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Impact of Single Wavelength (532 nm) Irradiation on the Physicochemical Properties of Sesame Oil

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Abstract

This paper investigates the influence of green laser (532 nm) radiation on some physicochemical properties of sesame oil before and after storage period of 15 consecutive days. The samples of sesame oil were irradiated with diode laser beam with wavelength 532 nm and 1 W output power, to duration times of 10, 20, 30, 40, 50 and 60 minutes, and kept for a storage period of 15 consecutive days along with an untreated control at ambient conditions. Physicochemical properties like acid value, ester value, free fatty acids, peroxide value, density, refractive index, viscosity, and moisture of sesame oil were studied. Fourier transform infrared spectroscopy was used to evaluate the degree of oxidation after irradiation processes. Their properties were compared at the 1st and 15th day of storage. Study reveals that green laser irradiation increases ester value, saponification, acid value, free fatty acids, peroxide value, viscosity and moisture content of sesame oil; while, it slightly changes refractive index and density. Study also indicates that the storage period of 15 days decreases the ester value, saponification value, and moisture content; while, it accelerates acid value, free fatty acid, peroxide value, density viscosity, and slightly increases the refractive index. Meanwhile, FTIR spectra of the stored samples revealed a notable difference due to the green laser irradiation and storage. These results suggest that exposing sesame oil to the green laser irradiation influences their oxidation stability and quality.

Keywords

Edible Oils, Food Irradiation, Physicochemical Characteristics, Quality Constants, Sesame Oil

1. Introduction

Electromagnetic radiations and electrons are used in food irradiation process, whereas, extensive damage was caused to food when treated with some other types of radiations like neutrons, deuterons and α-rays [1]. Electromagnetic radiation caused various chemical and physical changes when it interacts with materials [2]. Light plays a photochemical initiator role and is capable to inducing photochemical reactions when exposed to food [3]. The mechanism of the photochemical oxidation of vegetable oils has been extensively studied [4] [5]. Recently, several researchers studied the impact of laser matter interaction; which could happen with metal, tissue, ceramic or food [6] [7] [8] [9] [10].

Irradiation technology usage in food preservation grew a large interest, because of its efficiency and its potential application. Various benefits are obtained with the use of irradiation such as protecting meats from pathogenic microorganism and increase their shelf lifetime. Likewise, irradiation produces structural changes in many nutrients [11]. In addition, irradiation of milk and yoghurt improves their shelf life [12] [13].

Changes in nutritional and organoleptic characteristics of foods are due to the carbonyl compounds produced from the interaction of the free radicals formed by irradiation of unsaturated fatty acids and oxygen. Irradiation plays an important role in the storage life of food and enhances the safety by reducing pathogenic and spoilage microorganisms [14]. Various chemical and physical parameters of edible oil are utilized to monitor the compositional quality of oils [15] [16]. The chemical changes in the oil lead to physical changes like viscosity and density, darken color, production of foam [17].

Sesame (*Sesamum indicum L.*) is a source of excellent vegetable oil; it is one of the highest oil contents (35% - 63%) among oil crops [18] [19]. The presence of some natural antioxidants such as sesamum, sesamin, sesamolin, and sesamol in the sesame oil makes them one of the most stable vegetable oils in the world [20]. The oil of the sesame seed is very resistant to rancidity especially after hydrogenation due to the presence of natural antioxidants [21]. Until now, to the best of our knowledge, researchers studied the effects of different portions of electromagnetic radiation such as gamma, X-ray, sunlight and infrared on the physicochemical characteristics of edible oils; but they have not studied the effect of the single wavelength. In this work, we tried to determine the effect of green diode laser (532 nm) irradiation on the physicochemical characteristics of sesame oil before and after storage period of 15 consecutive days.

2. Materials and Methods

2.1. Material

Sesame oil was obtained from the local market in Khartoum, Sudan. Seven samples of sesame oil were taken with amount of 50 ml for each sample. Then the following processes were done.

2.2. Laser Irradiation

The irradiation process was done using diode laser (Green Laser Pointer 303, China) with a wavelength 532 nm and output power 1 Watt, while the oil samples were placed in open beaker with a capacity of 100 ml on magnetic stirring at room temperature. The distance between the oil and the end of the laser was 1 cm. Six samples were exposed to the laser beam at different time durations, namely 10, 20, 30, 40, 50 and 60 minutes, the seventh one was left to be control sample with duration time of exposure equal to 0 minutes.

2.3. Physicochemical Properties Characterization

The characterization of the stored and non-stored sesame oil samples physicochemical properties: acid value, ester value, free fatty acids, peroxide value, density, refractive index, viscosity, and moisture; was carried out according to the methods described in the [22]; All tests were performed in triplicate. The measurement of these parameters was repeated after two weeks storage at ambient conditions, for radiated and control samples, in order to determine their relative stability.

2.4. FT-IR Characterization

FT-IR spectra of irradiated and non-radiated sesame oil samples after the storage period were carried out using a Fourier Transform Infra-Red Spectrometer (IR Spirit, Shimadzu, Japan). It is used to compare the chemical structure of the irradiated and un-irradiated sesame oils samples after the storage period for monitoring the oxidation process in oils.

3. Results and Dissections

The exposure of oils to sunlight (with its all wavelengths) can induce photooxidation in the oils in two ways: 1) A direct photochemical reaction occurs with the photons from the high-intensity sunlight rays, being directly absorbed and causing a change in the oil's chemical composition [23]. The oil undergoes a photochemical change, and the C-C bond dissociates into radicals. The free radical state is unstable and readily reacts with atmospheric triplet oxygen, which initiates the oxidation of the oil [4]. 2) The second way in which oxidation could occur is referred to as photosensitised oxidation, which is triggered by the presence of photosensitisers in oils [24]. In this study, laser irradiation of sesame oil samples were investigated for the changes in the physicochemical properties like acid value, ester value, free fatty acids, peroxide value, density, refractive index, viscosity, and moisture content. The results of these properties were compared at the 1st and 15th day of storage.

