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Effect of Accelerated Storage on Microencapsulated Kenaf Seed Oil

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Abstract In order to improve the quality and protect against degradation, kenaf (*Hibiscus cannabinus* L.) seed oil was microencapsulated by using spray drying. The microencapsulated kenaf seed oil (MKSO) was then stored at 65 °C for 24 days, the changes of fatty acids and bioactive compounds were examined every six days. Bulk (unencapsulated) kenaf seed oil was used as a control and was compared to the MKSO. The fatty acids and phytosterols compositions were determined by using gas chromatography, while tocopherols and phenolic acids of microencapsulated kenaf seed oil were determined by using high performance liquid chromatography. The results showed that there was a significant decrease ($p < 0.05$) in bioactive compounds in kenaf seed oil while the bioactive compounds in MKSO were maintained in a stable condition upon accelerated storage. Microencapsulation was shown to protect kenaf seed oil against oxidation, as well as preventing the degradation and/or loss of bioactive compounds in kenaf seed oil.

Keywords *Hibiscus cannabinus* seed oil · Spray drying · Fatty acids · Phytosterols · Tocopherols · Phenolic acids · Gas chromatography (GC) · High performance liquid chromatography (HPLC)

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Introduction

In the past decades, kenaf (*Hibiscus cannabinus* L.) seeds have been disposed as industrial waste during the harvesting or processing of kenaf. However, researchers found that kenaf seeds have an edible oil content with possible nutraceutical values and can be utilized in food resources or industrial products for human consumption [1]. One of the reasons for the renewed interest in kenaf seed oil production is its high polyunsaturated fatty acids (PUFAs) and phytosterols content that have cholesterol lowering ability, which is beneficial to human health [2]. However, kenaf seed oil is chemically unstable and susceptible to oxidative deterioration, especially when exposed to oxygen, light, moisture, and a warm temperature, due to its high content of unsaturated fatty acids. The oxidative deterioration causes a loss of nutritional quality, affecting shelf stability and the sensory properties of the oil [3]. These issues can be overcome by microencapsulation of kenaf seed oil to lower the oxidation rate which transforms the oils into powdery solids that can be used for the supplementation of food products [4]. Spray drying is a common technique used for microencapsulation because it is efficient, cost effective using readily available equipment and produces particles of reasonably good quality [5]. It has also proved to be more efficient than freeze drying in encapsulating of oils [6–8]. Various studies have shown that the microencapsulation can be successfully used to encapsulate oils to prevent oxidation and to improve stability [9–11]. Although microencapsulation can protect the oils from oxidation, severe lipid oxidation on the surface of the

microcapsule could also occur due to the high temperature during the spray drying process [12].

In this study, the changes in fatty acids and bioactive compounds in kenaf seed oil with and without microencapsulation upon accelerated storage were evaluated. Fatty acid and phytosterol compositions in the kenaf seed oil were determined by using gas chromatography (GC). The tocopherol and phenolic acid contents in the kenaf seed oil were investigated by using high performance liquid chromatography (HPLC).

Materials and Methods

Materials

Kenaf (*Hibiscus cannabinus* L.) seeds were obtained from the Malaysia Agricultural Research and Development Institute (MARDI), Selangor, Malaysia. Wall materials, such as sodium caseinate (China), maltodextrin DE10 (China) and soy lecithin (China; used as an emulsifier) were purchased from a local food ingredient supplier (VIS Food Tech Ingredient Supplies, Malaysia). All chemicals used were of analytical grade (Merck, Darmstadt, Germany).

Methods

Kenaf Seed Oil Extraction

The kenaf seeds were ground into fine powder using a coffee grinder (National, Osaka, Japan). The oils were extracted from the seeds with a Soxhlet extractor using hexane at 60 °C for 8 h [13]. The oil was then recovered by evaporating off the solvent using rotary evaporator Model N-1 (Eyela, Tokyo Rikakikal Co., Ltd., Japan) and residual solvent was removed by flushing with 99.9 % nitrogen.

