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Identification of Sudanese Sesame Oil Quality Using a 680 nm Semiconductor Laser Spectrometer and Other Techniques

Mohammed Uthman Orsod[1*], Mubarak Dirar Abdalla[2], Ganesan Krishnan[3], Babikir Osman Elbashir[4], Faiz Mohamed Budr Elshafia[2,5]

[1]Institute of Laser, Sudan University of Science and Technology, Khartoum, Sudan
[2]Department of Physics, Faculty of Science, Sudan University of Science and Technology, Khartoum, Sudan
[3]Laser Center, Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia
[4]Department of Physics, University of Tabuk, Tabuk, Saudi Arabia
[5]Department of Physics, Faculty of Science & Arts, Al-Baha University, Al-Baha, Saudi Arabia
Email: *Mohammed Uthman Orsod-mohursod@gmail.com

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Abstract

This study investigates the optical properties of sesame oil from traditional and industrial sources using a custom-designed semiconductor laser spectrometer, UV-Vis spectroscopy, and FTIR spectroscopy. Six samples were collected from traditional presses and factories in Khartoum State and White Nile State. The spectrometer, constructed with a 680 nm semiconductor laser and various resistor values, measured the absorbance of sesame oil samples. UV-Vis spectroscopy identified absorbance peaks at 670 nm and 417 nm, corresponding to chlorophyll a and b. FTIR analysis showed nearly identical spectra among the samples, indicating similar chemical compositions. Laser spectrometer analysis revealed specific absorbance values for each sample. The results highlight the feasibility of using a 680 nm semiconductor laser for analyzing sesame oil, providing a cost-effective alternative to other wavelengths. This study demonstrates the potential of integrating traditional methods with modern spectroscopic techniques for the quality assessment of sesame oil.

Keywords

Industrial Oil Production, Laser Spectroscopy, Quality Control, Sudanese Sesame Oil, Traditional Sesame Oil, Traditional Oil Presses

1. Introduction

Laser absorption spectroscopy (LAS) is a method of absorption spectroscopy that uses a laser as the light source to measure chemical concentrations. It does this by detecting changes in the intensity of the laser beam after it passes through a sample. LAS is used in various applications, including environmental monitoring, medical diagnostics, industrial process control, and research in fundamental physics and chemistry [1]. The technique is highly valued for its accuracy, precision, and capability to provide real-time measurements.

Laser spectroscopy has been extensively utilized in the study of food and edible oils. Techniques such as Laser-Induced Breakdown Spectroscopy (LIBS) have been applied to olive oil analysis [2], as well as to the analysis of olive oil, milk, and honey [3]. Visible Raman spectroscopy has been employed to discriminate olive oils from different vegetable oils and detect adulteration [4]. FT-NIR combined with Confocal Microscope Raman Spectroscopy has been used to study sesame oil adulteration [5]. Additionally, various spectroscopic techniques have been applied to investigate the thermal aging of edible oils [6], and UV-Vis spectroscopy has served as a method for quantifying vegetable oil in adulterated olive oil [7]. Moreover, Fourier Transform-Infrared Spectroscopy (FTIR) has been widely used for the analysis of edible oils [8]-[10].

Spectroscopy plays a crucial role in the authentication of various types of oils. For instance, the detection of extra virgin olive oil adulterated with sesame oil has been achieved using FTIR spectroscopy and gas chromatography [11]. Additionally, FTIR spectroscopy and chemometric class modeling techniques have been utilized for the authentication of Chinese sesame oil [12]. Non-destructive detection of sesame oil adulteration has been accomplished using portable FT-NIR, FT-MIR, and Raman spectrometers combined with chemometrics [13]. Adulteration of sunflower oils has been detected using ATR-FTIR spectroscopy [14]. Furthermore, Fourier Transform Infrared (FTIR) spectroscopy has been employed to determine the presence of thermally deteriorated oil used as an adulterant in sunflower oil [15]. Quality control of sesame oil is crucial for sesame-producing countries such as Sudan. In this work, we use a custom-designed 680 nm semiconductor laser and other techniques to identify the quality of Sudanese sesame oil.

2. Materials and Methods

2.1. Samples Collection

Three samples of sesame oil (S1, S2, S3) were collected from traditional sesame oil presses located in Khartoum State and White Nile State, using wooden parts and camels to drive the press. Sample (S1) was collected from a camel wooden press in Alremailah, Khartoum State. Sample (S2) was collected from a camel wooden press in Alhaj Yousif, Khartoum State. Sample (S3) was collected from a camel wooden press in Alzeraidah, White Nile State. The other three samples of sesame oil (S4, S5, S6) were collected from different factories in Khartoum. Sample (S4) was collected from Alzaki Factory, Khartoum State. Sample (S5) was collected from Alnassr Factory, Khartoum State. Sample (S6) was collected from Alyahya Factory, Khartoum State.

2.2. Designation of Semiconductor Laser Spectrometer

The custom semiconductor laser spectrometer designed for this study involves a 680 nm laser diode and a series of resistors to control the intensity of the laser light passing through sesame oil samples. Here's a detailed breakdown of the construction process, including the rationale behind the selection of laser and resistance values and their impact on measurements.

2.2.1. Selection of Laser Source

The 680 nm laser was selected because it closely matches the absorbance peak of chlorophyll a, which was identified at 670 nm in the UV-Vis spectroscopy results. Although a 670 nm laser would have been ideal, its unavailability led to the choice of a 680 nm alternative, which offers a cost-effective solution while still being suitable for detecting the absorbance characteristics of sesame oil.

