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Design and Development of a Spectral Characterization Tool for Halal Fat Based on UV-LED Fluorescence as a Pillar of Halal-Tech Innovation in the Perspective of Maqāṣid al-Sharīʿah and Ethical Muslim Consumption

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ABSTRACT
Ensuring the halal status of food products, particularly those containing fat, is a crucial aspect of the ever-growing halal industry. This research aims to design and test a spectral characterization tool for halal fat based on UV-LED fluorescence technology, an innovation in Halal-Tech. This tool is designed to detect and differentiate fat types based on their fluorescence spectrum patterns. Tests were conducted on four types of fat samples: beef tallow, chicken tallow, butter (vegetable fat), and palm cooking oil. The test results show that chicken and beef tallow have relatively similar spectral patterns with a dominant pixel value range of 50–100, but with different intensities, indicating distinctive absorption levels. In contrast, the spectrum of vegetable fat shows significantly different patterns, particularly in peak intensity and pixel distribution. With six tests demonstrating consistent results, this tool demonstrates great potential as a rapid and non-destructive analysis system for fat identification. This innovation not only supports the technical aspects of product halal certification but also strengthens consumption ethics from the perspective of maqāṣid al-sharīʿah, namely the protection of Muslim consumers from ingredients that are not in accordance with sharia.

Keywords:
Halal; fluorescence; chicken fat; beef fat; halal fat.

Introduction

In an increasingly complex global food ecosystem, ensuring a product's halal status is not only a religious obligation but also a significant scientific challenge (Ernayani et al., 2024). The issue of halal product safety, especially for food products, continues to be a hot topic, particularly in Muslim-majority countries like Indonesia (Japar et al., 2024; Chasanah, 2023; Warto et al., 2020). Indonesia's Muslim market is highly potential, with a population of over 200 million, making monitoring the distribution of halal products crucial (Qoni'ah, 2022; Hidayat et al., 2024). For Muslim consumers, compliance with halal food laws is not solely related to ritual procedures, but is a reflection of ethical awareness rooted in maqāṣid al-sharīʿah, especially in terms of protecting religion (ḥifẓ al-dīn), soul (ḥifẓ al-nafs), and property (ḥifẓ al-māl). Allah SWT has ordered us as His people to consume and use things that are halal and tayyib as stated in (QS al-Baqarah: 168):

يٰٓاَيُّهَا النَّاسُ كُلُوْا مِمَّا فِى الْاَرْضِ حَلٰلًا طَيِّبًاۖ وَّلَا تَتَّبِعُوْا خُطُوٰتِ الشَّيْطٰنِۗ اِنَّهٗ لَكُمْ عَدُوٌّ مُّبِيْنٌ ﴿١٦٨﴾

Meaning: "O people! Eat what is halal and good from what is on earth, and do not follow the steps of the devil, because in fact the devil is a real enemy for you." This verse emphasizes to all of us as

Muslims to use, consume goods or products that are halal, both the essence of the substance, the process and the method of obtaining it (Putri, 2021; Haryarta et al., 2021).

One of the most ambiguous and frequently questioned components in this context is animal fat, which can originate from both halal and non-halal sources, but is visually difficult to distinguish. Conventional laboratory methods such as gas chromatography, mass spectrometry, or DNA detection are capable of identifying non-halal fats such as lard, but these procedures are generally expensive, time-consuming, and require impractical equipment for field use or for MSMEs (Widodo et al., 2013; Sucipto, 2013). These limitations create the need for alternative technologies that are portable, affordable, non-destructive, and capable of real-time analysis.

In response to these challenges, this study designed and developed a high-power UV-LED fluorescence-based halal fat spectral characterization system, which functions to map and differentiate the spectral profiles of various halal fat sources, such as chicken fat, beef tallow, cooking oil, and butter. By compiling a halal fat spectral database, this system is expected to be an initial tool to detect anomalies or mixtures of ingredients that deviate from recognized halal patterns. Fluorescence is a phenomenon when atoms absorb energy at a certain wavelength, undergo a transition from a low to a high energy level, then emit light with lower energy and a longer wavelength (Rahmaningrum et al., 2020). Research conducted by Widayanti et al. in 2022 stated that pork fat can exhibit a fluorescence phenomenon when exposed to UV light with a wavelength of 365 nm, so in this study will use a High Power UV LED with a wavelength of 365 nm. Rakhmadi et al (2020) and Shiddiq et al (2019) stated that each material, especially fat, has a different fluorescence pattern, so this fluorescence phenomenon can be used to quickly identify material specifications.

This research does not directly detect haram substances, but rather builds the foundation of a halal fat mapping system that can be used as a reference for indirect detection. Thus, this research supports the realization of Halal-Tech innovations that integrate optical spectroscopy technology with Islamic ethical values, providing scientific and spiritual assurance for Muslim consumers. Furthermore, this research contributes to strengthening a sustainable, inclusive, and ummah-oriented halal system.

Methods

In this study, it is divided into 3 parts, namely, hardware design, software, and data collection. The tools and materials needed in this study are as follows: high power 3 watt UV LEDs (4 pieces), 3 watt LED driver, heatsink, Arduino Uno, OV7670 mini camera and its module, UV filter, power supply, USB connector, cable, tool casing, NI LABVIEW, and beef fat, chicken fat, butter, cooking oil as test samples (Figure 1 and Figure 2).