Preparation of the Emulsion

Based on the preliminary studies conducted, the 40 % of total solids content in the emulsion was the optimized formulation according to its highest microencapsulation efficiency (MEE). To prepare 500 mL of emulsion, 20 g of sodium caseinate and 180 g of maltodextrin (protein/carbohydrate ratio of 1:9) were mixed and dissolved in deionized water. The solution was topped up to 433.33 mL with deionized water and was kept overnight at 4 ± 2 °C for rehydration. 66.67 mL of kenaf seed oil was then added to the wall material solutions (core/wall material ratio of 1:3). Subsequently, 2 g of soy lecithin was added as an emulsifier (emulsifier/protein ratio of 0.1:1) [14]. The mixture was then homogenized in a shear homogenizer (Silverson L4R, Buckinghamshire, UK) for 5 min at 3,000 rpm until complete dispersion was observed. The resultant emulsions were further homogenized in a high-pressure homogenizer (APV, Crawley, UK) at pressure of 500 bar for four cycles [14]. The emulsion droplet size was measured using a Malvern Mastersizer X (Malvern Instruments, UK) and the droplet size of the emulsion was 0.13 ± 0.00 μm.

Spray Drying of the Emulsion

The emulsion was spray-dried in a Buchi B-290 model mini spray dryer (Buchi Labortechnik AG, Switzerland) equipped with a 0.7 mm standard diameter nozzle. Spray drying conditions were selected based on preliminary experiments performed at different inlet air temperatures with the highest microencapsulation efficiency (MEE). The inlet temperature was set at 160 °C and the outlet temperature was 85 ± 2 °C. The dried microencapsulated kenaf seed oil (MKSO) was collected and sealed in high-density polyethylene (HDPE) plastic bags and stored at − 20 °C in a freezer for further analyses.

Microencapsulation Efficiency (MEE) Determination

Microencapsulation efficiency (MEE) of MKSO was calculated using Eq. (1) according to a previously described method [14] and was expressed as a percentage (%).

$$\text{MEE} = [(\text{total oil} - \text{extractable oil}) \times 100] / \text{total oil} \quad (1)$$

Total oil content of MKSO was determined according to the previously described method [14]. In the preparation of the de-emulsifier, 10 g of sodium salicylate and 10 g of sodium citrate were dissolved separately in deionized water, followed by mixing these solutions together with 18 mL of *n*-butanol, and topping up to 90 mL with deionized water. 10 g of MKSO was mixed with 20 mL water at 50 °C in an Erlenmeyer flask with a stopper. Then 15 mL of the pre-prepared de-emulsifier was added, and the mixture was shaken vigorously and left to stand in a 70 °C water bath for 6 min. The resulting mixture was then centrifuged at 3,000 × *g* for 10 min, and the total oil on the top layer was collected. In the determination of extractable oil, 200 mL of light petroleum ether (60–80 °C) was added to 10 g of the MKSO in an Erlenmeyer flask with a stopper and stirred at 25 °C in the dark for 15 min. The resulting mixture was filtered by passing through a Buchner funnel with a Whatman No. 4 filter paper, collected in a round-bottom flask, and evaporated using a rotary evaporator in a water bath at less than 30 °C to minimize the influence of heating on lipid oxidation.

Accelerated Storage Condition

The MKSO was kept under accelerated storage conditions by the Schaal oven test [15], condition at 65 °C for 24 days. Bulk (unencapsulated) kenaf seed oil was kept in a Schott bottle and stored under the same accelerated storage conditions which were used as positive control to make a comparison with the MKSO. In order to remove the availability of oxygen in the Schott bottle, all the samples in the Schott bottles were flushed with 99.9 % nitrogen. The analyses of the fatty acids profile and bioactive compounds were carried out at day 0, 6, 12, 18 and 24 to examine their changes upon accelerated storage.

Extraction of Total Oil by Demulsification

Prior analyses, the total kenaf seed oil was extracted out from the coating wall material according to the prescribed method in the MEE determination.

Fatty Acids Profile and Bioactive Compounds of Oil Samples

The fatty acid profile and bioactive compounds such as phytosterols, tocopherols and phenolic acids in kenaf seed oil and MKSO were determined according to the established method from the previous study [16].

Statistical Analysis

All experiments were performed in duplicate and measurements were replicated two times. The results were expressed as means ± standard deviations ($n = 4$). Two way analysis of variance (ANOVA) was carried out to determine the significant differences ($p < 0.05$) between the average values. Data were analyzed using Predictive Analytics Software (PASW Statistic for Windows 18.0, SPSS Inc., USA).