Power Output (2 mW): The laser's power output of 2 mW was chosen to ensure sufficient intensity for absorption measurement without causing excessive heating or alteration of the sample properties. This power level is low enough to avoid damaging the samples while providing a stable output for consistent measurements.

2.2.2. Electronic Circuit Design

The spectrometer circuit includes six resistors, each adding 500 ohms, allowing for a total range of 500 ohms to 3000 ohms. These resistors are used to control the current flowing through the laser diode, thereby adjusting the laser intensity (see **Figure 1**).

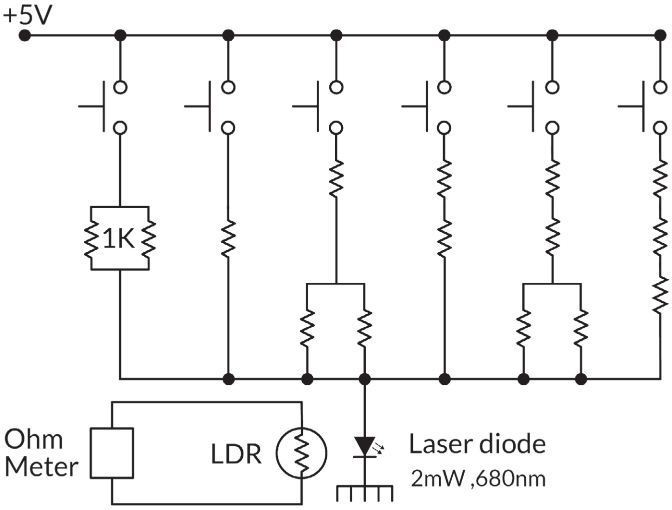


Figure 1. Electronic circuit diagram of the laser spectrometer.

Rationale: The varying resistance values allow the experimenter to modulate the laser's output power, providing a means to study the relationship between laser intensity and sample absorbance. By adjusting the resistance, the experimenter can generate multiple data points for absorbance at different laser intensities, offering a detailed understanding of the optical properties of the sesame oil.

Impact on Measurements: As the resistance increases, the current through the laser diode decreases, reducing the laser intensity. This controlled variation is critical for analyzing how absorbance changes with different intensities. The consistent order of the absorbance curves across different resistance values suggests that the resistor range effectively spans the necessary intensity variations for detailed analysis.

2.2.3. Measurement System

An LDR is positioned to detect the transmitted laser light after it passes through the sesame oil sample. The resistance of the LDR changes according to the light intensity, which is measured using an ohmmeter.

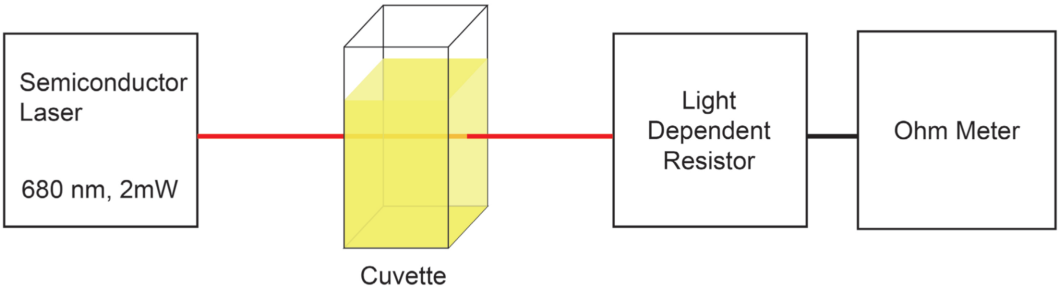


Figure 2. Design of the semiconductor laser spectrometer.

Ohmmeter Readings: A UNI-T multimeter, Model: UT33D, made in China, was connected to the LDR provides a resistance value that corresponds to the light intensity reaching the LDR. This value is inversely related to the absorbance of the sample, allowing the calculation of absorbance based on the LDR readings (see Figure 2).

Sample Holder: The samples were placed in standard plastic cuvettes, ensuring uniform path lengths for light transmission. The cuvettes were held in a fixed position between the laser source and the LDR to maintain consistent measurement conditions.

2.2.4. Housing and Light Isolation

The spectrometer's housing was constructed from acrylic sheets, cut using a CO_2 laser CNC machine. The assembled housing was painted black to prevent external light from interfering with the measurements, ensuring that the LDR only detects the light from the 680 nm laser.

2.2.5. Impact of Design Choices on Measurement Outcomes

Laser Intensity Control: The range of resistor values provides flexibility in controlling the laser intensity, allowing for a comprehensive study of the absorbance characteristics at various light levels.

Cost-Effectiveness: The use of a 680 nm semiconductor laser, combined with simple resistor-based intensity control, represents a cost-effective approach to constructing a functional spectrometer for sesame oil analysis. This design makes the spectrometer accessible for studies where budget constraints limit the use of more advanced and expensive equipment.

2.3. Measurement Procedures

The six samples of sesame oil were analyzed using the custom-designed 680 nm semiconductor laser spectrometer, in conjunction with FTIR and UV-Vis spectroscopy.

2.3.1. UV-Vis Spectroscopy Analysis

The UV-Vis absorption spectra acquisition was conducted using (SCO Tech, SPUV-26 double beam) UV-Vis spectrophotometer, made in Germany to study the absorbance properties of sesame oil samples and determine the appropriate wavelength for the custom-designed semiconductor laser spectrometer. The spectra were measured over the spectral range of 190 nm to 1100 nm, encompassing both ultraviolet and visible wavelengths.