3.1. Physicochemical Properties

The variations in the effects of laser irradiation durations time on the physical and chemical characteristics of sesame oil are presented in **Figures 1-7**.

3.1.1. Results of the Chemical Properties

Figure 1(a) shows that the initial ester value of the sesame oil was 185.29 mg

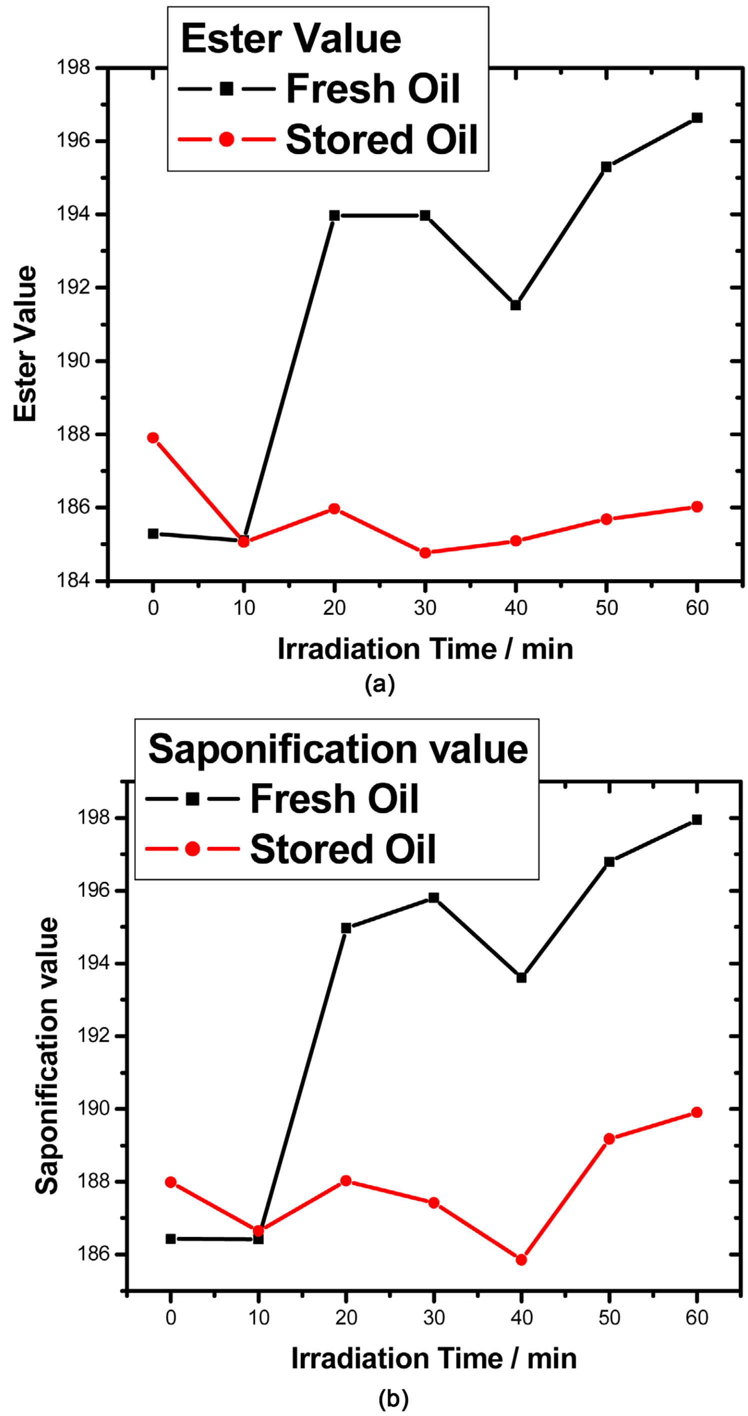


Figure 1. Effect of green laser irradiation time on (a) Ester value; (b) Saponification value of fresh and stored sesame oil.

KOH/g; whereas, after irradiation to 10 minute using laser it slightly decreased to 185.10 mg KOH/g; when increasing of 532 nm laser irradiation time from 20 to 60 minutes, it gradually increased to the range from 191.52 to 196.63 mg KOH)/g. After storage period of 15 consecutive days; the ester value of the control sample raised to 187.91 mg KOH/g; whereas, the ester value of all irradiated