Results and Discussion

Effect of Microencapsulation on Kenaf Seed Oil

Spray drying of the emulsion involves formation of spray droplets and contact of the spray with hot air. In the present work, the criteria of preparation of microencapsulated kenaf seed oil were selected based on preliminary experiments performed at different inlet air temperatures and total solids content so as to maximize the MEE. MEE refers to the ability of the wall material to encapsulate the core material within the spherical structure. The MEE of the MKSO was 97.02 ± 0.52 %, which was optimized at 40 % of total solids content in the emulsion and inlet air temperature of 160 °C. Although spray drying uses a high temperature for dehydration of the spray droplets, it is suitable for drying the heat sensitive product as the product temperature is usually low and below 100 °C due to exposure to the heat for only few seconds [17]. In fact, a range of 160–180 °C was used by many researchers for spray drying of highly unsaturated oils [10, 18–20].

Results showed that there were decreases in unsaturated fatty acids after the microencapsulation of kenaf seed oil by spray drying. The most abundant unsaturated fatty acid, linoleic acid (C18:2n-6c), was detected as 33.6 ± 0.2 % in bulk kenaf seed oil (Table 1) while 25.7 ± 0.2 % in the MKSO (Table 2). However, the oleic acid (C18:1n-9c) detected in the MKSO was found to be higher than in the bulk oil. The result obtained was in accordance with the study of extra-virgin olive oil [21] where there was an increase in oleic acid after microencapsulation of extra-virgin oil. Similarly, the saturated fatty acids content in the extra-virgin olive oil was found to be significantly decreased ($p < 0.05$) after microencapsulation. Figure 1 shows that the amount of phytosterols in MKSO (4,680.4 ± 171.9 mg/100 g) was significantly lower ($p < 0.05$) than the fresh (day 0) kenaf seed oil (6,510.3 ± 54.2 mg/100 g), which can be ascribed to the spray drying process of microencapsulation that caused excessive evaporation and the loss of phytosterols. Similarly to the total tocopherols content (Fig. 2) and total phenolic acids (Fig. 3). This showed that the exposure of MKSO to heat during the process of spray drying causes the destruction and loss of bioactive compounds (phytosterols, tocopherols and phenolic acids).

Changes in Fatty Acid Composition upon Accelerated Storage

As shown in Table 1, fresh (day 0) kenaf seed oil contained a high percentage of polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA). Linoleic acid (C18:2n-6c) was the predominant unsaturated fatty acid (33.7 %), followed by oleic acid (C18:1n-9c) that was 31.8 %. Palmitoleic acid (C16:1), linolenic acid (C18:3n-6c) and eicosenoic acid (C20:1) were present in minor amounts which were 0.8, 0.5 and 0.3 %, respectively. However, the fatty acids composition were found to be slightly different from the previous study [16] which reported that oleic acid (37.1 %) was predominantly found in kenaf seed oil, followed by linoleic acid (36.6 %) and palmitic acid (20.3 %). This can be attributed to the different solvent used in oil extraction. The hexane was reported to be more efficient as an extracting solvent than petroleum ether because of its higher percentage in recovery of oil [22]. Upon accelerated storage,

Table 1 Relative percent composition of fatty acids in bulk (unencapsulated) kenaf seed oil with accelerated storage