Tool Design

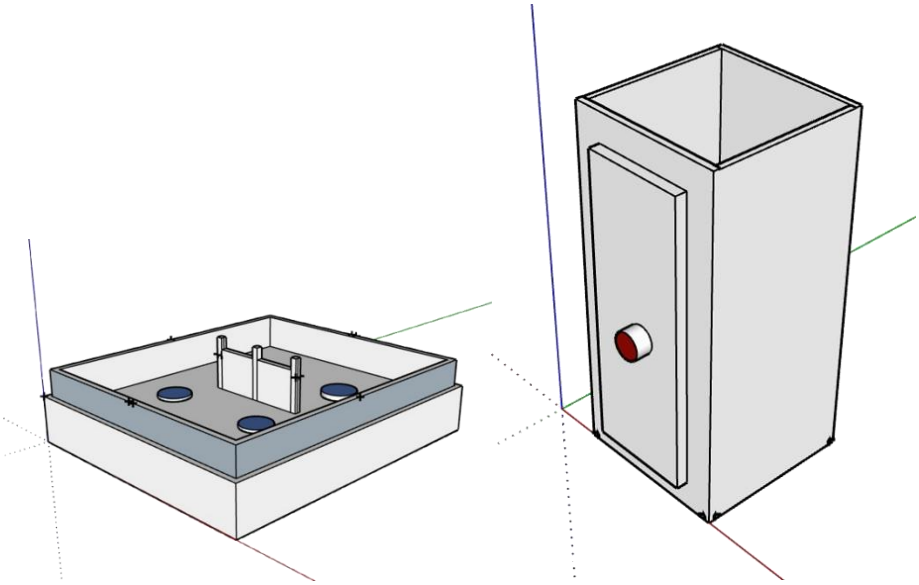

Figure 1. Fluorescence Tool Body Design

Software Design

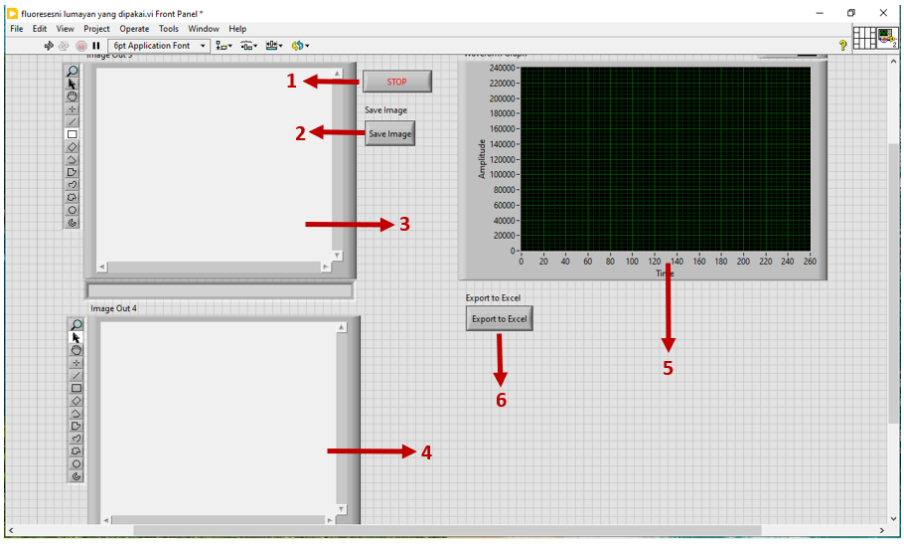

Figure 2. Fluorescence imaging system software design

1. Stop button
2. Save image (save image)
3. Viewfinder
4. Image viewer
5. Image histograph viewer
6. Exporthistograph to excel

Results and Discussions

Data collection of chicken fat, beef fat, cooking oil, and butter samples was carried out 6 times, including background and holder samples.

Background Spectrum

Prior to testing, the samples were scanned six times to determine the shape and position of the pixel spectrum. The background served as the baseline spectrum to determine the original spectrum of each sample. An average spectrum was then created from the six spectra as a baseline for testing subsequent samples.