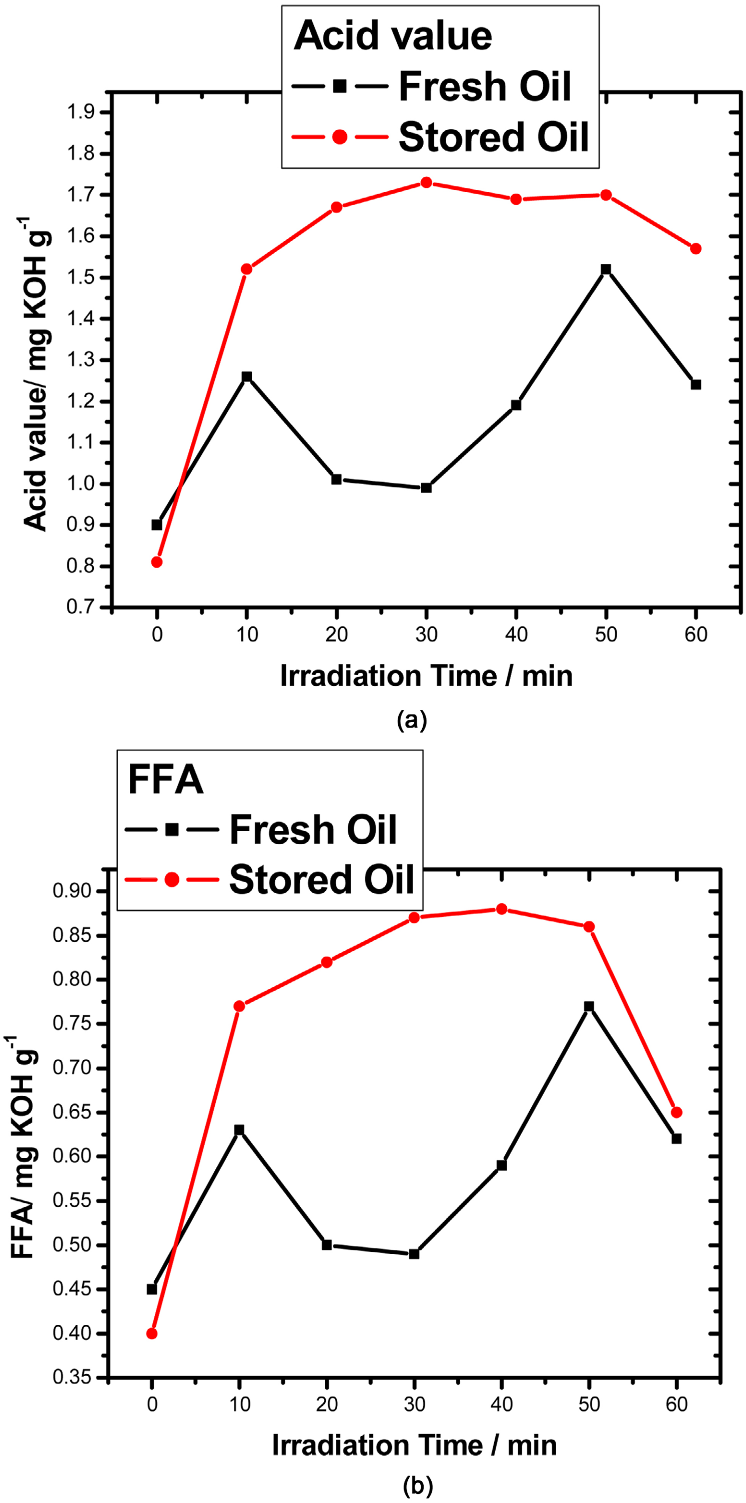


Figure 2. Effect of green laser irradiation time on (a) Acid value; (b) Free Fatty Acids (FFA) of fresh and stored sesame oil.

sesame oil samples reduced and became close to the initial value of the sesame oil 185.29 mg KOH/g.

The obtained saponification value of the oil samples in Figure 1(b), showed

186.43 mg KOH/g for the control sample before storage and it ranged from 186.42 to 197.95 mg KOH/g for the laser irradiated oil samples. These values are lying in the expected range of 186 - 195 mg KOH/g for sesame oil as specified by Codex Standard (2001) [25]. The highest saponification value indicates a high content of triacylglycerol, consistent with the high ester value [26]; this is why graph in **Figure 1(a)** matching graph in **Figure 1(b)**.

Figure 2(a) shows acid values of irradiated and non-irradiated sesame oil samples; it indicates that the acid value of the control sesame sample found to be 0.9 mg KOH/g oil; which is lower than that reported for Brazzaville-Congo sesame oil (1.8%) [27]. While the irradiated samples, were very small between 0.99 and 1.26%. All other irradiated sesame oil exhibit acid values greater than the acid values of the control sample and lies within desirable limits 0.0 - 4.0 mg KOH/g oil [18]. After the storage period, the acid vale of the control sample slightly decreased, while the irradiated samples showed acid values higher than before storage period. It can be noticed that the acid value of irradiated sesame oil samples before and after storage period lie within the desirable range.

Free fatty acids of the irradiated and control samples before and after storage period are shown in **Figure 2(b)**. Its value was 0.45% for the control sample and it ranged from 0.49 up to 0.77% for the irradiated samples. While it decreased to 0.40% for the control sample and ranged from 0.65% - 0.88% for laser irradiated samples after a storage period of two weeks. The data indicates the increase in free fatty acids with the presence of radiation due to the photochemical interaction that catalyzed by the visible green laser photons which convert triglycerides into free fatty acids. Free fatty acids are produced by the hydrolysis of fats in the presence of water or enzyme lipase during storage [28].

Acid value is the measure of percentage content of free fatty acids (FFAs) in a substance, and it is an important reference parameter to determine the conservation quality of fat and oils [29]. Acid value of oil is an indicator of hydrolytic rancidity [30]. The acid value is related with the lipase activity and hydrolysis of triacylglycerols in the seed [31].

Peroxide value is one of the most widely used tests for oxidative rancidity; it measured the concentration of peroxides and hydroperoxides formed in the initial stages of lipid oxidation.

