Open Access Library Journal
2022, Volume 9, e8883
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Evaluation of Laser-Heating and Laser-Reheating of Sunflower (*Helianthus annuus*) Seed Oil Quality

Alaa Ahmed Mudawi, Ali A. S. Marouf*

Institute of Laser, Sudan University of Science and Technology, Khartoum, Sudan
Email: alisaeed@sustech.edu, *marouf.44@gmail.com

How to cite this paper: Mudawi, A.A. and Marouf, A.A.S. (2022) Evaluation of Laser-Heating and Laser-Reheating of Sunflower (*Helianthus annuus*) Seed Oil Quality. *Open Access Library Journal*, **9**: e8883.
https://doi.org/10.4236/oalib.1108883

Received: May 15, 2022
Accepted: June 19, 2022
Published: June 22, 2022

Abstract

This paper focuses on the difference between the effect of heating and reheating on sunflower oil properties by using carbon dioxide laser and electrical heater. Two samples of sunflower oil were heated and reheated with carbon dioxide laser beaming up to 50˚C, which takes 30 minutes; another two samples were heated and reheated up to 250˚C using electrical heater in two minutes, along with an unheated control sample at ambient conditions. Chemical properties like acid value, free fatty acids, peroxide value, saponification value and ester value beside physical properties such as moisture, density, viscosity, refractive index and color measurements of sunflower oil were studied. Fourier transform infrared spectroscopy was used to differentiate between the chemical changes in the samples. The results demonstrate that when the same cooking oil is reheated, the chemical reactions enhance foaming, darkening of oil color, increased viscosity, and off-flavor. Hence, repeated heating of the oil can lead to degradation of the cooking oil, both chemically and physically. It was found that the long time of heating using laser rising temperature up to 50˚C catalyzed chemical reactions that resulted in effects in the oil samples characteristics greater than the effects of the electrical heater in a few minutes with temperature 250˚C.

Subject Areas

Composite Material, Nanometer Materials

Keywords

Food Irradiation, Laser-Heating, Laser-Reheating, Physicochemical Characteristics, Quality Constants, Recycled oils, Thermal Oxidation

1. Introduction

Laser heating has been recognized since the 1970s, focusing on the CO_2 laser. Utilizing CO_2 laser allows non-metallic materials to be heated directly. CO_2 laser with a wavelength of 10.6 μm equates to the photon energy of 943 cm^{-1}, which is of the same order as lattice phonons in covalent crystals and is absorbed by existing lattice vibrations. This absorption technique also provides the advantage of more uniform heating for the materials that are generally transparent to the wavelength of 10.6 μm, meaning that heating is provided via this process throughout the entire thickness of the sample, contrarily in metallic materials where the laser beam is absorbed primarily at the surface [1].

Several studies were done in different applications of the laser heating techniques such as in thermoluminescence imaging of spatial dose distributions of ionizing radiation and the measurement of two-dimensional temperature distributions in high-power laser dielectric coating [2]. Some researchers studied laser-heating in the combustion of agricultural wastes [3] [4] [5]. Other researchers used it in enhancing the ceramic mechanical properties [6] [7]. Numerous studies were done by using lasers in food irradiations such as milk pasteurization [8] [9], production of yogurt [10], oil irradiation [11] and irradiation of bee honey [12]. Very promising results for applications involving non-destructive detection and classification of materials were obtained by Kassu *et al.* 2021 [13].

Edible oil is a vital component of our daily diet. It provides energy and essential fatty acids, and serves as a carrier of fat-soluble vitamins. Edible oils such as sunflower (*Helianthus annuus*) oil are continuously used for deep-fat frying. Usage of the same frying oil repeatedly is a common practice in the household or the restaurants to save costs. The methods used in assessing the quality of cooking oil and discarding it are observing foam, color turning dark or when it emits a bad odor [14]. Chemical reactions such as thermal polymerization, hydrolysis and oxidation occur when cooking oil is heated during the deep-frying process [15]. Using reheated edible oil is unhealthy. Edible oil is subjected to high temperatures for long periods in the process of frying food; this practice yields lipid peroxidation products, which is harmful to human health [16].

In this work, we tried to determine the effect of carbon dioxide laser (10,600 nm) heating and reheating on the chemical and physical characteristics of sunflower oil compared with the effect of electrical heater heating and reheating, in order to determine the most healthy heating method for cooking.