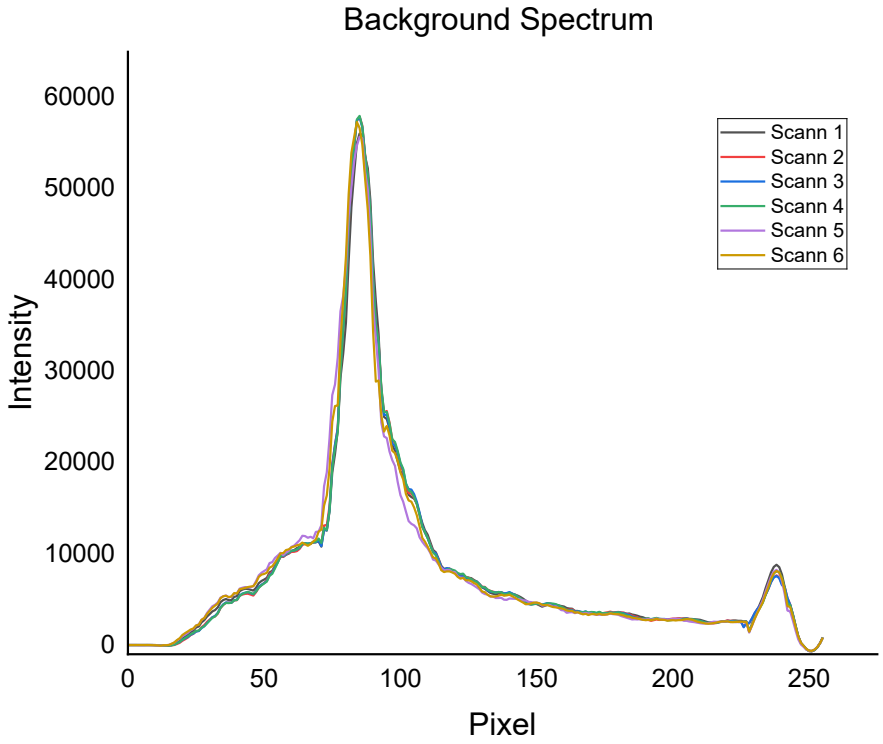

Figure 3. Background fluorescence spectrum

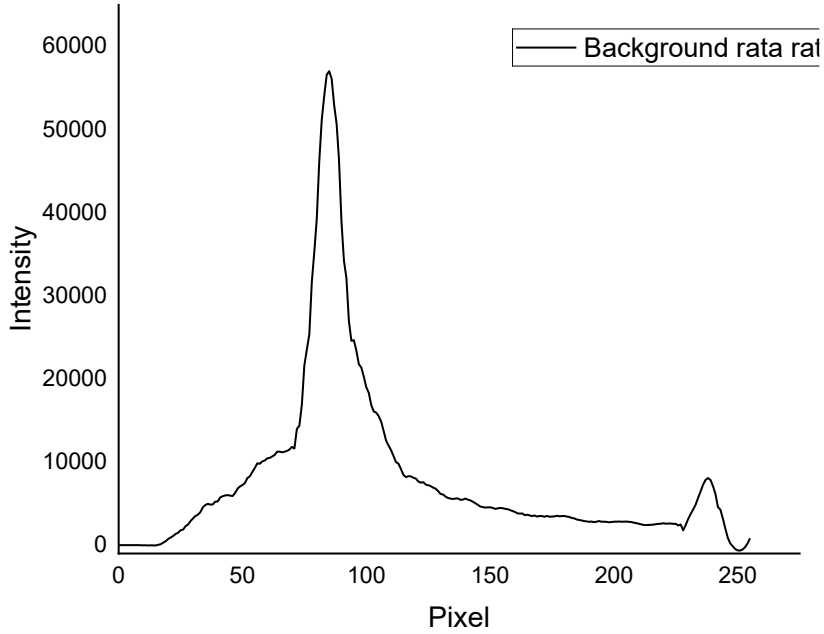

Figure 4. Average background spectrum

Background measurement is a crucial step in a fluorescence spectroscopy system to ensure that the signal detected during sample testing is truly derived from the fluorescence emission of the test material, and not from system noise or optical artifacts (Figure 3 and Figure

4). In this study, background measurements were performed without the presence of the sample or sample holder to obtain basic characteristics of the detection system.

The measurement results show that the background signal intensity is consistently within the pixel value range between 70 and 110. This range is observed to be stable in six repeated measurements, which were carried out under identical conditions and without external interference. This consistency indicates the stability of the optical-electronic system, and indicates that the fluorescence imaging system used has reliable performance in terms of basic signal reproducibility.

This range of pixel intensity values can be formally defined as a background reference for subsequent fluorescence tests. With this reference, any signal detected outside this range can be interpreted as the actual fluorescence signal from the sample, after background correction. Using this baseline is crucial for improving the accuracy of fluorescence signal quantification and minimizing potential misinterpretation due to system interference.

Determining these background values also provides an important foundation for developing advanced signal processing methods, such as background subtraction, thresholding, and intensity-based segmentation algorithms. Going forward, comprehensive and systematic background characterization like this is expected to improve the validity of fluorescence spectroscopy systems in various scientific and industrial applications, including biomolecular analysis, food compound detection, and halal ingredient verification.