2.3.2. FTIR Spectroscopy Analysis

FT-IR spectra of six sesame oil samples were obtained using a Fourier Transform Infrared Spectrometer (IR Spirit, Shimadzu, Japan). This analysis was conducted to compare the chemical structures of the sesame oil samples.

2.3.3. Laser Spectrometer Analysis

The laser absorbance analysis of the six sesame oil samples was conducted using a custom-designed 680 nm semiconductor laser spectrometer. This analysis aimed to compare the differences among the sesame oil samples.

3. Results and Discussions

3.1. UV-Vis Spectroscopy Results

The results obtained from UV-Vis spectroscopy for the six sesame oil samples showed maximum absorbance peaks at 670 nm and 417 nm (see **Figure 3**). These results indicated the need for a laser source emitting at 417 nm for the custom-designed semiconductor laser spectrometer, but it was unavailable. Alternatives such as 405 nm and 450 nm were considered, but they were deemed too expensive. Although a laser source at 670 nm was also unavailable, options at 680 nm and 650 nm were considered. Ultimately, a laser emitting at 680 nm was chosen for the analysis.

These peaks at 670 nm and 417 nm correspond to the absorption of light by specific pigments in the oil, primarily chlorophyll a and chlorophyll b.

3.1.1. Absorption Peak at 670 nm

Chlorophyll a: The absorption peak at 670 nm is attributed to chlorophyll a, a green pigment commonly found in plants. Chlorophyll a plays a critical role in photosynthesis by absorbing light energy and converting it into chemical energy. Biochemical Relevance: The presence of chlorophyll a in sesame oil indicates the retention of plant material or impurities during the oil extraction process. Chlorophyll is typically found in the oil when it is extracted from seeds that still have some green plant tissues or when the oil has been exposed to light during storage, leading to chlorophyll degradation products [16].

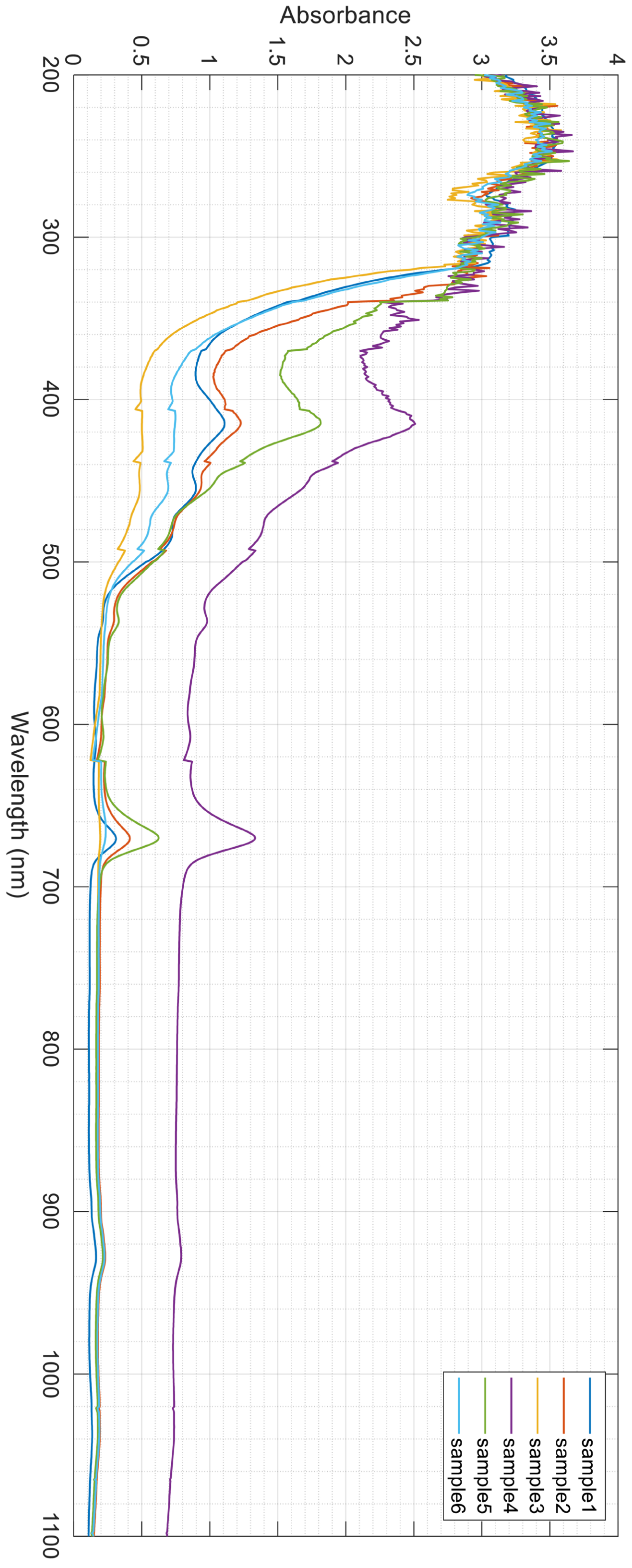


Figure 3. UV-Vis spectra obtained from different sesame oil samples.

Practical Application: The intensity of the 670 nm peak can be used as a quality indicator for sesame oil. Higher absorbance at this wavelength suggests higher chlorophyll content, which can affect the oil's color, flavor, and stability. Oils with high chlorophyll content are more prone to oxidation and may have a shorter shelf life [17]. Therefore, monitoring this peak can help in assessing the freshness and purity of the oil.

