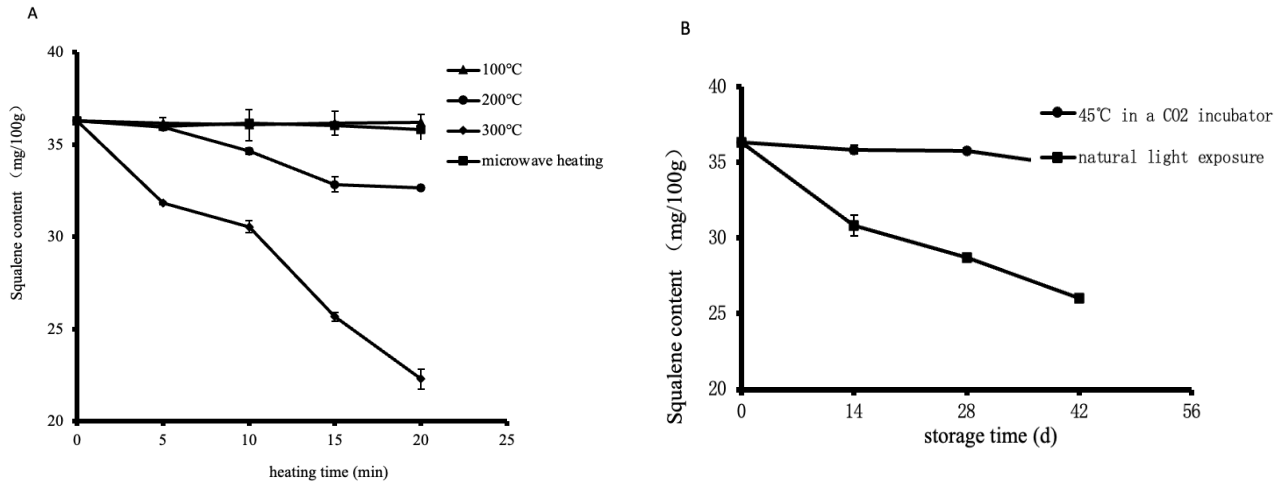

FIG.3 EFFECTS OF DIFFERENT STORAGE TIME AND STORAGE TIME ON SQUALENE IN MACADAMIA OIL

3.5 The Influence of Different Temperatures and Storage Conditions on the Content of Sterols in Macadamia Nut Oil

Macadamia nut oil was subjected to different heating times under conditions of 100℃, 200℃, 300℃, as well as microwave heating at 50 Hz with an output power of 700 W, and the changes in sterol content are shown in Figure 4A. The original Macadamia nut oil did not contain stigmasterol; only β-sitosterol was detected, with a value of 0.132 g/100 g. After high-temperature heating, no significant change in the content of β-sitosterol was observed in Macadamia nut oil. Furthermore, Macadamia nut oil was subjected to storage at a constant temperature of 45℃ in a CO_2 incubator and under natural light exposure, and the changes in sterol content are shown in Figure 4B. There was a slight downward trend in the content of β-sitosterol in Macadamia nut oil during long-term storage at a constant temperature of 45℃ and storage under natural light exposure, but the variations were not significant. Dong Dan et al. [20] found that during the accelerated storage period of red raspberry seed oil, the content of β-sitosterol initially decreased and then stabilized. Fang Bing et al. [29] discovered, through their study on the effects of different levels of phenolics and sterols on the oxidative stability of soybean oil, that the oxidative stability of soybean oil could be enhanced when the content of β-sitosterol and α-tocopherol was below 0.30%±1.29%. This could be attributed to the fact that β-sitosterol acts as a synergist to enhance the antioxidant activity of α-tocopherol by replenishing the lost hydrogen atom [30].