Fatty acid	Storage (days)				
	0	6	12	18	24
C14:0	1.6 ± 0.1^{a}	2.0 ± 0.1^{b}	2.4 ± 0.1^{c}	2.4 ± 0.0^{c}	2.4 ± 0.0^{c}
C16:0	26.9 ± 0.8^{a}	30.2 ± 1.9^{b}	31.8 ± 0.6^{b}	34.2 ± 1.9^{bc}	36.4 ± 0.4^{c}
C16:1	0.8 ± 0.0^{c}	0.8 ± 0.0^{c}	0.7 ± 0.0^{b}	0.6 ± 0.0^{a}	0.6 ± 0.0^{a}
C18:0	3.3 ± 0.2^{a}	4.4 ± 0.5^{b}	6.5 ± 0.4^{c}	6.4 ± 0.4^{c}	7.5 ± 0.5^{d}
C18:1n9c	31.8 ± 0.7^{c}	30.7 ± 0.5^{bc}	30.3 ± 0.2^{b}	30.0 ± 0.4^{b}	28.1 ± 0.9^{a}
C18:2n6c	33.6 ± 0.2^{b}	29.0 ± 1.4^{a}	25.6 ± 0.7^{a}	24.0 ± 0.7^{a}	22.3 ± 0.6^{a}
C18:3n6c	0.5 ± 0.0^{d}	0.4 ± 0.0^{c}	0.4 ± 0.0^{c}	0.3 ± 0.0^{b}	0.2 ± 0.0^{a}
C20:0	0.8 ± 0.1^{a}	1.7 ± 0.0^{d}	1.5 ± 0.0^{c}	1.2 ± 0.2^{b}	1.7 ± 0.5^{bcd}
C20:1	0.2 ± 0.1^{ab}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}	0.3 ± 0.0^{b}	0.2 ± 0.0^{a}
C24:0	0.5 ± 0.1^{a}	0.6 ± 0.0^{b}	0.6 ± 0.0^{b}	0.6 ± 0.0^{b}	0.6 ± 0.0^{b}
SAT	33.1	38.9	42.8	44.8	48.6
MONO	32.8	31.7	31.2	30.9	28.9
POLY	34.1	29.4	26.0	24.3	22.5

Means ± standard deviations ($n = 4$) with different superscript letters within the same row indicate significant differences ($p < 0.05$)

Table 2 Relative percent composition of fatty acids in microencapsulated kenaf seed oil (MKSO) with accelerated storage

Fatty acid	Storage (days)				
	0	6	12	18	24
C14:0	0.4 ± 0.0^{a}	0.4 ± 0.1^{a}	0.3 ± 0.1^{a}	0.4 ± 0.1^{a}	0.4 ± 0.1^{a}
C16:0	26.0 ± 0.8^{a}	24.9 ± 0.8^{a}	24.7 ± 0.6^{a}	25.4 ± 0.7^{a}	25.3 ± 0.9^{a}
C16:1	0.7 ± 0.1^{a}	0.7 ± 0.0^{a}	0.7 ± 0.1^{a}	0.7 ± 0.0^{a}	0.7 ± 0.2^{a}
C18:0	3.3 ± 0.2^{a}	3.1 ± 0.2^{a}	3.1 ± 0.3^{a}	3.2 ± 0.2^{a}	2.9 ± 0.5^{a}
C18:1n9c	33.5 ± 1.2^{a}	34.1 ± 1.3^{a}	33.7 ± 0.6^{a}	33.6 ± 1.0^{a}	34.2 ± 1.0^{a}
C18:2n6c	25.7 ± 0.2^{a}	25.8 ± 1.4^{a}	26.5 ± 0.4^{a}	26.4 ± 0.4^{a}	26.2 ± 0.8^{a}
C18:3n6c	0.4 ± 0.0^{a}	0.5 ± 0.0^{a}	0.5 ± 0.0^{a}	0.5 ± 0.0^{a}	0.5 ± 0.0^{a}
C20:1	0.3 ± 0.0^{a}	0.2 ± 0.1^{a}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}	0.2 ± 0.1^{a}
C20:2	5.0 ± 0.1^{a}	5.0 ± 0.2^{a}	5.2 ± 0.3^{a}	4.8 ± 0.5^{a}	4.7 ± 0.3^{a}
C22:2	4.4 ± 0.4^{a}	4.8 ± 0.7^{a}	4.5 ± 0.3^{a}	4.3 ± 0.2^{a}	4.4 ± 0.2^{a}
C24:0	0.3 ± 0.0^{a}	0.5 ± 0.0^{b}	0.5 ± 0.0^{b}	0.5 ± 0.1^{b}	0.5 ± 0.1^{b}
SAT	30.0	28.9	28.6	29.5	29.1
MONO	34.5	35.0	34.6	34.5	35.1
POLY	35.5	36.1	36.7	36.0	35.8