The effect of increasing laser irradiation time on the peroxide value of sesame oil before and after storage period is presented in **Figure 3**. It shows that the peroxide values ranged from 4.01 to 11.86 Meq/Kg in fresh oils and from 5.70 to 12.47 in the stored oils. It indicates that the laser initiate oxidation processes in sesame oil. Peroxide values of all oil samples after the storage period is higher than they were before the storage period. It is also clear from the data that the peroxide value increases with increasing radiation durations; this peroxide value increase can be due to the bond cleavage of sesame oil. Peroxide values for all oil samples studied showed levels value lower than the (20.0 meq O_2/kg) limitation in the standard for sesame oil. The storage of irradiated lipid food, in the

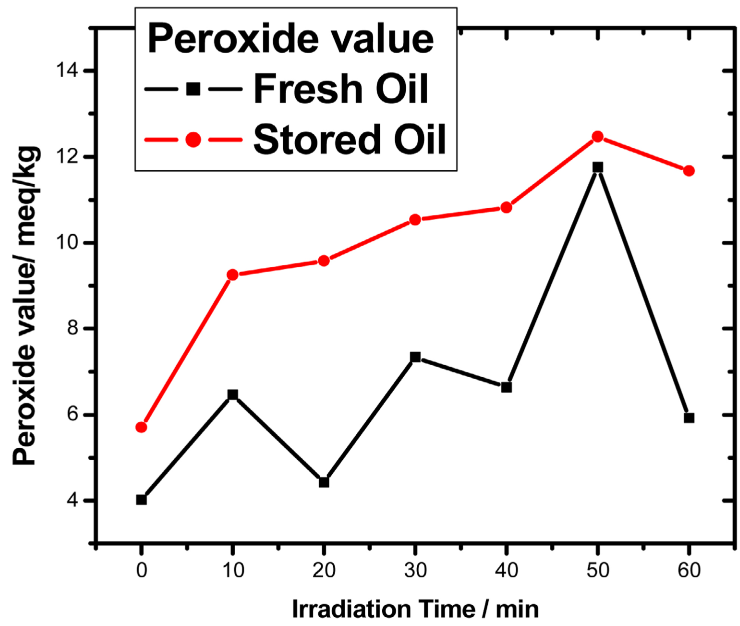


Figure 3. Effect of green laser irradiation time on the peroxide value of fresh and stored sesame oil.

presence of oxygen, accelerates the autoxidation [32]. It has been proved that irradiation accelerates the oxidation of unsaturated fatty acids and cholesterol during storage of foods [33] [34]. The chemical changes leads to physical changes as reported by Ku, *et al.*

3.1.2. Results of the Physical Properties

The chemical changes of the sesame oil samples due to laser radiation processing and during the storage time lead to some physical changes.

The effect of increasing laser irradiation time on the refractive index of sesame oil before and after storage period is presented in **Figure 4**.

Refractive index is an important optical parameter to analyze the light rays traversing through materials medium. Refractive index can be used as a quality control technique to identify the adulteration of edible oils. From the obtained results it is found that laser irradiation slightly affect the refractive index of the fresh sesame oil samples in the range from 1.4684 to 1.4784. While, it is found that, refractive index of the stored sesame oil samples higher than it before storing ranged from 1.4773 to 1.4898, and most of them excesses the recommended codex standard of 1.469 - 1.479 for sesame oil.

The initial density of the fresh sesame oil was 0.9173 cm^{-1}; when it irradiated by laser, it ranged between 0.9188 and 0.9157 cm^{-1}, it fall in the recommended codex standard of 0.915 - 0.924 cm^{-1} for sesame oil. While after the storage period it increases and ranged from 0.9182 to 0.9272 cm^{-1}, with two samples slightly excesses the recommended codex standard, see **Figure 5**.

Figure 6 illustrates the effect of increasing 532 nm laser irradiation time on the sesame oil viscosity before and after storage. The viscosity of the control

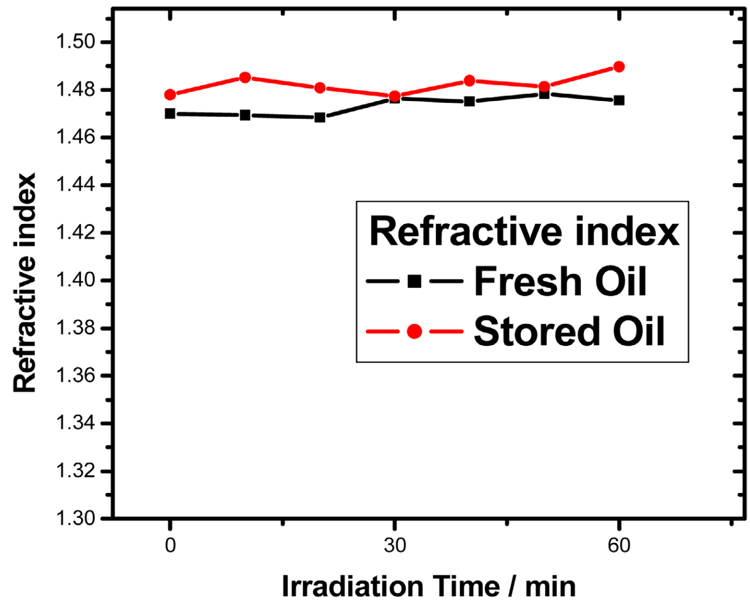


Figure 4. Effect of green laser irradiation time on the refractive index of fresh and stored sesame oil.