Background Holder Spectrum

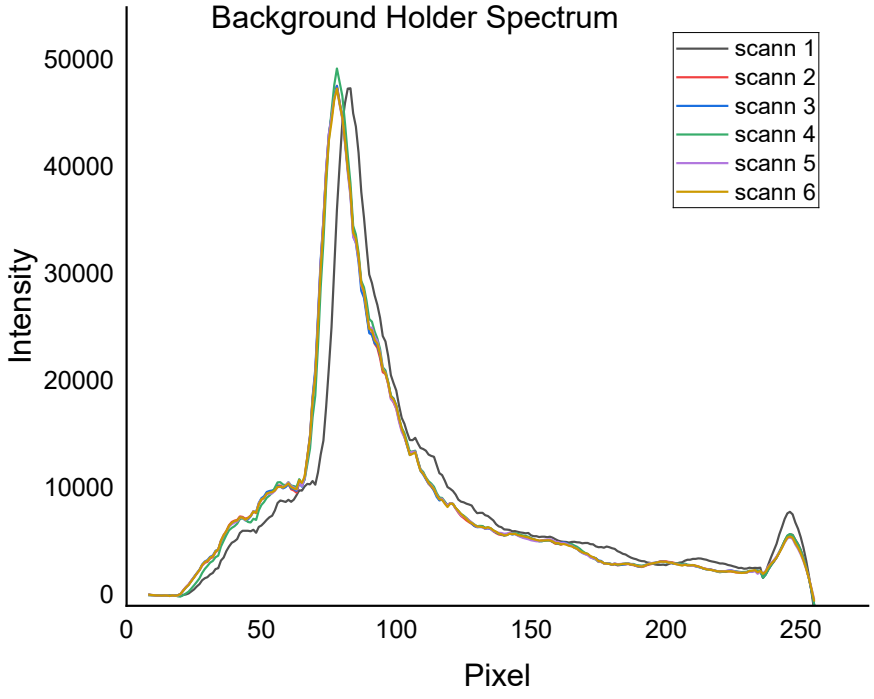

Figure 5. Background Holder Spectrum

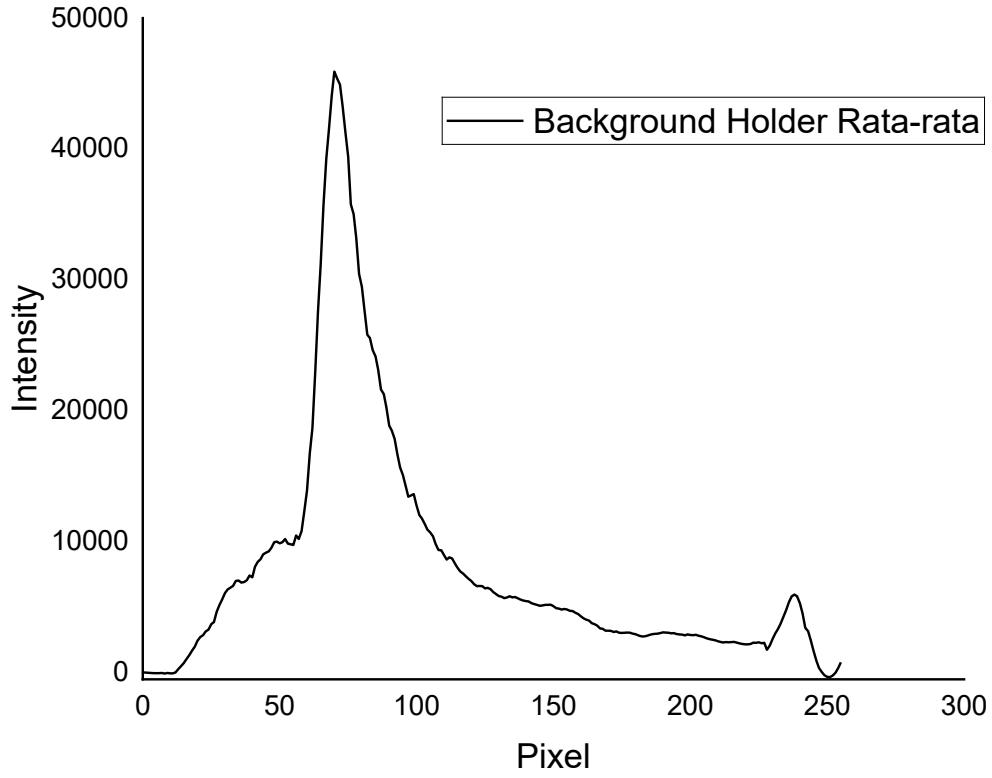

Figure 6. Background Holder Spectrum

The results of background spectrum measurements using a plastic sample holder showed a signal in the pixel range between 50 and 100, with a maximum intensity reaching approximately 49,000 digital intensity units (Figure 5 and Figure 6). When compared to the background spectrum without the holder, there was a shift in the dominant pixel value towards the lower end and a significant decrease in the peak intensity value. This phenomenon indicates an interaction between the excitation light and the plastic material of the holder.

The decrease in intensity and spectral shift indicate that the plastic sample holder absorbs some of the UV light emitted by the HPL LED source with a wavelength of 365 nm. This absorption reduces the energy reaching the detector, resulting in a lower and shifted background signal. This finding is important because it confirms that the material and design of the holder have a direct influence on the response of the fluorescence system. Therefore, the optical characteristics of the sample holder need to be carefully considered in the system calibration process and data interpretation to ensure the accuracy of the overall fluorescence test results.