3.1.2. Absorption Peak at 417 nm

Chlorophyll b: The absorption peak at 417 nm corresponds to chlorophyll b, another photosynthetic pigment found in plants. Chlorophyll b assists chlorophyll a in capturing light energy, primarily in the blue-violet region of the spectrum.

Biochemical Relevance: Similar to chlorophyll a, the presence of chlorophyll b in sesame oil suggests incomplete removal of plant material during processing. The peak at 417 nm can also indicate the presence of degradation products that may form due to prolonged exposure to light and oxygen [18].

Practical Application: The 417 nm peak serves as another crucial marker for assessing the quality of sesame oil. Elevated absorbance at this wavelength may indicate the presence of unwanted pigments or degradation products, potentially leading to off-flavors or reduced nutritional value [19]. Therefore, this peak's intensity can be used to evaluate the oil's processing efficiency and storage conditions.

In this study, the six UV-Vis spectra obtained from different sesame oil samples showed minimal variation, indicating a lack of distinct differences between the various types of oil samples analyzed.

The absorbance peak of the samples at 417 nm matches the absorbance peak of chlorophyll a. The absorbance peak of the samples at 670 nm also matches the absorbance peak of chlorophyll a. Additionally, the absorbance peak of the samples at 458 nm matches the absorbance peak of chlorophyll b.

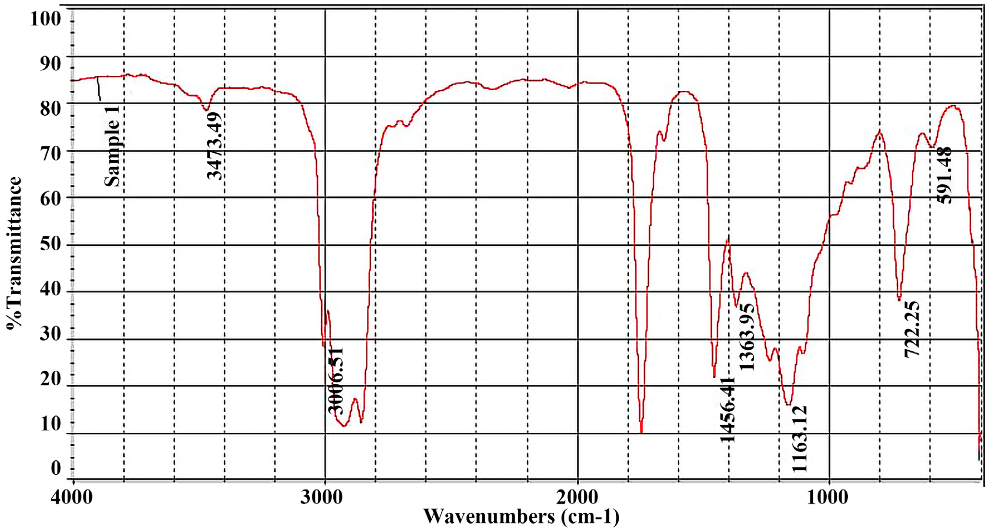
The absorbance values of the main peaks at 670 nm and 417 nm for all samples are presented in **Table 1**.

Table 1. Absorbance values at 670 nm and 417 nm for all samples.

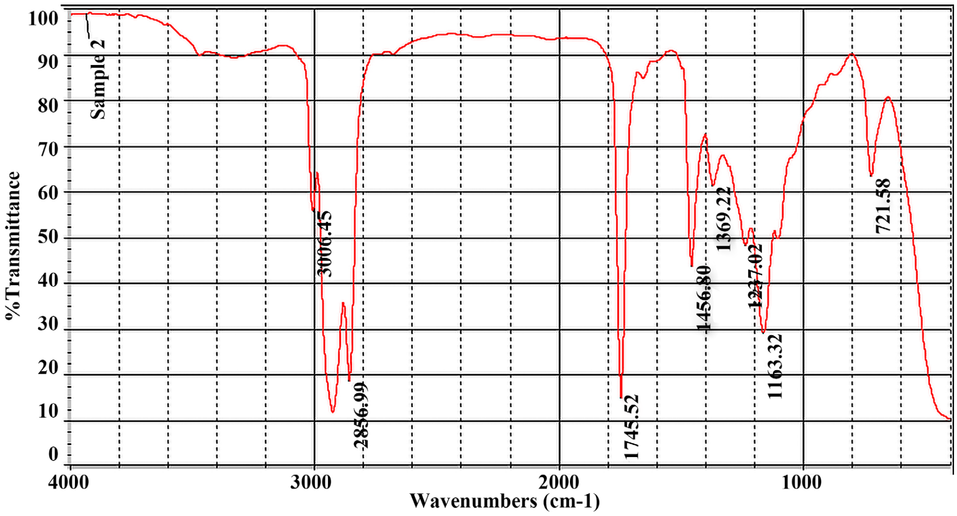
Sample	Absorbance Values of the Peaks at 670 nm	Absorbance Values of the Peaks at 417 nm
S1	0.3 %	1.1 %
S2	0.4%	1.22%
S3	0.2%	0.5%
S4	1.32%	2.5%
S5	0.6%	1.8%
S6	0.22%	0.75%