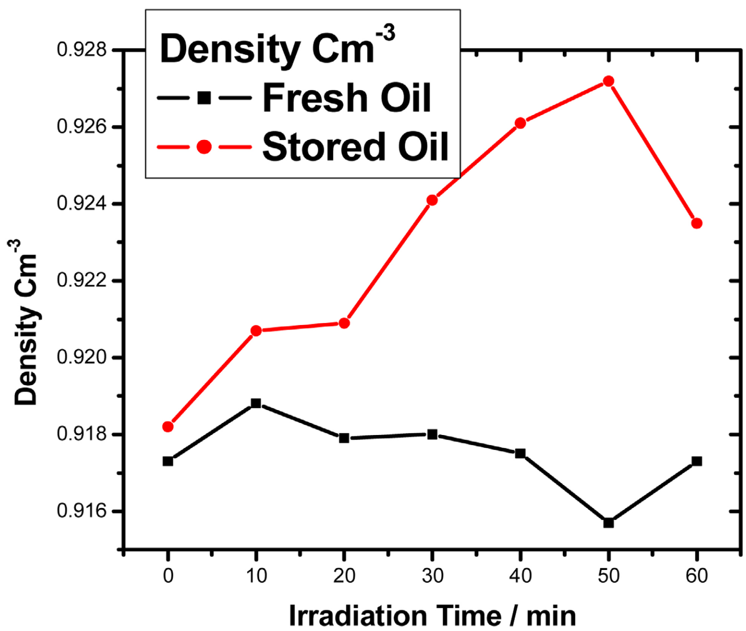


Figure 5. Effect of green laser irradiation time on the density of fresh and stored sesame oil.

sample was 61.16 cP, after the stored period it increased to 61.32 cP. Meanwhile, the viscosity of the irradiated samples increased to range 61.87 to 61.47 cP. After the stored period it observed that there is a gradually increase in the viscosity with the increase of the irradiation time of all samples from 61.32 to 62.25 cP.

Viscosity is related to the chemical properties of the oils. The increase in viscosity of emulsions when irradiated can be explained by unavoidable evaporative loss of volatile contents of oil. Formation of smaller oil micelles during irradiation not only has physical significance in terms of stability but also has effects on viscosity. Smaller micelles promote viscous emulsions due to more particle-particle interactions as a result of a larger interfacial area [35].

The effect of increasing 532 nm laser irradiation time on the sesame oil moisture, before and after the storage period is shown in Figure 7. It is clear from the data that the moisture of the sesame oil increases with increasing irradiation

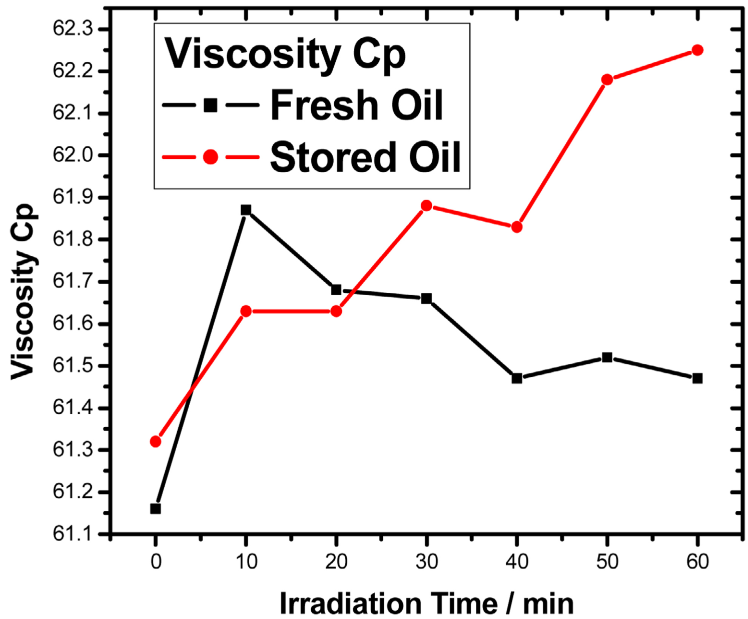


Figure 6. Effect of green laser irradiation time on the viscosity of fresh and stored sesame oil.