Means ± standard deviations ($n = 4$) with different superscript letters within the same row indicate significant differences ($p < 0.05$)

the total MUFA and PUFA in kenaf seed oil was found to be decreased significantly ($p < 0.05$) from day 0 to day 24 due to the ease breakage of double bond of unsaturated fatty acids which contribute to lipid oxidation. Despite this, the proportion of saturated fatty acids increased due a decrease in the proportion of unsaturated fatty acids. Table 2 shows that there were no significant changes in all type of fatty acids in MKSO upon storage (Table 2). In spite of this, kenaf seed oil with microencapsulation provided a relatively low and insignificant level of oxidation. In addition, the total contents of MUFA and PUFA in MKSO were higher than in kenaf seed oil at the end of the incubation period. Therefore, from a nutritional point of view, MKSO, which contained a high amount of unsaturated fatty acids, is considered as a good oil source for healthy nutrition. It is more practical for storage due to its potential in the prevention of lipid oxidation.

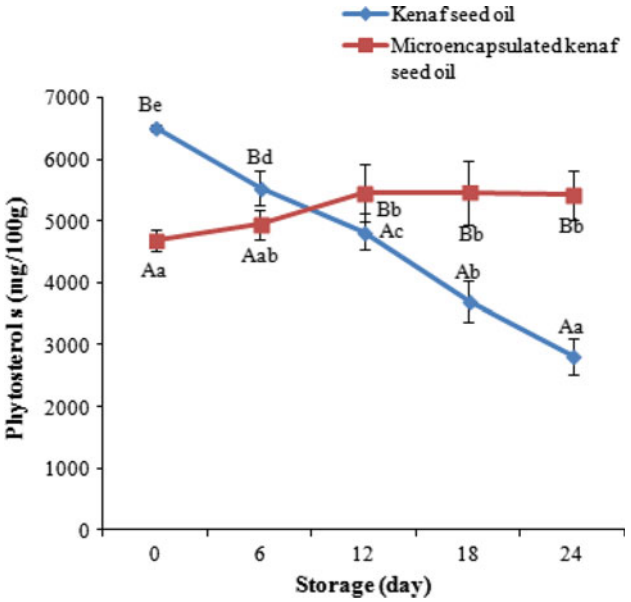

Fig. 1 Phytosterols in kenaf seed oil and microencapsulated kenaf seed oil (MKSO) with accelerated storage. Means ± standard deviations ($n = 4$) with different superscript letters *abcde* indicate significant differences ($p < 0.05$) among different days of the same sample and means ± standard deviations ($n = 4$) with different superscript letters *AB* indicate significant differences ($p < 0.05$) between two samples at the same day of storage

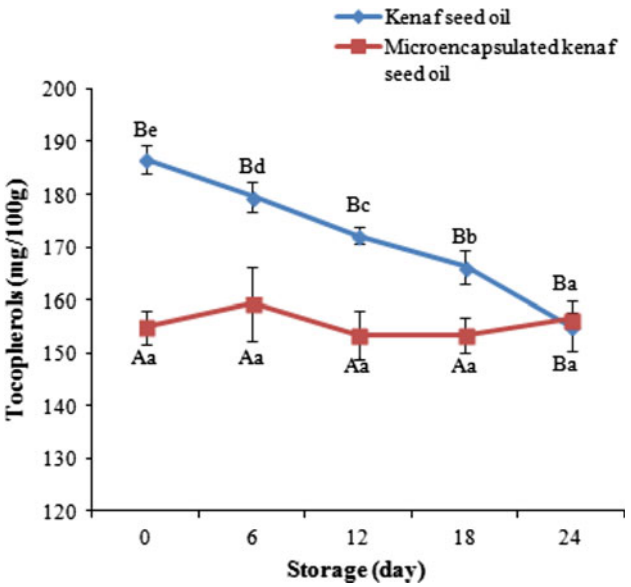

Fig. 2 Tocopherols in kenaf seed oil and microencapsulated kenaf seed oil (MKSO) upon accelerated storage Means ± standard deviations ($n = 4$) with different superscript letters *abcde* indicate significant differences ($p < 0.05$) among different days of the same sample and means ± standard deviations ($n = 4$) with different superscript letters *AB* indicate significant differences ($p < 0.05$) between two samples at the same day of storage