3.2. FTIR Spectroscopy Results

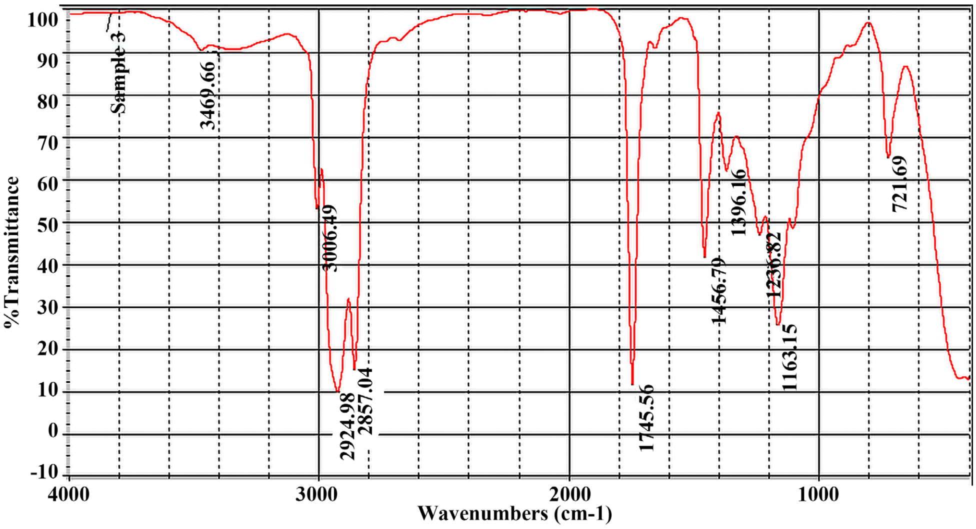
The FTIR spectra obtained from sesame oil samples in **Figure 4**, appear nearly identical and lack clear differences. This similarity likely arises from the samples having very similar compositions, which makes them challenging to distinguish solely through FTIR analysis. Assigned FTIR shifts for sesame oil samples are used to compare the chemical structures of the samples (see **Table 2**).


%Transmittance
Wavenumbers (cm-1)
Sample 1
3473.49
3006.51
1456.41
1363.95
1163.12
722.25
591.48
0
10
20
30
40
50
60
70
80
90
100
4000
3000
2000
1000

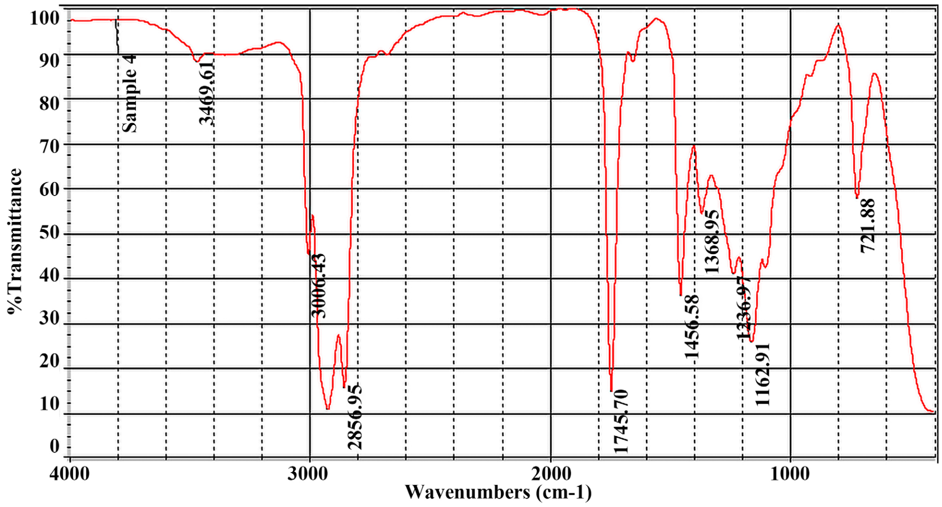
(a)


%Transmittance
Wavenumbers (cm-1)
Sample 2
3006.45
2856.99
1745.52
1456.30
1369.22
1237.02
1163.32
721.58
0
10
20
30
40
50
60
70
80
90
100
4000
3000
2000
1000

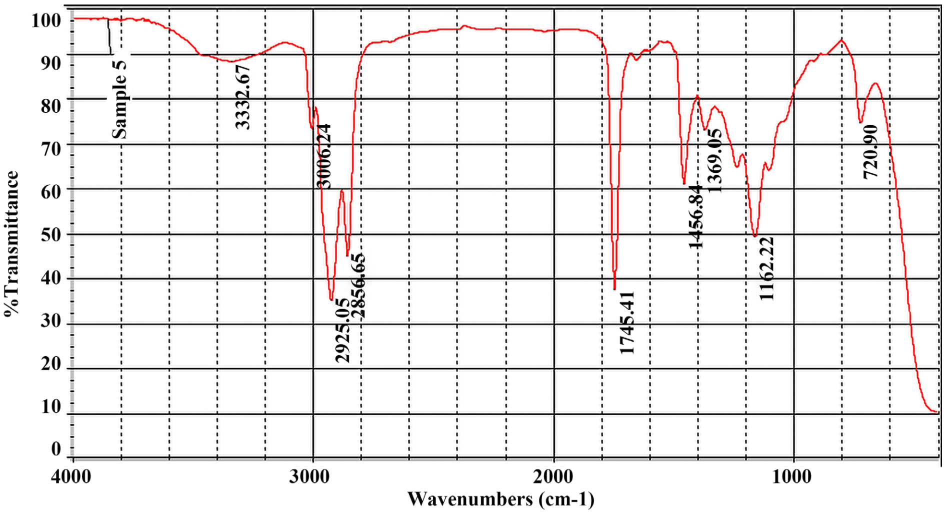
(b)