2. Materials and Methods

2.1. Material

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

2.2. Heating Process

One of the five sunflower oil samples was heated to 250˚C using electrical heater.

The second sample was heated twice to the same degree (250˚C) using electrical heater; it was left to cools to the room temperature then reheated; it takes two minutes in heating and in reheating. The third sample was heated to 50˚C using laser irradiation. The fourth sample was heated twice to the same degree (50˚C) using laser irradiation; it was left to cools to the room temperature then reheated. The irradiation process was done using carbon dioxide laser (CO_2) (Model IB-601B, Beijing Innobri Technology, China) with wavelength 10,600 nm and output power 30 Watt, with duration time of exposure equal to 30 minutes. The sunflower oil sample was 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. The fifth one was left to be control sample.

2.3. Physicochemical Properties Characterization

Physicochemical properties such as acid value, ester value, free fatty acids, peroxide value, density, refractive index, viscosity, and moisture of the five sunflower oil samples were characterized according to the methods described in the A.O.A.C. 1990 [17]; All tests were performed in triplicate.

2.4. Determination of Oil Color

Color measurement of the oil samples was determined using a Lovibond Tintometer (Model E AF900 (The Tintometer Ltd.)) as units of red, yellow and blue according to the AOAC method [17]. Each visual measurement of every sample was taken in triplicate.

2.5. FT-IR Characterization

FT-IR spectra of the five sunflower oil samples were carried out using a Fourier Transform Infra-Red Spectrometer (Shimadzu, Japan). It is used to compare the chemical structure of the different five sunflower oils.

3. Results and Dissections

Due to repeated heating, the quality, color, smell and taste of edible oil changes due to the formation of polymers and polar compounds [18].

In this study; the effects of heating and reheating of the sunflower oil samples using electrical heater and carbon dioxide laser 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 with the unheated sample.

3.1. Physicochemical Properties

The effects of heating and reheating on the physical and chemical characteristics of sunflower oil using laser and electrical heater compared with the unheated sunflower oil are presented in **Tables 1-3**.

Table 1. Values of the chemical properties of the five sunflower oil samples.

Sample		Acid Value	FFA	Peroxide Value	Saponification Value	Ester Value
Control		0.56	0.30	3.98	186.01	184.10
Electrical Heater	heated once	0.75	0.37	6.41	186.09	184.82
	heated twice	0.84	0.46	8.37	187.08	185.30
Laser-Heating	heated once	1.27	0.65	9.37	187.43	186.97
	heated twice	1.52	0.76	10.43	189.12	186.58

Table 2. Color measurements of the five sunflower oil samples.

Oil Sample		B	R	Y
Control		0	1.2	10.2
Electrical heater	heated once	0	1.6	10.6
	heated twice	0	1.8	11.5
Laser-heating	heated once	0.1	2.3	11.7
	heated twice	0.2	2.5	11.9

Table 3. The other physical properties of the five sunflower oil samples.

Sample		Moisture %	Density cm^3	Viscosity Cp	Refractive Index
Control		0.34	0.9150	60.58	1.4698
Electrical Heater	heated once	0.46	0.9178	60.83	1.4767
	heated twice	0.63	0.9173	60.85	1.4786
Laser-Heating	heated once	0.79	0.9176	61.06	1.4794
	heated twice	0.91	0.9176	61.47	1.4866

3.1.1. Results of the Chemical Properties

The obtained results of heating processes of the sunflower oil in Table 1 showed increasing in the oil chemical properties. Reheating processes caused in more increasing in the oil chemical properties; these results agree with the results of Adriana Abdul Aziz1 *et al.* [19]. It was observed that laser-heating process increased the oil chemical properties greater than the increasing of reheating processes by electrical heater.

This obtained results showed that the trend of chemical properties was increased crossover all tested samples starting from the once-heated electrically sample undergoing with the twice-heated electrically then once-laser-heated undergoing with twice-laser-heated sample. Chemical properties had increased with the increasing number of heating sessions. The increment of chemical properties of the oils is due to the development of hydroperoxides of unsaturated fatty acids because of the lipid oxidation process. Oxidation of oils is influenced by means of different factors which include the degree of unsaturation, heat, light, oil processing, antioxidants and transition metals [19].

3.1.2. Results of the Physical Properties

The chemical reactions in the oil leads to changing in some physical properties such as viscosity, density, darken color, or production of foam [20]; these changes clearly showed in this study in the results presented in Table 2 and Table 3.