Beef Fat Spectrum

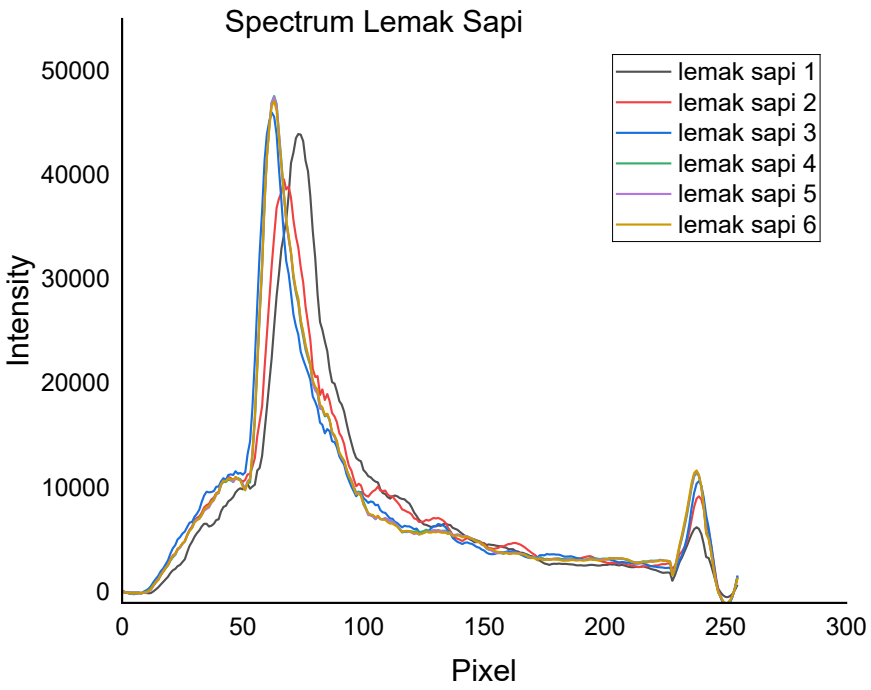

Figure 7. Spectrum Beef Fat

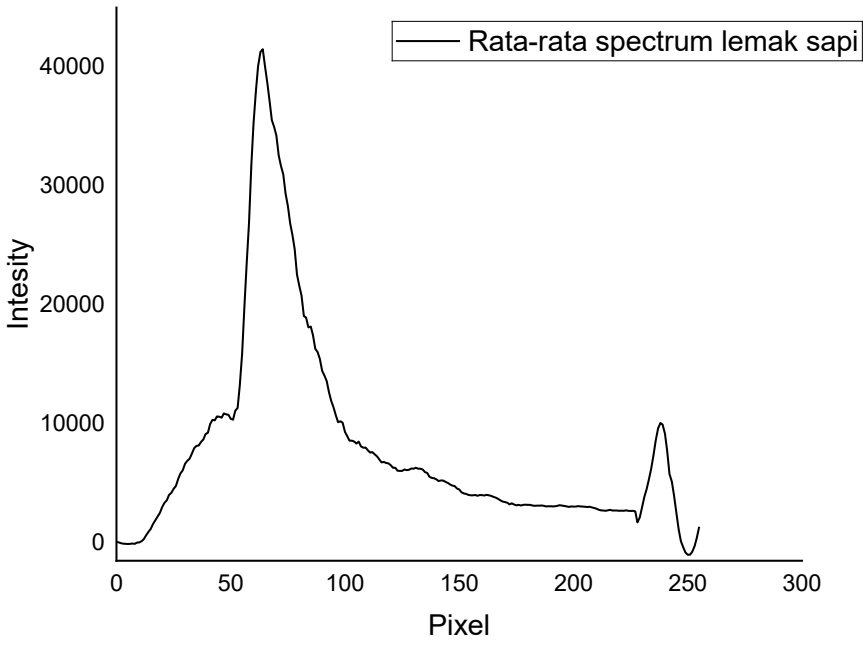

Figure 8. Average spectrum of beef fat

Beef fat testing using the fluorescence spectroscopy imaging system was performed six times to obtain representative spectral data (Figure 7 and Figure 8)The test results showed differences in the spectral patterns in the first two tests compared to the next four tests. The spectrum in the first test showed the typical characteristics of fat in the liquid phase, while in the second test, fat globules began to form, indicating a phase transition. The spectra in tests 3 through 6 showed a relatively uniform graphic pattern, indicating that the fat sample had completely undergone a phase change to a solid. These differences in characteristics provide evidence that the physical phase of the fat directly affects the fluorescence response captured by the system.

From the results of the six tests, an average spectrum was calculated to obtain a general representation of the fluorescence characteristics of beef fat. The average spectrum shows a dominant pixel value in the range of 50–100, with a maximum intensity of approximately 45,000 digital units. When compared with the background spectrum without a sample and the spectrum with a sample holder, the position of the dominant pixel remains relatively constant, but there is a decrease in signal intensity. This indicates that some of the UV excitation light (365 nm) has been absorbed by the beef fat, resulting in a lower fluorescence signal. These findings strengthen the indication that the fat material has an absorbance capacity for UV radiation and that the system used is sensitive enough to detect phase changes and light interactions with the sample.