%Transmittance
Wavenumbers (cm-1)
Sample 3
3469.66
3006.49
2924.98
2857.04
1745.56
1456.79
1396.16
1236.82
1163.15
721.69
-10
0
10
20
30
40
50
60
70
80
90
100
4000
3000
2000
1000

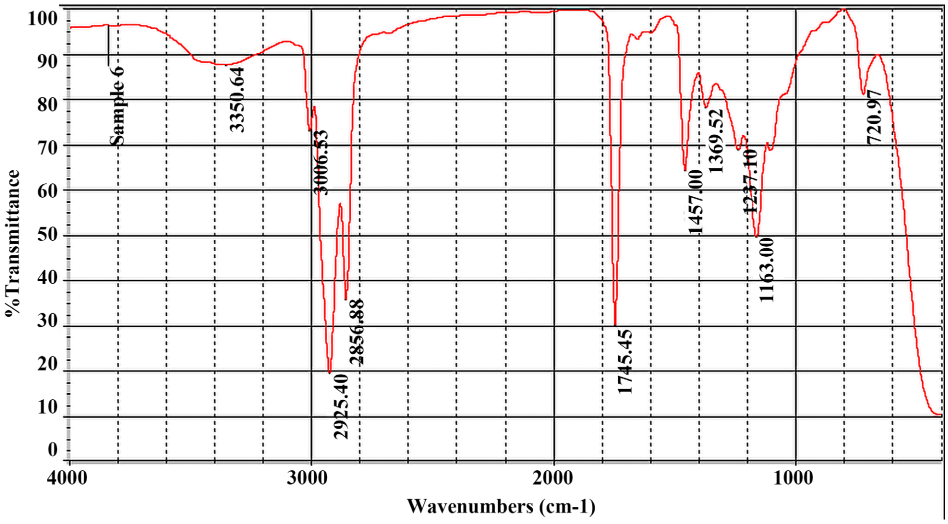
(c)



(d)



(e)



(f)

Figure 4. FTIR spectra of the six sesame oil samples.

Table 2. Assigned FTIR shifts for sesame oil samples.

	FTIR shift/cm^{-1}						Assign	Reference
No.	S1	S2	S3	S4	S5	S6		
1	722.25	721.58	721.69	721.88	720.90	720.97	C–H	(Mukhametov *et.al.*, 2023) [20]
2	1163.12	1163.32	1163.15	1162.91	1162.22	1163.00	C-O st.vib.	(Bunaciu and Aboul-Enein, 2024) [21]
3	1237.02	1237.02	1236.02	1236.97	1237.02	1237.10	–C–O stretching	(Bunaciu and Aboul-Enein, 2024) [21]
4	1368.95	1369.22	1369.16	1368.95	1369.05	1369.52	CH_3, CH_2 bend	(Bunaciu and Aboul-Enein, 2024) [21]
5	1456.41	1456.90	1456.79	1456.58	1456.84	1457.00	CH_2 and CH_3	Mudawi and Marouf, (2022) [22]
6	1745.52	1745.52	1745.56	1745.70	1745.41	1745.45	C=O st.vib.	(Vlachos *et al.*, 2006) [8]
7	2856.99	2856.99	2857.04	2856.95	2856.65	2856.88	C-H_2 st.vib.	(Mukhametov *et.al.*, 2023) [20]
8	-	2924.98	2924.98	2925.05	2925.05	2925.40	C-H_2 st.vib.	(Mukhametov *et.al.*, 2023) [20]
9	3006.51	3006.45	3006.29	3006.43	3006.24	3006.33	C-H st.vib.	(Vlachos *et al.*, 2006) [8]
10	3473.49	3473.49	3459.66	3469.61	3332.67	3350.64	O-H str	Mudawi and Marouf, (2022) [22]

3.3. Laser Spectrometer Results

The results of the absorbance of sesame oil to the laser with wavelength of 680 nm as a function of the resistance reading by the Ohmmeter are depicted in **Figure 5**. For each sample, the laser had a specific absorbance. The intensity of the laser beam decreased as the value of the series-connected resistors increased.

It is observed that the order of the curves is remains constant regardless of the resistance values, it affects only the slope of the curves. So, any of the resistance values in the resistance range from 500 Ohms to 3000 Ohms will operate the system.

To obtain a graph using a designed laser spectrometer, a specific wavelength (e.g., 680 nm) is selected, and the relationship between the intensity of the laser beam and the absorbance value is investigated. This is achieved by varying the resistance values connected in series with the laser. As the resistance increases, the intensity of the laser beam decreases, allowing for a detailed study of how absorbance changes with different laser intensities. Additionally, the effect of the sample's thickness on absorbance can be studied. As the thickness of the sesame oil sample increases, the absorbance also increases. However, adjusting the thickness of the oil vertically inside a transparent flat-bottom glass tube requires significant time and effort.