Table 2 showed the changing of the oil color for the control, heated, and reheated samples. The blue color does not appear by heating and reheating using the electrical heater; while it was increased from 0 up to 0.2. The red color increased from 1.2 up to 1.8 by heating and reheating using the electrical heater; while it was increased from 1.2 up to 2.5. The yellow color increased from 10.2 up to 11.5 by heating and reheating using the electrical heater; while it was increased from 10.2 up to 11.9. It was observed that oil has darkened its color and emanated smoke during heating sessions, which indicates oil degradation. Chemical reactions, which influenced by heating processes; results in foaming production, darkening of oil color, and off-flavor. Increase in color of oil by heating was reported by Sonia and Badereldeen [21], and was found also by Augustin *et al.* [22] and Mudawi *et al.* [23].

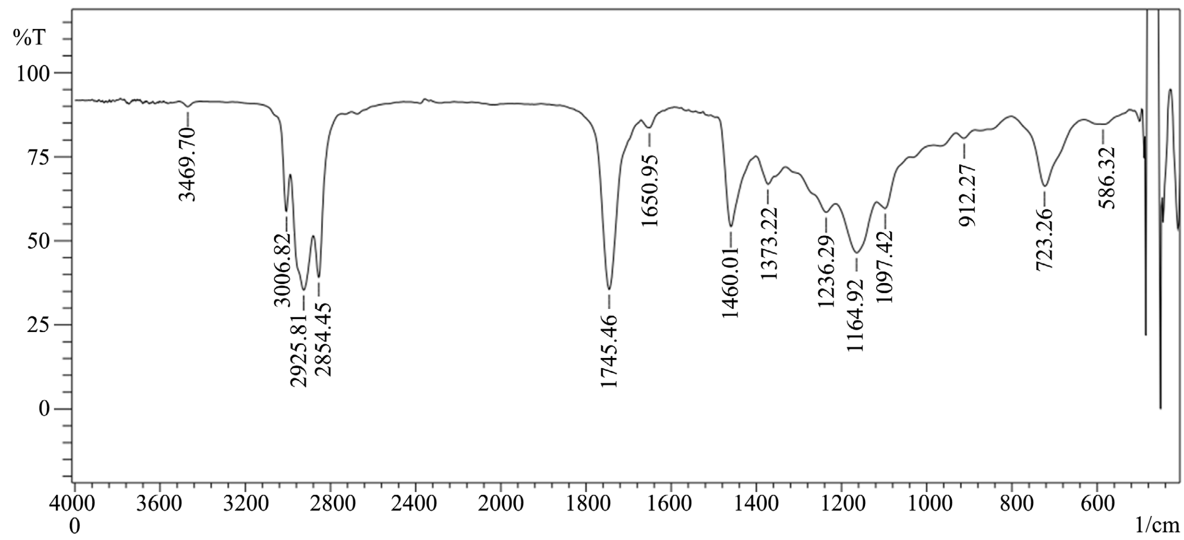
Table 3 shows changes in moisture, density, viscosity and refractive index (RI) of all oil samples during heating and reheating. Moisture increased from 0.34% in control sample to 0.63% after reheating process using electrical heater, while it increased up to 0.91% after reheating process using laser. The density increased from 0.9150 cm^3 in control sample to 0.9178 cm^3 after heating and it decreased to 0.9173 cm^3 after reheating process using electrical heater, while it increased up to the same value 0.9176 cm^3 after heating and reheating process using laser. While viscosity increased from 60.58 Cp in control sample up to 60.85 Cp after reheating process using electrical heater, whereas it increased up to 61.47 Cp after reheating process using laser. The refractive index increased from 1.4698 in control sample to 1.4786 after reheating process using electrical heater, while it increased up to 1.4866 after reheating process using laser. It is clear that all physical properties of the five sunflower oil samples increased by heating and reheating at 50˚C. Physical properties temperature dependence is agree with the study of Wiege *et al.* in 2020 [24].