Chicken Fat Spectrum

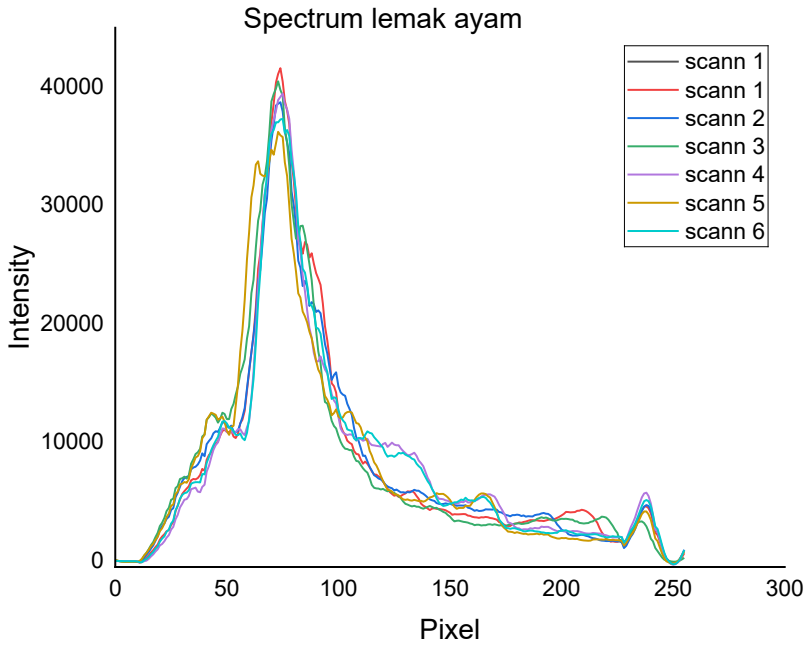

Figure 9. Chicken fat spectrum

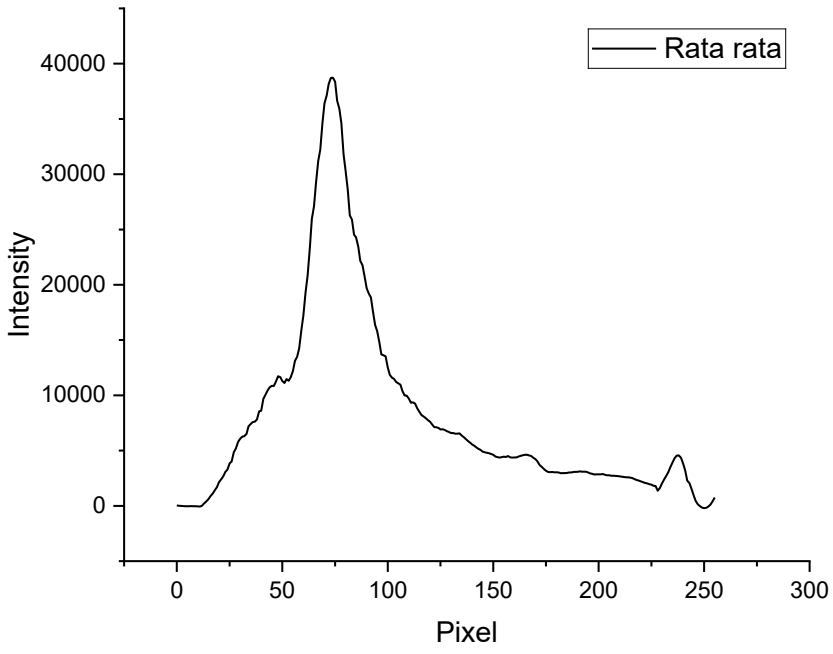

Figure 10. Average spectrum of chicken fat

The fluorescence spectrum produced by the chicken fat sample shows a graphic pattern similar to the spectrum of beef fat, especially in the dominant pixel value position which is in the range of 50–100 (Figure 9 and Figure 10). However, the maximum intensity measured from the chicken fat sample is recorded lower, which is around 39,000 digital intensity units. This difference in intensity values indicates that chicken fat has a higher absorption level of UV excitatory light (365 nm) compared to beef fat. This greater light absorption causes the energy transmitted as a fluorescence signal to be lower to the sensor.

All chicken fat tests were conducted six times under consistently controlled conditions. The results from the six data collection sessions showed a relatively consistent and stable spectral pattern, both in terms of curve shape and intensity values. This stability indicates that the fluorescence imaging system used has reliable performance and is sensitive to variations in biological materials. Furthermore, the stability of the results also indicates that the chicken fat did not undergo significant phase changes during the measurement process, strengthening the validity of the obtained spectral data.

Butter Spectrum

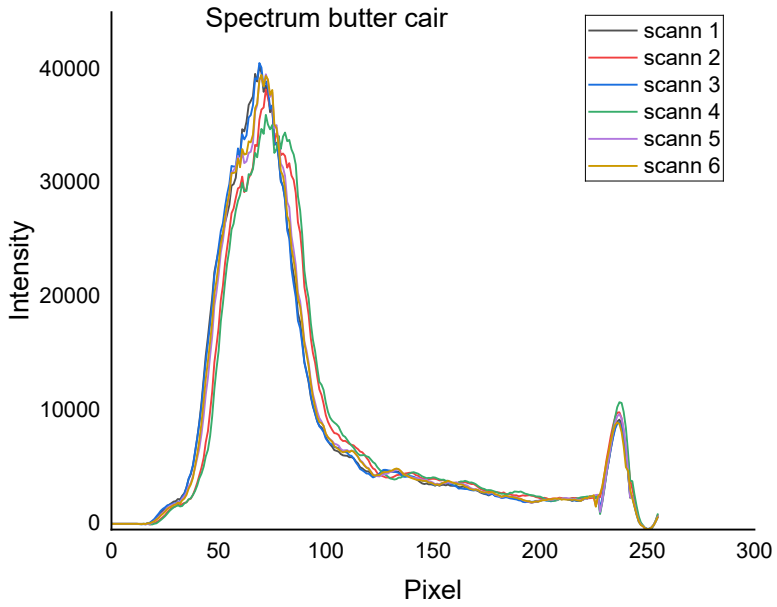

Figure 11. Liquid butter spectrum

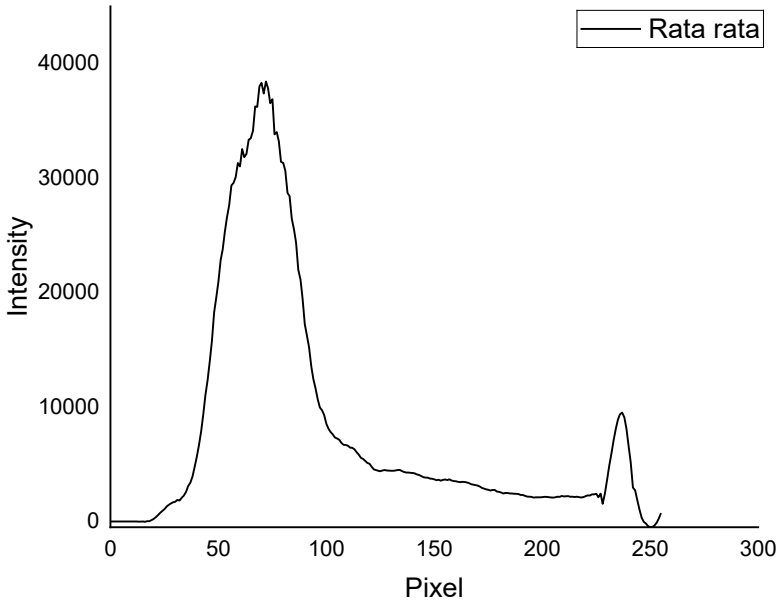

Figure 12. Average spectrum of melted butter

Further testing was conducted on vegetable fats, namely Blue Band brand butter and cooking oil, to compare the characteristics of their fluorescence spectra with those of animal fats (Figure 11 and Figure 12). The spectra recorded by the fluorescence imaging system showed quite striking differences in patterns, both in terms of the width of the pixel value distribution and the intensity of the resulting signal. The spectrum of butter showed a dominant pixel range between 48 and 110, with an average intensity reaching around 39,000 digital units. This range showed a slight shift towards lower pixels compared to beef fat, but was relatively close to the spectrum pattern of chicken fat.