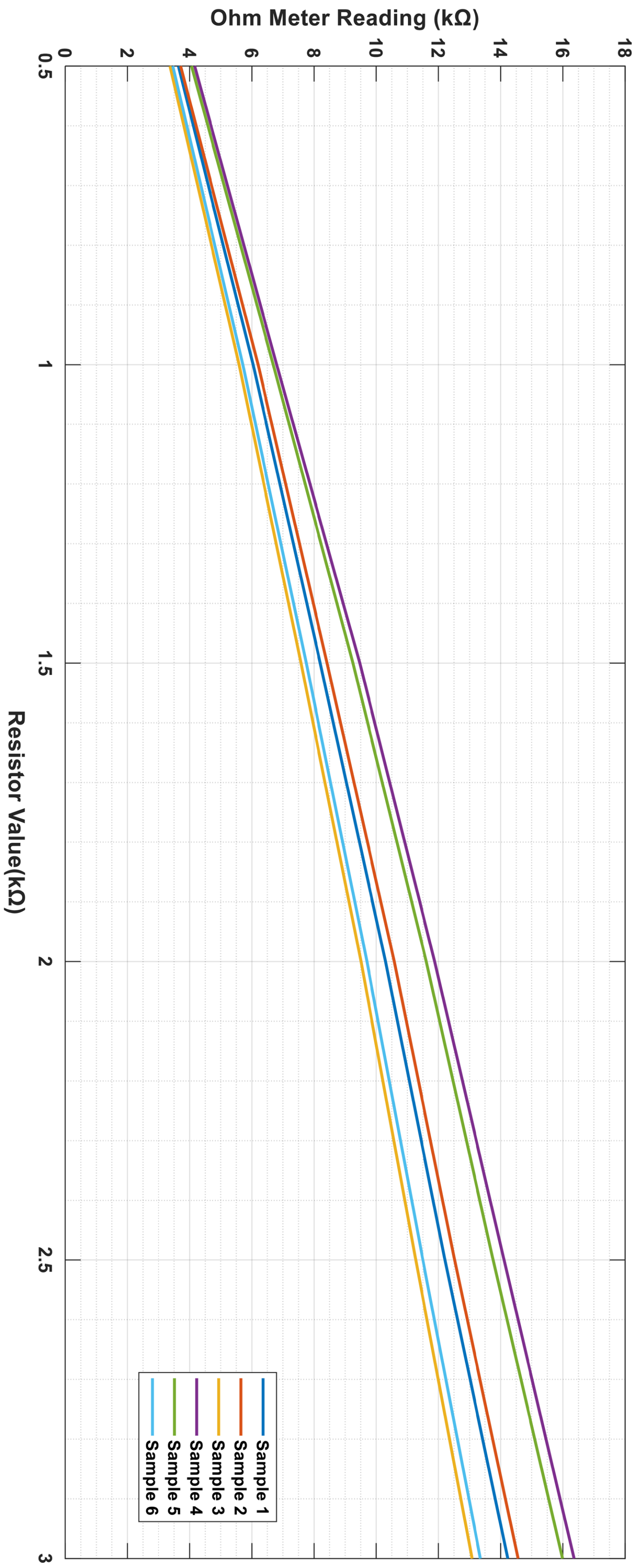


Figure 5. Resistor value (K Ohm) vs. ohmmeter reading (K Ohm).

3.4. Comparison with Other Wavelength Laser Spectrometers

To evaluate the advantages and limitations of the 680 nm laser spectrometer used in the study, it's essential to compare its measurement results with those obtained from laser spectrometers operating at different wavelengths. This comparison can highlight the specific suitability of the 680 nm wavelength for analyzing sesame oil and reveal any potential trade-offs.

3.4.1. Absorbance Sensitivity

680 nm Laser (This Study): The 680 nm laser was chosen due to its proximity to the 670 nm absorbance peak associated with chlorophyll a. This selection provided a cost-effective alternative while still being able to detect the chlorophyll content in sesame oil samples effectively. Advantages: The 680 nm laser spectrometer showed good sensitivity to chlorophyll a, allowing for clear differentiation of sesame oil samples based on their chlorophyll content. This wavelength is particularly effective for assessing oil quality related to chlorophyll contamination. Limitations: The 680 nm laser may not detect other important pigments or components that absorb at different wavelengths, such as carotenoids or other chlorophyll degradation products. This limits its scope to primarily chlorophyll-related analysis.

Other Wavelengths (e.g., 405 nm, 450 nm, 532 nm): 405 nm Laser: Lasers at 405 nm can detect a broader range of compounds, including those absorbing in the blue-violet region, which may include degradation products or other pigments like carotenoids. However, 405 nm lasers tend to be more expensive. 450 nm Laser: Lasers at 450 nm are also effective for detecting pigments like carotenoids and some chlorophyll degradation products. However, they may not be as sensitive to chlorophyll a as the 680 nm laser. 532 nm Laser: Lasers at 532 nm (green) are commonly used for detecting a wide range of organic compounds, including some pigments, but may not align as closely with the specific absorbance peaks of chlorophyll a and b.

Comparison: The 680 nm laser is advantageous for targeted analysis of chlorophyll-related quality indicators in sesame oil. However, other wavelengths may offer broader spectral analysis, detecting a wider variety of compounds at the expense of specificity for chlorophyll.

3.4.2. Cost and Availability

680 nm Laser (This Study): The 680 nm laser was chosen because it was a cost-effective and readily available option compared to other wavelengths like 670 nm or 405 nm lasers. Advantages: The lower cost of the 680 nm laser makes it an accessible option for routine quality control in oil processing, especially in regions with limited resources. Limitations: The focus on cost-effectiveness may limit the spectrometer's capability to detect a broader range of quality-related compounds, reducing its overall versatility.

Other Wavelengths: 405 nm and 450 nm Lasers: These lasers are more expensive and less commonly available, especially in regions with limited access to advanced technology. They offer broader detection capabilities but at a higher cost.