3.2. FTIR Results

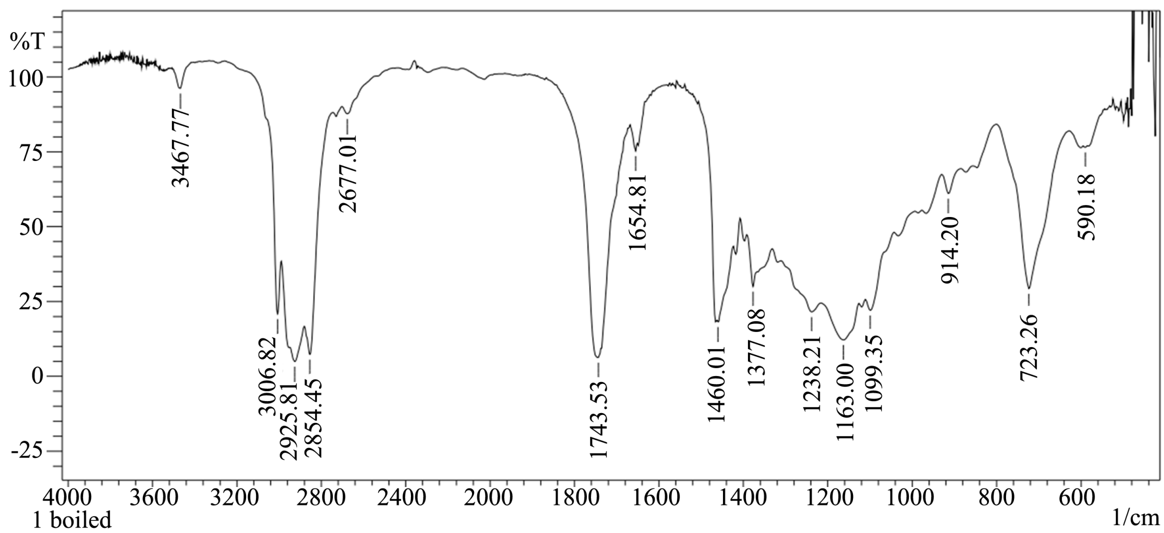
FT-IR spectroscopy is a very good technique for analysis, as the intensities of the bands in the spectrum are proportional to concentration. FT-IR spectra of the control, heated and reheated sunflower oil samples are presented in Figure 1.

Each sample contains C=O (1745.46 cm^{-1}) and C-O (1163.00 cm^{-1}) which may indicate possible existence of COO, ester functionality (oils), samples were rich in C-H (sp^3) (2923.88 cm^{-1} and 2854.45 cm^{-1}) indicating presence of CH_3 and CH_2 as reinforced by bands in (1463.87 cm^{-1} and 1377.08 cm^{-1}). Weak band at 1650 cm^{-1} C=C with C=C-H 3006 cm^{-1} but not conjugated with C=O.

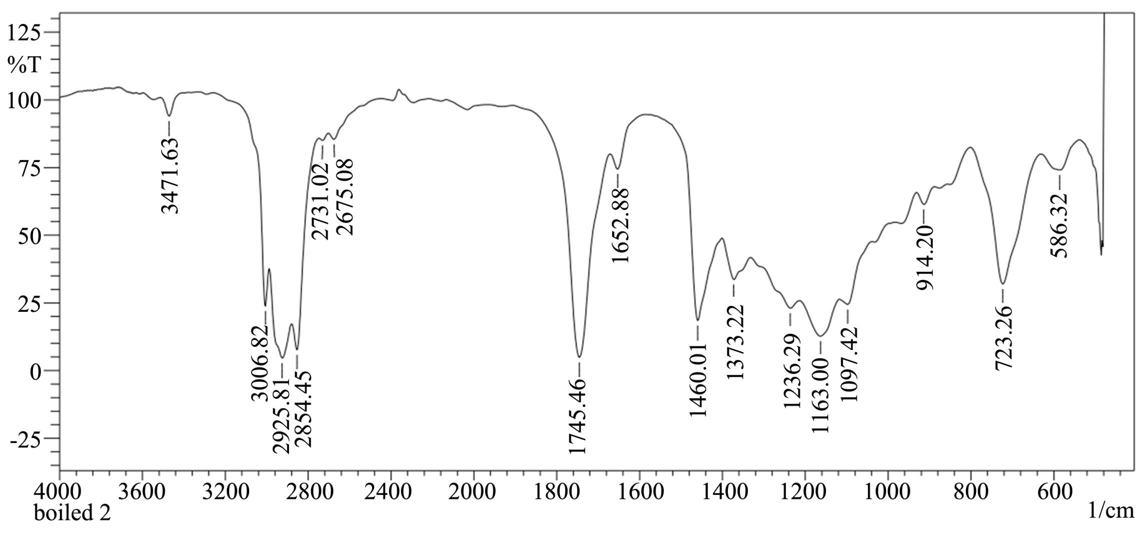
As shown in Table 4, the changed band assignments of sunflower oil samples were: 3469.70 cm^{-1}, 2677.01 cm^{-1} 2731.02 cm^{-1}, 2360.71 cm^{-1}, 1654.81 cm^{-1} and