Despite having a similar intensity to chicken fat, at around 39,000, butter displays a wider pixel distribution. This indicates that butter-type vegetable fats have an absorbance profile similar to chicken fat, but with a more dispersed spectrum. This difference is likely due to different chemical compositions, particularly the content of saturated and unsaturated fatty acids, as well as the presence of additives in processed products such as commercial butter. The shift in the dominant pixel range also indicates that the optical properties and interactions between vegetable fats and excitation light have unique characteristics that need to be taken into account in the process of identifying and discriminating fat types using fluorescence systems.

Cooking oil Spectrum

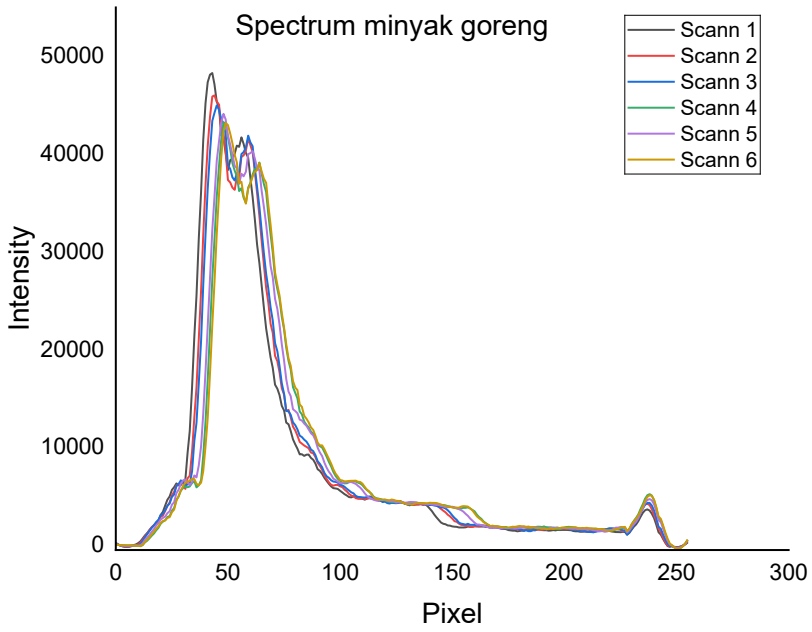

Figure 13. Spectrum of cooking oil

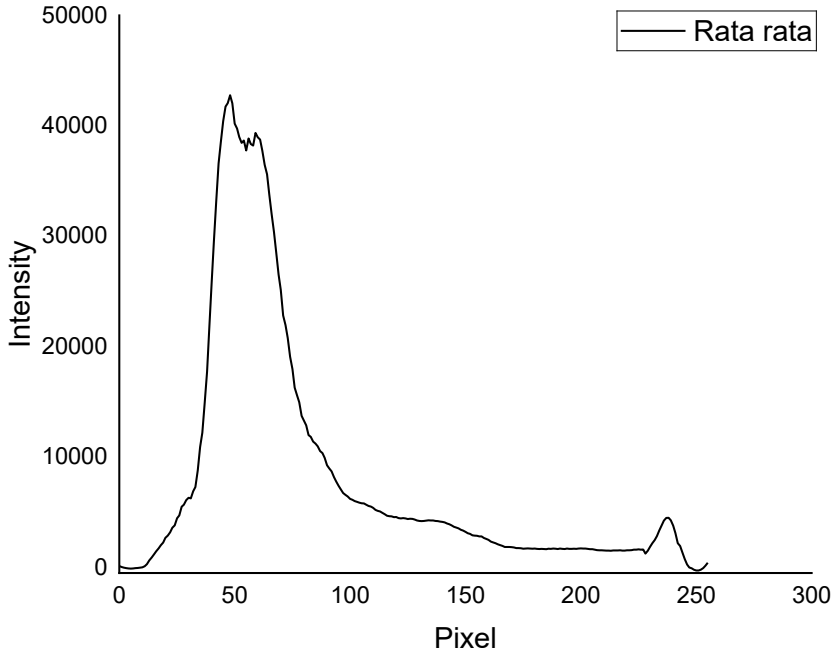

Figure 14. Average spectrum of cooking oil

In addition to butter as a representative of processed vegetable fat, testing was also conducted on palm-based cooking oil to broaden the scope of fluorescence spectra characterization of various types of fats (Figure 13 and Figure 14). The spectrum results from cooking oil show a pattern that tends to be different compared to animal fats and butter. The dominant pixel value range lies in the interval 47 to 100, but the highest intensity is concentrated in a narrow range, namely pixels 47–50, with a maximum intensity value of 42,000 digital units. This indicates that cooking oil has a different absorbance profile, where the absorption peak occurs earlier in the spectrum, and its distribution is narrower than other fats.