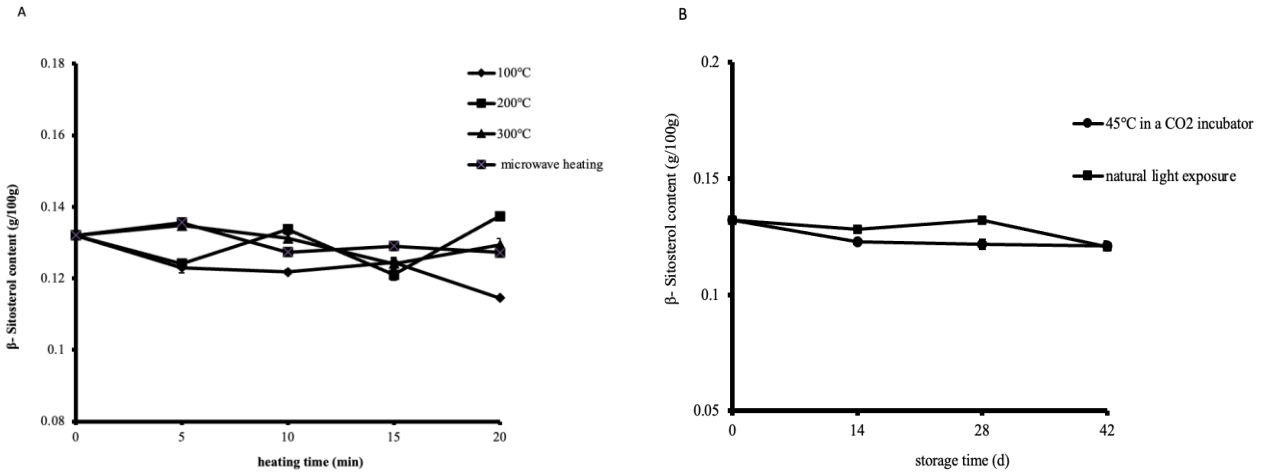

FIG.4 EFFECTS OF DIFFERENT STORAGE TIME AND STORAGE TIME ON B-SITOSTEROL IN MACADAMIA OIL

4 DISCUSSION

Different heating temperatures and times have varied effects on the quality of Macadamia nut oil. After heating at 100℃, there were no significant changes in acid value, peroxide value, squalene content, and β-sitosterol content of Macadamia nut oil. However, the oleic acid content decreased from 34.6% to 18.3%, palmoleic acid content decreased from 10.4% to 5.57%, and palmitic acid content decreased from 5.14% to 2.76%. On the other hand, after heating at 300℃ for 20 minutes, the acid value and peroxide value of Macadamia nut oil increased with the heating time, with increases of 63.8% and 43.7% respectively. The squalene content decreased with the heating time, exhibiting a decrease of 38.6%. The changes in sterol content were not significant as the heating time increased. The oleic acid content decreased from 34.6% to 8.42%, the palmoleic acid content decreased from 10.4% to 2.57%, and the palmitic acid content decreased from 5.14% to 1.33%, with decreases of 75.66%, 75.28%, and 74.12% respectively.

Different heating times under the conditions of a microwave oven with a frequency of 50 Hz and an output power of 700 W resulted in varying effects on the quality of Macadamia nut oil. Microwave heating for 5 minutes and 20 minutes did not show significant trends in acid value, peroxide value, squalene, and sterol content of Macadamia nut oil. However, there was an initial decrease followed by an increase in the content of oleic acid, palmoleic acid, and palmitic acid.

Under long-term storage at a constant temperature of 45℃, the acid value, peroxide value, and sterol content of Macadamia nut oil did not show significant changes. However, the content of oleic acid decreased from 34.6% to 7.38%, palmoleic acid decreased from 10.4% to 2.25%, and palmitic acid decreased from 5.14% to 1.13%. Other fatty acids also exhibited varying degrees of decrease.

After 42 days of storage under natural light exposure, the acid value of Macadamia nut oil significantly increased, rising from 0.47 mg/g to 0.62 mg/100 g, representing a 31.9% increase. The peroxide value initially increased and then decreased, increasing from 4.30 mmol/g to 12.97 mmol/g, with an increase of 201.6%. However, after 42 days of storage under natural light exposure, the peroxide value decreased from 12.97 mmol/g to 6.28 mmol/g. The content of squalene decreased from 36.3 mg/100 g to 26.0 mg/100 g, with a decrease of 28.4%. The β-sitosterol content in Macadamia nut oil did not show significant changes under storage conditions with natural light exposure. The changes in fatty acid content were more complex, generally exhibiting a trend of initially decreasing and then increasing.

High-temperature cooking methods and storage conditions have a significant impact on the quality of Macadamia nut oil. The cooking temperature for Macadamia nut oil should not exceed 100℃, and it is preferable to use microwave heating for heating purposes. Additionally, the duration of light exposure also has a major influence on the quality of Macadamia nut oil; therefore, it is advisable to store Macadamia nut oil in a light-protected environment.

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