%T
100
75
50
25
0
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
4000 3600 3200 2800 2400 2000 1800 1600 1400 1200 1000 800 600
0
1/cm

(a)


%T
100
75
50
25
0
-25
3467.77
2677.01
3006.82
2925.81
2854.45
1743.53
1654.81
1460.01
1377.08
1238.21
1163.00
1099.35
914.20
723.26
590.18
4000 3600 3200 2800 2400 2000 1800 1600 1400 1200 1000 800 600
1 boiled
1/cm

(b)


125
%T
100
75
50
25
0
-25
3471.63
2731.02
2675.08
3006.82
2925.81
2854.45
1745.46
1652.88
1460.01
1373.22
1236.29
1163.00
1097.42
914.20
723.26
586.32
4000 3600 3200 2800 2400 2000 1800 1600 1400 1200 1000 800 600
boiled 2
1/cm

(c)

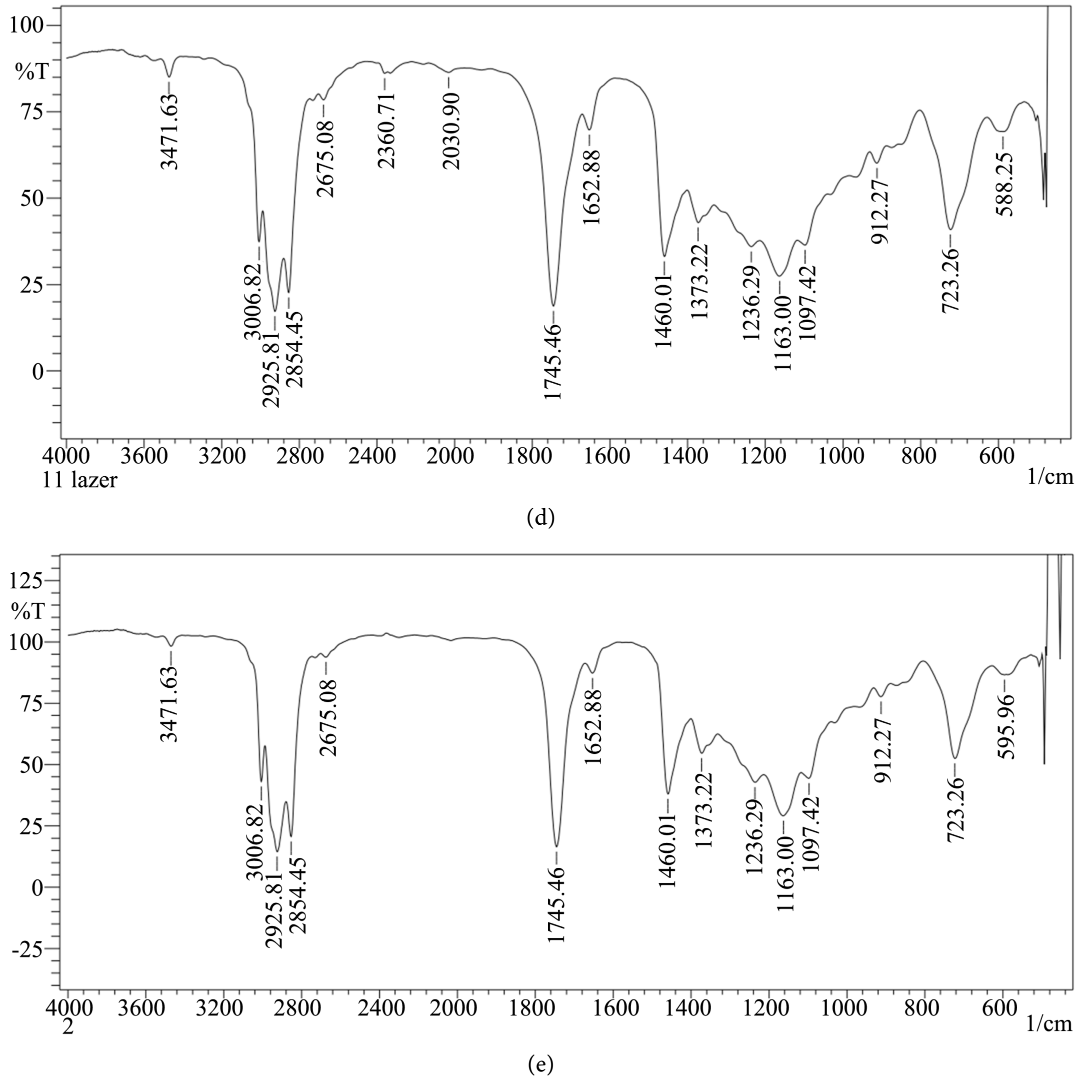


Figure 1. FT-IR spectrum of the sunflower oil samples: (a) control (unheated); (b) electrical heated once; (c) electrical heated twice; (d) laser heated once; (e) laser heated twice.

Table 4. Band assignments of sunflower oil samples.

FTIR shift/cm^{-1}	Assign	Ref.
3469.70	O-H str	Sudhakar *et al.*, 2018 [25]
3006.82	C-H st.vib. (sp^2)	Poiana, *et al.*, 2015 [26]
2923.88 - 2854.45	C-H st.vib. (sp^3)	Liu, and Kazarian, 2022 [27]
2731.02	Aldehydic C-H Str.	Hafeez, *et al.*, 2019 [28]
2360.71	C-H	Evangelin and Gurulakshmi, 2020 [29]
1745.46	C=O st.vib.	Zhuang, 2020 [30]
1654.81	C=O Str.	Gupta, *et al.*, 2011 [31]
1650	C=C st.vib.	Panicker, *et al.*, 2009 [32]
1463.87, 1377.08	CH_3, CH_2 bend.	Priest, *et al.*, 1999 [33]
1163.00	C-O st.vib.	Simonova, and Karamancheva, 2013 [34]

585 - 595 cm^{-1}. It showed a notable difference depend on heating and reheating processes using laser and electrical heater.

4. Conclusions

In this paper, the effect of carbon dioxide laser (10,600 nm) heating and reheating on the chemical and physical characteristics of sunflower oil compared with the effect of electrical heater heating and reheating were investigated. As a result, when the same cooking oil is reheated, the chemical reactions enhance foaming, darkening