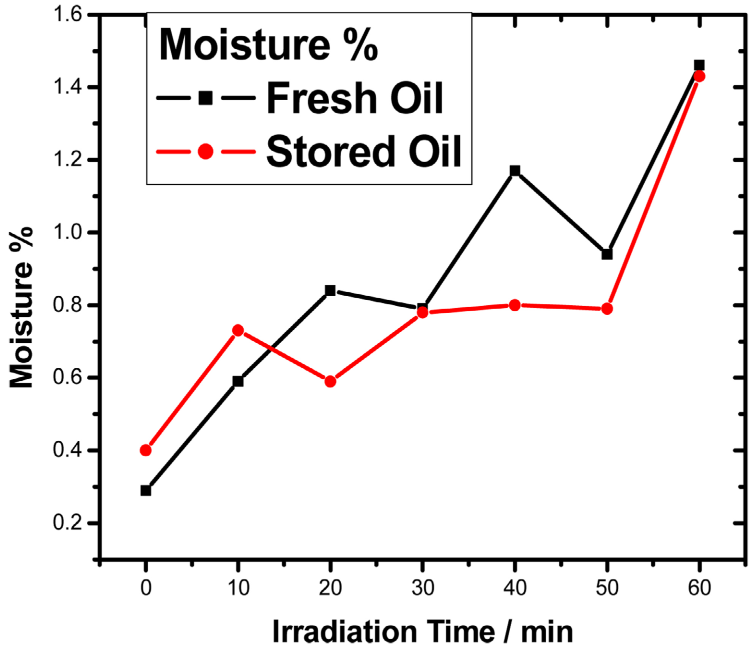
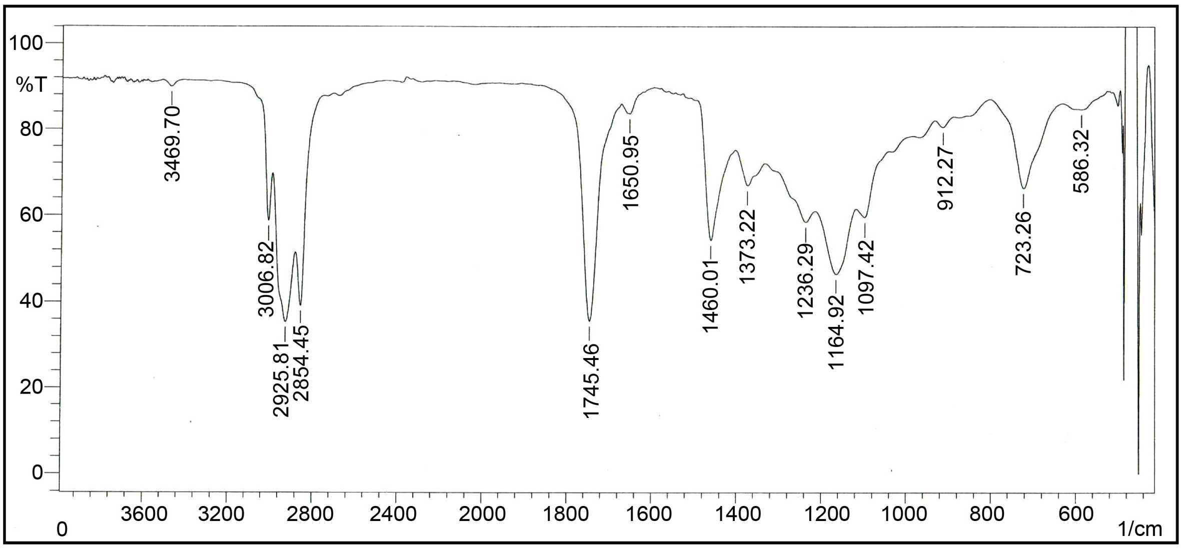
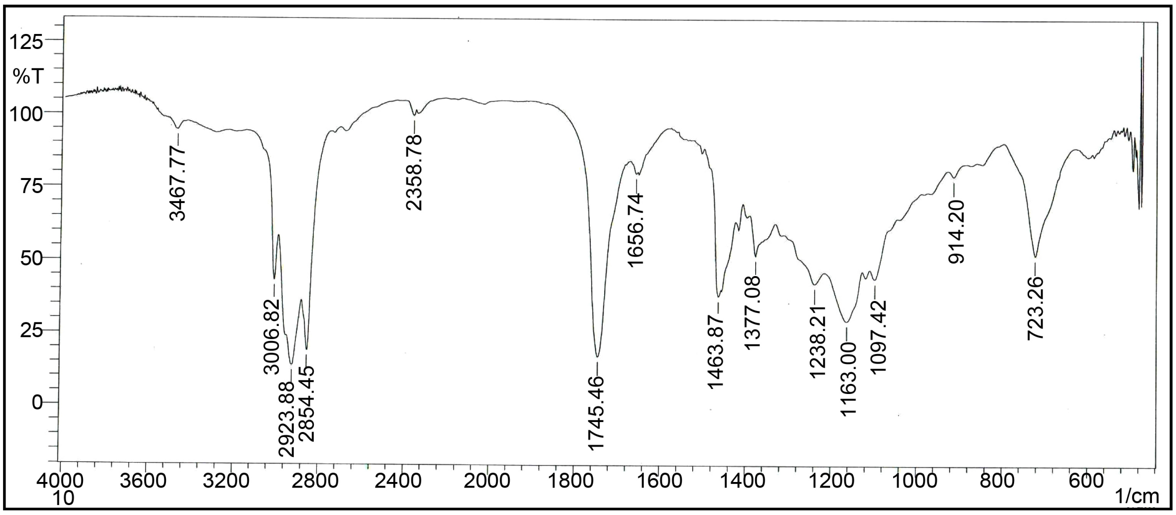


Figure 7. Effect of green laser irradiation time on moisture of fresh and stored sesame oil.


%T
3469.70
3006.82
2925.81
2854.45
1745.46
1650.95
1460.01
1373.22
1236.29
1164.92
1097.42
912.27
723.26
586.32
1/cm