Compared to butter, cooking oil exhibits slightly higher peak intensity, but its overall absorbance is lower and narrower. This indicates that the molecular structure and chemical composition of cooking oil—which generally contains high levels of unsaturated fatty acids—have different light interaction characteristics. To gain a more comprehensive understanding, a comparative analysis of the average spectra of all samples, both animal and vegetable fats, was performed. The results of this comparison were used to identify the characteristic differences in fluorescence of each type of fat and to assess the potential of the fluorescence imaging system in accurately detecting and classifying fat sources.

Comparison of each sample spectrum

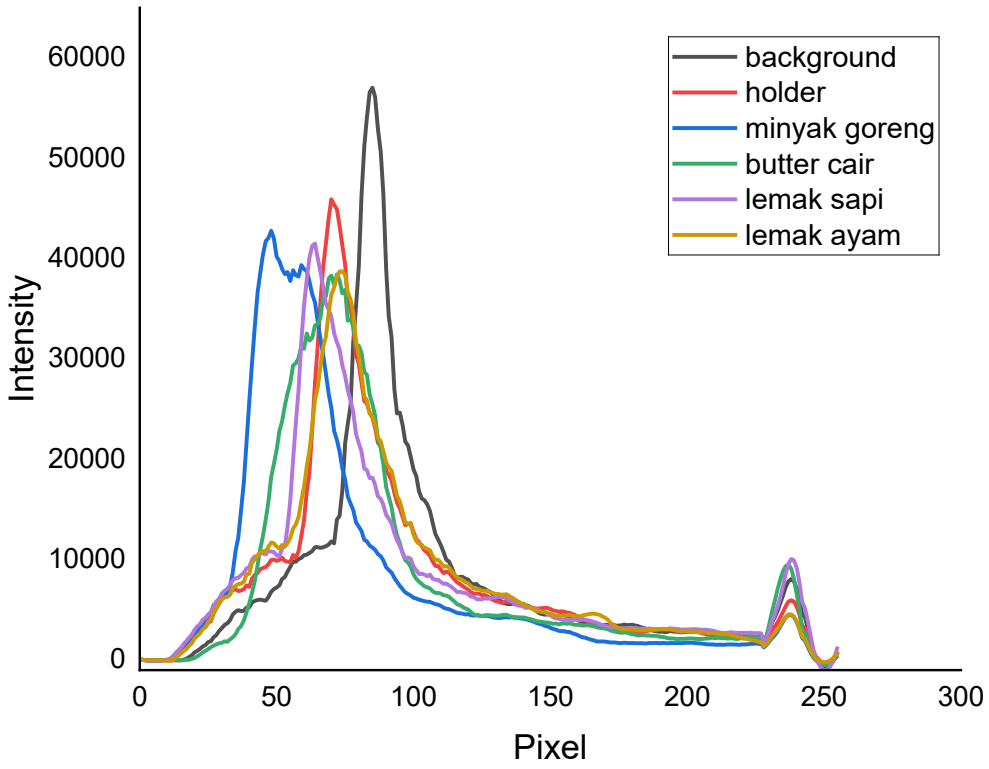

Figure 15. Comparison of the spectrum of each sample

Analysis of the pixel intensity distribution in the fluorescence images of each sample shows quite clear differences, both in terms of maximum intensity values and the range of dominant pixel values. Each type of fat—both animal fat (beef and chicken) and vegetable fat (butter and cooking oil)—has its own spectral characteristics reflected in its fluorescence image (Figure 15). These differences include the distribution of the spectrum width, the position of the intensity peak, and the level of absorption of the excitation light. This indicates that the fluorescence imaging system has the ability to capture optical variations related to the physical and chemical properties of each type of fat.

Initial testing of the fluorescence instrument showed that the background pixel intensity values without sample and without holder were consistently in the range of 70–110, with peak intensity remaining stable over six repetitions. This stability provides an important basis for establishing a baseline detection threshold, which is then used as a reference for spectral analysis of fat samples. This value reflects the instrument's baseline response to UV radiation without interference from fluorescent materials, thus improving the accuracy and credibility of further analysis.

Furthermore, the distribution of pixel intensities in the fluorescence images of each type of fat shows significant variations, both in terms of maximum intensity and the range of dominant pixel values. For example, cooking oil has a dominant range of values 47–100, with a peak at 42,000 at 47–50, while butter displays a slightly higher pattern. This variation indicates that the chemical structure and saturation level of each fat affect their ability to absorb and reflect UV signals, which can be represented in the fluorescence image.

However, the average spectral analysis of all samples revealed slight differences in spectral patterns, suggesting overlap between specific fat types. This suggests that while the device is capable of detecting fluorescence differences in general, advanced approaches based on numerical image analysis and statistical classification or machine learning are needed to improve the sensitivity and selectivity of this detection system. Thus, this device is not only a promising optoelectronic prototype for halal fat detection but also a starting point for the development of adaptive, efficient, and ethical halal characterization technology that aligns with the ethical principles of modern Muslim consumption.

Conclusion

Based on the results of fluorescence spectrum testing on various types of fat—namely beef fat, chicken fat, butter (vegetable), and cooking oil—it was found that each type of fat showed a relatively distinctive spectral pattern, both in terms of the dominant pixel value range and its intensity. Chicken and beef fat had similar patterns but with differences in intensity, while vegetable fats such as butter and cooking oil showed significantly different spectra. These findings confirm that the designed UV-LED-based fluorescence system has the potential as an effective characterization tool to differentiate animal and vegetable fat types. With relatively stable accuracy in six tests, this tool plays an important role in supporting Halal-Tech innovation, in line with the maqāṣid al-sharīʿah which guarantees the halal consumption of Muslims through an ethical scientific approach.

Acknowledgments

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Conflicts of interest

None.

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