of oil color, increased viscosity, and off-flavor. Hence, repeated heating of the oil can lead to degradation of the cooking oil, both chemically and physically. It was found that the long time of heating using laser rising temperature up to 50˚C catalyzed chemical reactions that resulted in effects in the oil samples characteristics greater than the effects of the electrical heater in a few minutes with temperature 250˚C.

Acknowledgements

The authors would like to thank the Institute of Laser at Sudan University of Science and Technology (SUST) for providing equipment used in this work.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Smith, D., Smith, J.S., Childs, C., Rod, E., Hrubiak, R., Shen, G. and Salamat, A. (2018) A CO_2 Laser Heating System for *in Situ* High Pressure-Temperature Experiments at HPCAT. *Review of Scientific Instruments*, **89**, Article ID: 083901. https://doi.org/10.1063/1.5040508

[2] Bräunlich, P., Gasiot, J., Fillard, J.P. and Castagne, M. (1981) Laser Heating of Thermoluminescent Dielectric Layers. *Applied Physics Letters*, **39**, 769-771. https://doi.org/10.1063/1.92848

[3] Awad, A.A.G., Gawbah, M.A.P., Orsod, M.U., Alsabah, Y.A. and Marouf, A.A. (2020) Investigation of the Effects of Laser-Based Combustion on Sorghum Bran. *Albaydha University Journal*, **2**, 52-59.

[4] Gawbah, M.A.P., Elbadawi, A.A., Alsabah, Y.A., Orsod, M.U. and Marouf, A.A. (2018) Characterization of the Crystal Structure of Sesame Seed Cake Burned by Nd: YAG Laser. *Journal of Materials Science and Chemical Engineering*, **6**, 121-131. https://doi.org/10.4236/msce.2018.64013

[5] Gawbah, M.A.P., Marouf, A.A., Alsabah, Y.A., Orsod, M.U. and Elbadawi, A.A. (2017) Synthesis of Silica, Silicon Carbide and Carbon from Wheat Bran and Converting its Crystal Structure Using Nd: YAG Laser. *International Journal of Advanced Research in Physical Science*, **4**, 31-37.