Comparison: While other wavelengths might provide more comprehensive data, their higher cost and lower availability make the 680 nm laser a more practical choice for many applications, particularly in settings where budget constraints are a significant factor.

3.4.3. Practical Application in Food Quality Analysis

680 nm Laser (This Study): The 680 nm laser spectrometer effectively analyzed sesame oil samples, identifying variations in chlorophyll content that can affect the oil's quality, flavor, and shelf life. Advantages: The study demonstrates the practical application of a 680 nm laser in food quality control, particularly for detecting chlorophyll-related impurities. This is especially useful for assessing the purity and freshness of oils. Limitations: The application is somewhat narrow, focusing mainly on chlorophyll detection. It may not be as effective for comprehensive quality analysis that includes other potential contaminants or adulterants.

Other Wavelengths: 405 nm and 450 nm Lasers: These lasers are often used in more detailed food quality analyses, capable of detecting a broader spectrum of compounds, including pigments, degradation products, and adulterants. They can provide a more comprehensive analysis but require more complex and expensive equipment.

Comparison: The 680 nm laser is advantageous for targeted, specific analysis of sesame oil quality, particularly related to chlorophyll content. In contrast, other wavelengths offer broader analysis capabilities but may be less practical for routine quality control due to their cost and complexity.

3.4.4. Summary of Advantages and Limitations of the 680 nm Laser

Advantages: Targeted Sensitivity: The 680 nm laser is well-suited for detecting chlorophyll a, making it effective for analyzing the freshness and purity of sesame oil. Cost-Effectiveness: It provides a more affordable option for routine quality control, especially in regions with limited access to high-tech equipment. Practicality: The 680 nm laser is easy to implement in a custom spectrometer setup, offering a straightforward solution for specific quality assessments. Limitations: Narrow Scope: The laser is primarily effective for chlorophyll-related analysis and may not detect other important quality indicators such as carotenoids or chemical degradation products. Limited Versatility: Compared to other wavelengths like 405 nm or 450 nm, the 680 nm laser has a narrower application range, making it less suitable for comprehensive food quality analysis.

Overall, the 680 nm laser spectrometer represents a balanced choice between cost, availability, and targeted sensitivity for specific quality assessments of sesame oil, particularly in detecting chlorophyll content. However, for broader and more detailed analyses, other wavelengths may be preferable, albeit at a higher cost and complexity.

3.5. Calibration Process

The calibration process of the 680 nm semiconductor laser spectrometer involves the following key steps:

Baseline Calibration: Establish a zero-absorbance point by measuring without a sample to account for ambient noise and light.

Reference Standard: Use a material with known absorbance at 680 nm to adjust the spectrometer's readings for accuracy.

Laser Intensity Adjustment: Fine-tune the laser's intensity using connected resistors to match the reference standard's absorbance characteristics.

Verification and Re-calibration: Periodically re-calibrate using the reference standard to maintain measurement accuracy and consistency.

This process ensures that the spectrometer provides accurate, consistent, and reproducible measurements by minimizing errors and accounting for environmental factors.

3.6. Review of Research in Related Areas

The literature review highlights the use of laser absorption spectroscopy (LAS) and UV-Vis spectroscopy in food analysis, particularly for edible oils like olive and sesame oil. Previous studies have effectively used various laser-based techniques, such as laser-induced breakdown spectroscopy (LIBS) [24] and Raman spectroscopy [4] [24], for oil quality assessment. UV-Vis spectroscopy is commonly used to detect key absorbance peaks related to chlorophyll content, a critical quality indicator in oils [25]. FTIR spectroscopy has also been extensively employed to analyze the chemical composition of edible oils [26].

The current study distinguishes itself by utilizing a cost-effective 680 nm semiconductor laser spectrometer, focusing on the quality assessment of Sudanese sesame oil a relatively underexplored area. This approach offers an innovative, affordable alternative to traditional spectrometers and contributes new insights into the quality of sesame oil from both traditional and industrial sources. The study's integration of modern spectroscopic techniques with traditional oil production methods underscores its potential impact on enhancing quality control practices in the edible oil industry, particularly in developing regions.

4. Conclusions

This study successfully utilized a custom-designed 680 nm semiconductor laser spectrometer, UV-Vis spectroscopy, and FTIR spectroscopy to analyze the optical properties of sesame oil samples from traditional and industrial sources. The findings reveal the following key points:

UV-Vis Spectroscopy: The UV-Vis analysis identified maximum absorbance peaks at 670 nm and 417 nm, corresponding to chlorophyll a and b. This result highlighted the necessity of a laser source at these wavelengths. Despite the unavailability of a 670 nm laser, a 680 nm laser was effectively utilized for the study.

FTIR Spectroscopy: FTIR spectra of the samples showed minimal variation, indicating similar chemical compositions across different sources of sesame oil.

Laser Spectrometer Analysis: The custom-designed spectrometer demonstrated that the absorbance of the sesame oil samples varied with changes in laser beam intensity, controlled by adjusting the resistance values. This relationship provided detailed insights into the optical behavior of the samples.

Feasibility and Cost-Effectiveness: The use of a 680 nm semiconductor laser proved to be a cost-effective alternative to other wavelengths, making it a viable option for sesame oil analysis.

Overall, the integration of traditional and modern analytical techniques offers a comprehensive approach to assessing the quality of sesame oil. This study not only confirms the effectiveness of the 680 nm semiconductor laser spectrometer but also paves the way for further research into the optical properties of various oils using similar cost-efficient methods.

Conflicts of Interest

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

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