(a)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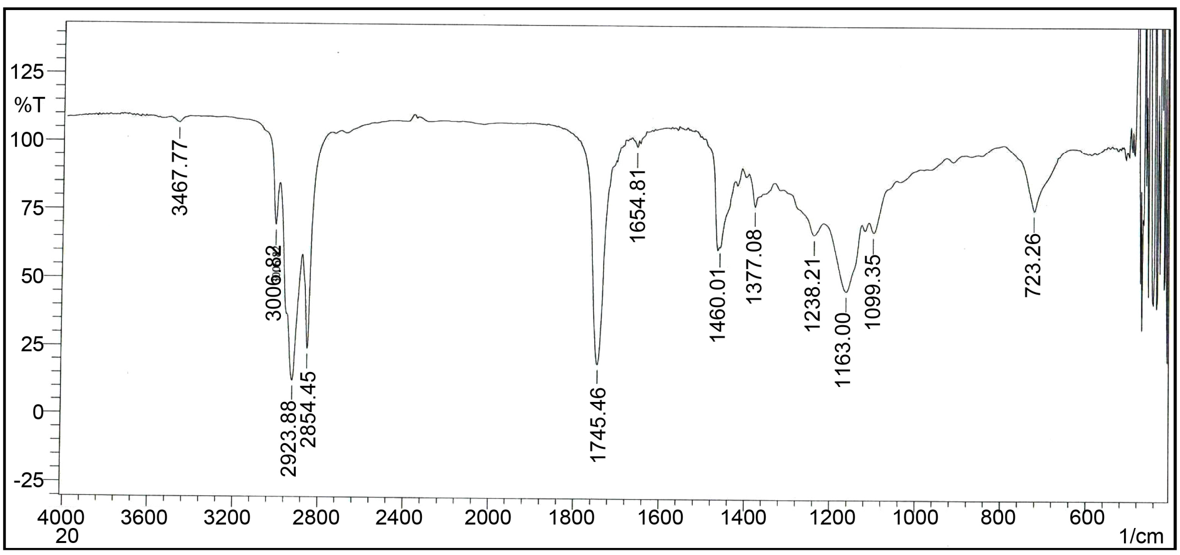
(b)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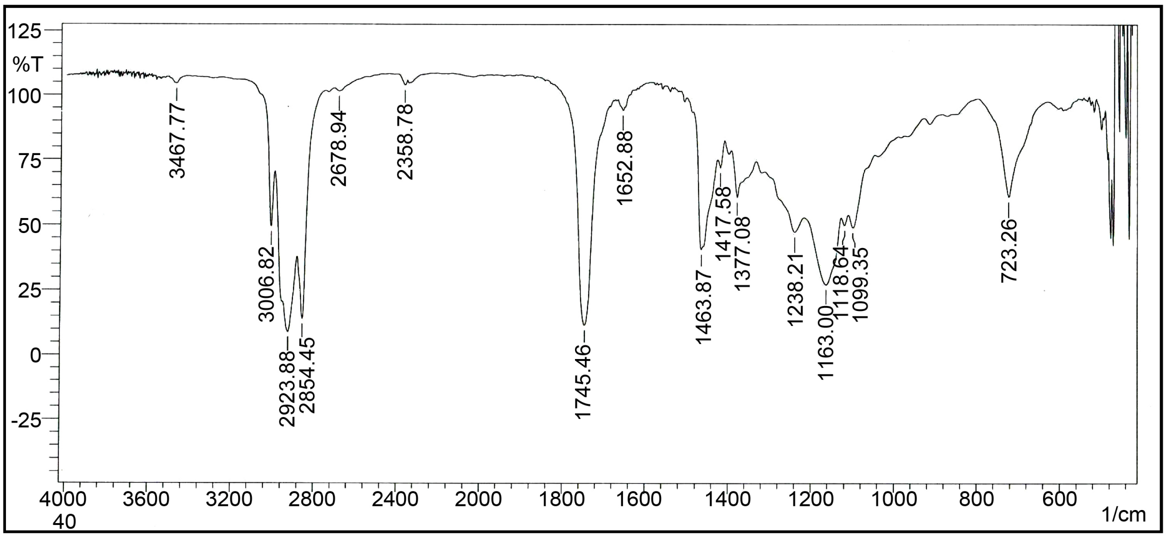
1163.00
1099.35
723.26
1/cm