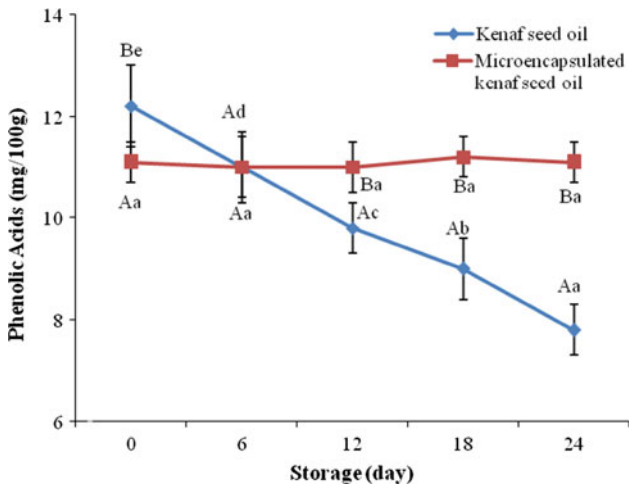

Fig. 3 Phenolic acids in kenaf seed oil and microencapsulated kenaf seed oil (MKSO) upon accelerated storage. Means ± standard deviations ($n = 4$) with different superscript letters *abcde* indicate significant differences ($p < 0.05$) among different days of the same sample and Means ± standard deviations ($n = 4$) with different superscript letters *AB* indicate significant differences ($p < 0.05$) between two samples at the same day of storage

Changes of Phytosterols Content upon Accelerated Storage

In this study, β-sitosterol was the most abundant phytosterol in kenaf seed oil, followed by campesterol and stigmasterol, which agrees with the previous study [16] which reported that the major phytosterols were β-sitosterol (289.9 mg/100 g), followed by 58.1 mg/100 g of campesterol and 23.3 mg/100 g of stigmasterol. Similarly, β-sitosterol was reported to be the main sterol in walnut oil [23] as well as seed parts of wheat [24] and adlay [25]. However, the amount of phytosterols was much higher in this study. This can be ascribed to the environmental factors such as soil conditions, ripeness of fruits or seeds and the length of storage which would affect the concentration of phytosterols [26]. The cultivation of new breeding lines was reported to have little effect on the concentration of phytosterol as well [27]. The phytosterols content in both samples is presented in Fig. 1. On day 6, the total phytosterols in kenaf seed oil and MKSO obtained was 5,541.3 ± 271.7 mg/100 g and 4,938.7 ± 244.6 mg/100 g, respectively. Meanwhile, the total phytosterols in kenaf seed oil was still relatively higher than the total phytosterols in MKSO from day 0 to day 6. After 12 days of storage, no significant difference ($p > 0.05$) was found in the total phytosterols in kenaf seed oil (4,829.0 ± 294.5 mg/100 g) and MKSO (5,447.0 ± 462.8 mg/100 g). The phytosterols content in kenaf seed oil (3,697.5 ± 337.5 mg/100 g) was found to be lower than MKSO (5,459.8 ± 512.4 mg/100 g) after

18 days of storage. The total phytosterols content in kenaf seed oil decreased to 2,818.6 ± 285.4 mg/100 g at day 24 while the total phytosterols content of MKSO was 5,421.7 ± 395.1 mg/100 g, which did not change significantly. The degradation of phytosterols caused the significant decrease ($p < 0.05$) in total phytosterols in kenaf seed oil without microencapsulation.