[6] Awadala, A.S., Elfaky, A.E. and Marouf, A.A. (2020) Influence of High Power Nd: YAG Laser on Hardness and Surface Properties of Zirconium Silicate. *International Journal of Mathematics and Mathematical Sciences*, **2**, 39-44. https://doi.org/10.34104/ijmms.020.039044

[7] Awadala, A.S., Elfaky, A.E. and Marouf, A.A.S. (2020) Investigation of the Effects of High-Power Nd: YAG Laser on Zirconium Silicate Surfaceroperties. *International Journal of Latest Research in Science and Technology*, **9**, 6-10.

[8] Marouf, A. and Sara, I.E. (2017) Monitoring pH During Pasteurization of Raw Cow's Milk Using Nd: YAG Laser. *International Journal of Advanced Research in Physical Science* (*IJARPS*), **4**, 1-4.

[9] Malik, A.O.B. and Marouf, A.A.S. (2018) Comparison of the Effects of Laser Pasteurization and Heat Pasteurization on The Cow's Milk. *Haya*: *The Saudi Journal of Life Sciences*, **3**, 46-50.

[10] Marouf, A.A.S. and Siddiq, E.O.H. (2018) Evaluation of Laser Pasteurization on Production of Yogurt. *International Journal of Advanced Research in Physical Science* (*IJARPS*), **5**, 15-23.

[11] Mudawi, A.A. and Marouf, A.A. (2022) Impact of Single Wavelength (532 nm) Irradiation on the Physicochemical Properties of Sesame Oil. *Journal of Materials Science and Chemical Engineering*, **10**, 1-15. https://doi.org/10.4236/msce.2022.104001

[12] Ahmmed, A.E.G. and Marouf, A.S. (2017) Effect of Pulsed He-Ne Laser Irradiation on Bee Honey Physicochemical Properties. *Research and Review Insights*, **1**, 6-7. https://doi.org/10.15761/RRI.1000122

[13] Kassu, A., Farley III, C. and Tsoli, C.P. (2021) Laser Heating and Infrared Thermography of Building Materials. *Journal of Building Construction and Planning Research*, **9**, 223-229. https://doi.org/10.4236/jbcpr.2021.93014

[14] Phiri, G., Mumba, P. and Mangwera, A. (2006) The Quality of Cooking Oil Used in Informal Food Processing in Malawi: A Preliminary Study. *International Journal of Consumer Studies*, **30**, 527-532. https://doi.org/10.1111/j.1470-6431.2006.00513.x

[15] Stevenson, S.G., Vaisey-Genser, M. and Eskin, N.A.M. (1984) Quality Control in the Use of Deep Frying Oils. *Journal of the American Oil Chemists Society*, **61**, 1102-1108. https://doi.org/10.1007/BF02636232

[16] Lapointe, A., Couillard, C. and Lemieux, S. (2006) Effects of Dietary Factors on Oxidation of Low-Density Lipoprotein Particles. *The Journal of Nutritional Biochemistry*, **17**, 645-658. https://doi.org/10.1016/j.jnutbio.2006.01.001

[17] AOAC (1990) Official Methods of Analysis. 15th Edition, Arlington, VA, 951-986.

[18] Azman, A., Shahrul, S.M., Chan, S.X., Noorhazliza, A.P., Khairunnisak, M., Azlina, M.N., Qodriyah, H.M., Kamisah, Y. and Jaarin, K. (2012) Level of Knowledge, Attitude and Practice of Night Market Food Outlet Operators in Kuala Lumpur Regarding the Usage of Repeatedly Heated Cooking Oil. *Medical Journal of Malaysia*, **67**, 91-101.

[19] Aziz, A.A., Elias, S.M. and Sabran, M.R. (2018) Repeatedly Heating Cooking Oil Among Food Premise Operators in Bukit Mertajam, Pulau Pinang and Determination of Peroxide in Cooking Oil. *Malaysian Journal of Medicine and Health Sciences*, **14**, 37-44.

[20] Ku, S.K., Ruhaifi, M., Fatin, S.S., Saffana, M., Das, S. and Kamsiah, J. (2014) The Harmful Effects of Consumption of Repeatedly Heated Edible Oils: A Short Review. *La Clinica Terapeutica*, **165**, 217-221.