(c)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1463.87
1417.58
1377.08
1238.21
1163.00
1118.64
1099.35
723.26
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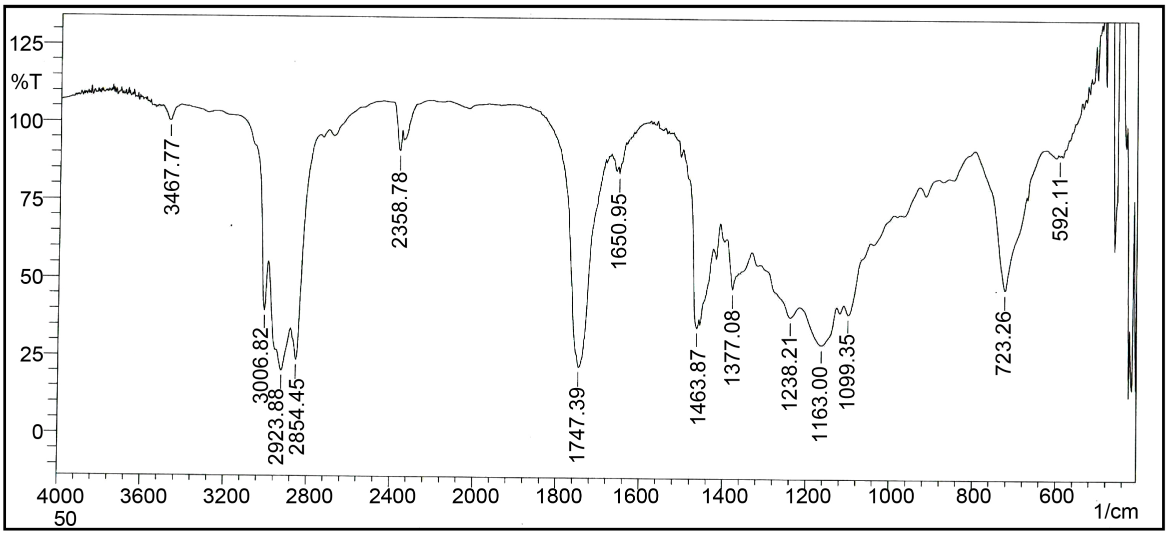
(d)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1163.00
1099.35
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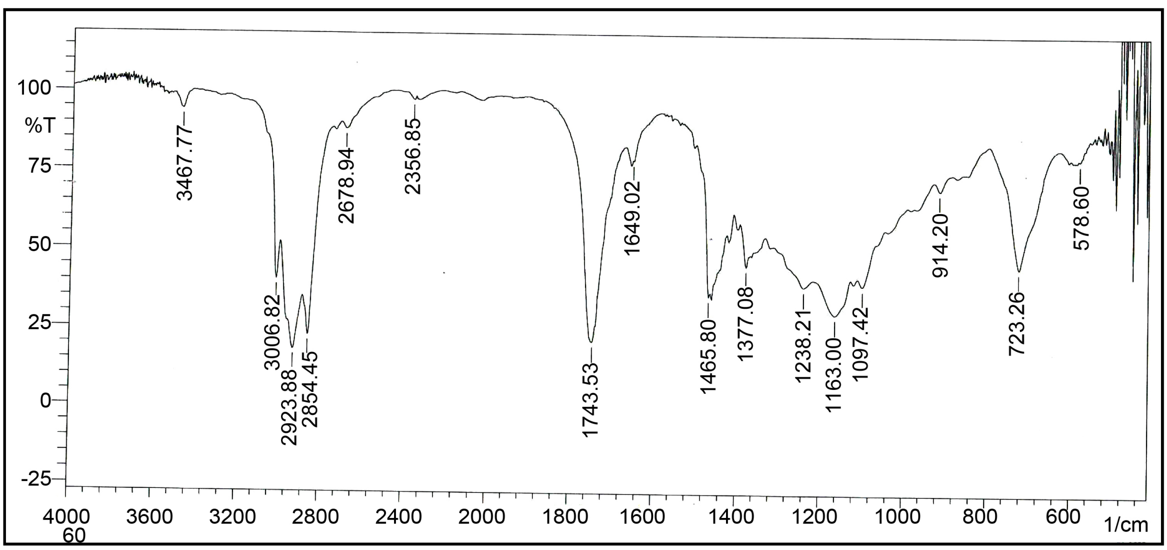
(e)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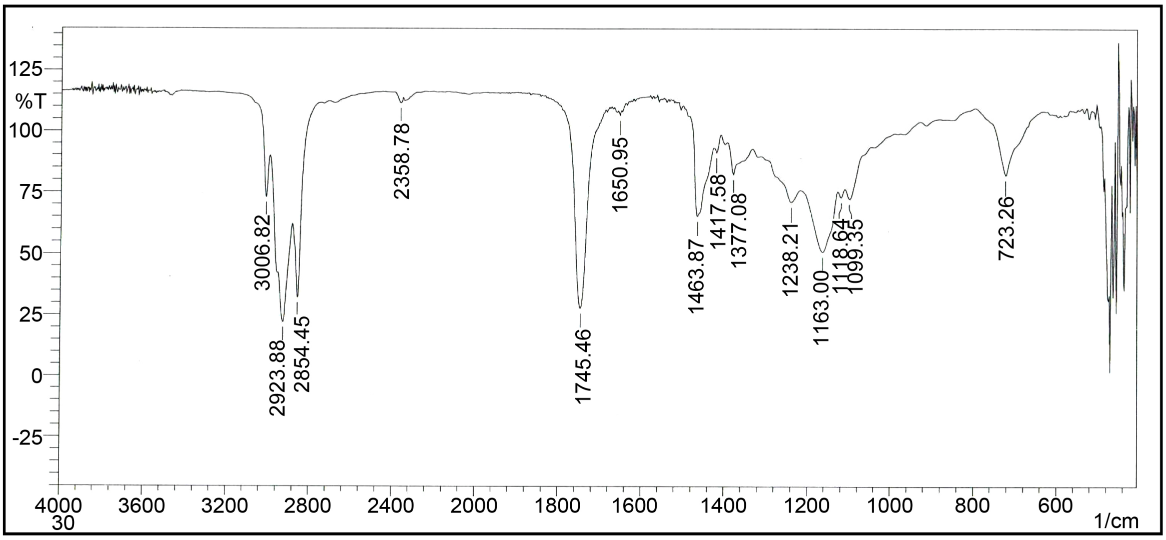
3006.82
2923.88
2854.45
2678.94
2356.85
1743.53
1649.02
1465.80
1377.08
1238.21
1163.00
1097.42
914.20
723.26
578.60
4000
60
3600
3200
2800
2400
2000
1800
1600
1400
1200
1000
800
600
1/cm

(f)



(g)

Figure 8. FT-IR spectrum of the irradiated sesame oil samples: (a) control (00 minutes); (b) 10 minutes; (c) 20 minutes; (d) 30 minutes; (e) 40 minutes; (f) 50 minutes; and (g) 60 minutes.

time before and after storage. The moisture of the control sample was 0.29%, which increased gradually to 1.46% with increasing the irradiation time. Likewise, after the storage period the moisture increased gradually from 0.40% in the control sample up to 1.43% with increasing the irradiation time.

3.2. FIR Results

FT-IR spectroscopy is a very good technique for analysis, as the intensities of the bands in the spectrum are proportional to concentration. FT-IR spectra of the control and laser irradiated samples after the storage period are presented in Figure 8.

It showed that there exists a notable difference in the bands between the control and laser irradiated samples appeared during the storage period. The spectra of the stored irradiated oil samples containing several absorption bands, that are absent from the spectrum of the control sample. The first new band is occurs in 2688.94 cm^{-1} shift in the spectra of the high-irradiated samples (40, 50, and 60 minutes). The other new band is appears at 2358.78 cm^{-1}, 11417.58 cm^{-1}, and 1118.64 cm^{-1}.

4. Conclusion

In this paper, the influence of green laser (532 nm) radiation on some physicochemical properties of sesame oil before and after storage period of 15 consecutive days was investigated. It was found that the green laser is capable to make changes in the physicochemical properties of sesame oil different from that occur by the visible light. Laser irradiation leads to photochemical interactions that change the chemical and physical properties of the oil. Moreover, storing to period of two weeks also caused changes in the physicochemical properties of sesame oil. All changes due to laser irradiation fall in the recommended codex standard (2001). Fourier transform infrared spectroscopy results confirm the physicochemical changes.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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