Changes in Tocopherols Content upon Accelerated Storage

Upon accelerated storage, the trend of the results also showed that the amount of tocopherols in bulk kenaf seed oil was significantly higher ($p < 0.05$) than the amount of MKSO until day 18. However, the difference between both kenaf seed oils got smaller as the day increased due to the degradation of total tocopherols in bulk kenaf seed oil. On the last day of storage (day 24), no significant difference ($p > 0.05$) was found between the total tocopherols content in kenaf seed oil (155.1 ± 4.8 mg/100 g) and MKSO (156.4 ± 1.3 mg/100 g). The total tocopherols content in kenaf seed oil decreased significantly ($p < 0.05$) every 6 days of storage until the day 24. In contrast, there were no significant changes in the tocopherols content in MKSO throughout the storage time. Results showed the trend of decreasing in total tocopherols content in kenaf seed oil was due to oxidation and degradation of oil without microencapsulation. Therefore, in this study, microencapsulation was shown to prevent tocopherol oxidation and degradation upon accelerated storage as well as maintaining the shelf life of the oil. In this study, γ-tocopherol was more predominant than α-tocopherol and there was no detection of δ-tocopherol in bulk kenaf seed oil and MKSO. The result obtained in this study agrees with the previous study [16], which reported that the γ-tocopherol was more predominant than α-tocopherol, which were 63.9 mg/100 g and 20.0 mg/100 g of the total lipids, respectively. Oils extracted from seeds were reported to contain predominantly the γ-tocopherol (>70 %) [28]. α-Tocopherol is the most biologically active form of vitamin E and functions as an antioxidant in preventing the oxidation of lipids including the polyunsaturated fatty acids and lipid components of cells and organelle membranes [16]. Therefore, it was found that no significant changes ($p > 0.05$) were found in the unsaturated fatty acids in the MKSO due the retention of the tocopherol content in the MKSO which acts as an antioxidant to prevent oxidation.

Changes of Phenolic Acids Content upon Accelerated Storage

The main phenolic acids in kenaf seed oil were determined, namely gallic acid, benzaldehyde, benzoic acid, caffeic acid, vanillic acid, ferulic acid and protocatechuic acid. Results showed that vanillic acid was the predominant phenolic acid, followed by caffeic acid and gallic acid, results which were similar to preliminary studies [16]. However, after 6 days of storage, the phenolic acids content in kenaf seed oil without microencapsulation, decreased significantly ($p < 0.05$) to 11.0 ± 0.6 mg/100 g and then having no significant difference ($p > 0.05$) with MKSO which was 11.0 ± 0.7 mg/100 g. It was determined that total phenolic acids in kenaf seed oil continued to decrease significantly ($p < 0.05$) every 6 days of storage until day 24, which were then 9.8 ± 0.5 mg/100 g (day 12), 9.0 ± 0.6 mg/100 g (day 18) and 7.8 ± 0.5 mg/100 g (day 24), respectively. This demonstrates that the degradation of phenolic acids varied with storage time. As the phenolic acids degrade, there will be slighter antioxidant activity, which can provide protection against oxidation in oil which was also reported from the study of oxidative stability on *Camelina sativa* oil during storage [29]. Thus, the content of polar phenolic compounds in the oil stored at 65 °C decreased more progressively. The total phenolic acids in MKSO remained stable, with no significant differences ($p > 0.05$) throughout the 24 days of accelerated storage, the values of which were 11.1 ± 0.4 mg/100 g (day 0), 11.0 ± 0.7 mg/100 g (day 6), 11.0 ± 0.5 mg/100 g (day 12), and 11.2 ± 0.4 mg/100 g (day 18), respectively. At the end of storage (day 24), the total phenolic acids content in MKSO was 11.1 ± 0.4 mg/100 g which was 42 % more than the total phenolic acids content in kenaf seed oil (7.8 ± 0.5 mg/100 g) without microencapsulation. This proves the efficiency of the microencapsulation technique in preventing the lost of bioactive compounds.

Conclusion

Without microencapsulation, the MUFA and PUFA in kenaf seed oil were found to decrease over the 24-day accelerated storage due to the lipid oxidation process that breaks down the double bond of both MUFA and PUFA. Moreover, the contents of bioactive compounds, such as phytosterols, tocopherols and phenolic acids in the kenaf seed oil were also found to have significantly decreased ($p < 0.05$) upon accelerated storage, which indicated that the degradation of kenaf seed oil occurred without the protection of wall materials. However, there was a loss of some bioactive compounds in MKSO during the spray drying process. The bioactive compounds that remained in the MKSO were preserved over the accelerated storage condition. The phytosterols content of MKSO was discovered to be significantly increased ($p < 0.05$) from day 0 to day 24. In addition, the tocopherols and phenolic acids

that contained in the MKSO did not change significantly ($p > 0.05$). Thus, the results of this study demonstrate that the microencapsulated kenaf seed oil produced by spray drying was resistant to lipid oxidation, as well as being resistant to the degradation and/or loss of bioactive compounds.

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