[21] Sonia, Z.G. and Badereldeen, A.E. (1983) Changes of Cottonseed Oil during Deep Fat Frying of Food. *Larivista Italiana Delle Sostanze Grasse*, **9**, 73.

[22] Augustin, M.A., Hena, L.K. and Teah, Y.K. (1987) Comparison of Frying Performance of Market Samples of Palmolein, Corn Oil and Soya Oil in Malaysia. *Perta-*

nika Journal, **19**, 295-304.

[23] Mudawi, H.A., Elhassan, M.S. and Sulieman, A.M.E. (2014) Effect of Frying Process on Physicochemical Characteristics of Corn and Sunflower Oils. *Food and Public Health*, **4**, 181-184.

[24] Wiege, B., Fehling, E., Matthäus, B. and Schmidt, M. (2020) Changes in Physical and Chemical Properties of Thermally and Oxidatively Degraded Sunflower Oil and Palm Fat. *Foods*, **9**, Article 1273. https://doi.org/10.3390/foods9091273

[25] Sudhakar, P., Pushkalai, S.P., Sabarinath, C., Priyadharshini, S. and Haripriya, S. (2018) Molecular Docking and Synthesis of 1,2,4-Triazin Analogue of Diclofenac as Potential Ligand for Parkinson's. *Research Journal of Pharmacology and Pharmacodynamics*, **10**, 8-12. https://doi.org/10.5958/2321-5836.2018.00002.2

[26] Poiana, M.A., Alexa, E., Munteanu, M.F., Gligor, R., Moigradean, D. and Mateescu, C. (2015) Use of ATR-FTIR Spectroscopy to Detect the Changes in Extra Virgin Olive Oil by Adulteration with Soybean Oil and High Temperature Heat Treatment. *Open Chemistry*, **13**, 689-698. https://doi.org/10.1515/chem-2015-0110

[27] Liu, G.L. and Kazarian, S. (2022) Recent Advances in Studies of Cultural Heritage Using ATR-FTIR Spectroscopy and ATR-FTIR Spectroscopic Imaging. *Analyst*, **147**, 1777-1797. https://doi.org/10.1039/D2AN00005A

[28] Hafeez, A., Akhter, Z., Gallagher, J.F., Khan, N.A., Gul, A. and Shah, F.U. (2019) Synthesis, Crystal Structures, and Spectroscopic Characterization of Bis-Aldehyde Monomers and Their Electrically Conductive Pristine Polyazomethines. *Polymers*, **11**, Article 1498. https://doi.org/10.3390/polym11091498

[29] Evangelin, B.P. and Gurulakshmi, P. (2020) Bio Fabrication and Characterisation of Metal Oxide Nanocomposite Using Piper Betel Leaves. *Journal of Advanced Scientific Research*, **11**, 184-189.

[30] Zhuang, J., Li, M., Pu, Y., Ragauskas, A.J. and Yoo, C.G. (2020) Observation of Potential Contaminants in Processed Biomass Using Fourier Transform Infrared Spectroscopy. *Applied Sciences*, **10**, Article 4345. https://doi.org/10.3390/app10124345

[31] Gupta, J.K., Sharma, P.K., Dudhe, R., Chaudhary, A., Mondal, S.C. and Verma, P.K. (2011) Synthesis and Analgesic Activity of Novel Pyrimidine Derivatives of Coumarin Moiety. *Acta Poloniae Pharmaceutica-Drug Research*, **68**, 785-93.

[32] Panicker, C.Y., Vanghese, H.T. and Thansani, T. (2009) Spectroscopic Studies and Hartree-Fock *ab Initio* Calculations of a Substituted Amide of Pyrazine-2-Carboxylic Acid-$C_{16}H_{18}ClN_3O$. *Turkish Journal of Chemistry*, **33**, 633-646.

[33] Priest, M., Ehret, P., Flamand, L., Dalmaz, G., Childs, T.H.C., Dowson, D., Berthier, Y., Taylor, C.M., Lubrecht, A.A. and Georges, J.M. (1999) Lubrication at the Frontier: The Role of the Interface and Surface Layers in the Thin Film and Boundary Regime. Elsevier, Amsterdam.

[34] Simonova, D. and Karamancheva, I. (2013) Application of Fourier Transform Infrared Spectroscopy for Tumor Diagnosis. *Biotechnology & Biotechnological Equipment*, **27**, 4200-4207. https://doi.org/10.5504/BBEQ.2013.0106