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Differentiation of Imported and Local Rice using Terahertz Time-Domain Spectroscopy (THz-TDS)

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Abstract

Accurate authentication of rice origin is critical for ensuring food quality and market integrity. This study investigates the feasibility of differentiating between imported (Thai Jasmine, Indian Basmathi) and local (Selangor, Kelantan) rice varieties using Terahertz Time-Domain Spectroscopy (THz-TDS). Four types of rice were analysed, consisting of two imported varieties (Indian Basmathi and Thai Jasmine) and two local varieties from Kelantan and Selangor. The samples were prepared by grinding the rice into fine powder and placing it on a glass slide for transmission measurements. Five repeated measurements were performed for each rice type to ensure consistency. The results show that clear differences in the absorption spectra and PCA score plots can be observed between imported and local rice samples, indicating that THz-TDS is a promising tool for rice authentication and origin classification. Transmission-mode measurements were conducted on powdered rice samples over the frequency range of 0.1 THz to 3.0 THz. The extracted frequency-domain data revealed distinct absorbance profiles for each variety, attributed to variations in compositional and structural properties. To evaluate the discrimination capability of the system, Principal Component Analysis (PCA) was employed on the spectral data. The PCA results demonstrated clear clustering and separation between imported and local rice samples, confirming the method's effectiveness. These findings establish THz-TDS, combined with multivariate analysis, as a promising rapid and non-destructive technique for rice origin verification and food safety applications.

1. Introduction

Rice is a staple food for a large portion of the global population, its quality and origin have an important effect on both market value and customer preference. In many countries, including Malaysia, imported rice is commonly mixed or replace with local varieties, making accurate identification of rice origin become more difficult. Modern methods used for rice authentication, such as chemical analysis and molecular techniques, frequently require complex sample preparation, skilled staff, and destructive testing procedures. These restrictions have encouraged research into different non-destructive methods for identifying the origin of rice. Conventional techniques for rice analysis include near-infrared spectroscopy, Raman spectroscopy, and chromatographic methods. However, many of these techniques require complex sample preparation, chemical reagents and times consuming.

Terahertz time-domain spectroscopy (THz-TDS) has become known as a successful non-destructive analytical method for material analysis. Operating in the frequency range between microwaves and infrared light, terahertz radiation is sensitive to moisture content, molecular vibrations and intermolecular interactions in biological materials. Because of this feature, THz-TDS is especially useful for applications in food science and agriculture, where small compositional changes can have a big impact on the terahertz spectrum response [7]; [10]. Previous studies have demonstrated the potential of THz spectroscopy in characterizing grains, powders, and other food products without changing their physical structure. Terahertz time-domain spectroscopy (THz-TDS) offers a non-destructive, rapid, and reagent-free alternative that can probe both physical and chemical properties of materials, making it suitable for food quality and origin studies.

In rice analysis, terahertz spectroscopy has demonstrated its ability to detect differences in starch structure, moisture absorption, and chemical composition. Local and imported rice can have different terahertz absorption trends due to differences in storage conditions, processing techniques and growth factors. However, overlapping of terahertz spectra might make direct interpretation of terahertz spectra more challenging. To address this issue, multivariate statistical techniques such as principal component analysis (PCA) are frequently used. PCA reduces the dimensionality of spectral data while preserving key variance patterns, allowing clearer visualization and discrimination between sample groups [1].

Consequently, this research explores the use of THz-TDS combined with PCA to differentiate between imported and local rice varieties. Terahertz measurements in transmission mode are conducted on selected rice samples and multivariate techniques are used to analyse the absorbance spectra. The outcomes of this study are to provide a quick and non-invasive way for determining the origin of rice and improving food authentication processes.

2. Materials and Methods

This study is based on experimental analysis involving terahertz spectroscopy of rice samples from different countries of origin. The primary objective of the experiment is to examine how rice samples absorb terahertz radiation. To maintain uniformity across the research, all measurements were conducted using same setup and procedure. Four varieties of rice were chosen for this research which is two imported varieties (Thai Jasmine and Indian Basmathi), and two local varieties from Kelantan and Selangor. These rice types were chosen because these rices are widely available in the Malaysian market.

All rice samples were prepared using the same procedure before measurement to keep consistent. The rice grains were first left to dry at room temperature to reduce the influence of moisture because moisture can affect terahertz measurements. After drying, the grains were blended into a powder using a blender. Care was taken to grind all samples by using the same equipment and duration to minimize the particle size variation. This step was performed to reduce grain size and minimise scattering effects during terahertz measurement. Then, the powdered rice was spread evenly on a glass slide to form a thin layer. An empty glass slide was used as a reference sample.

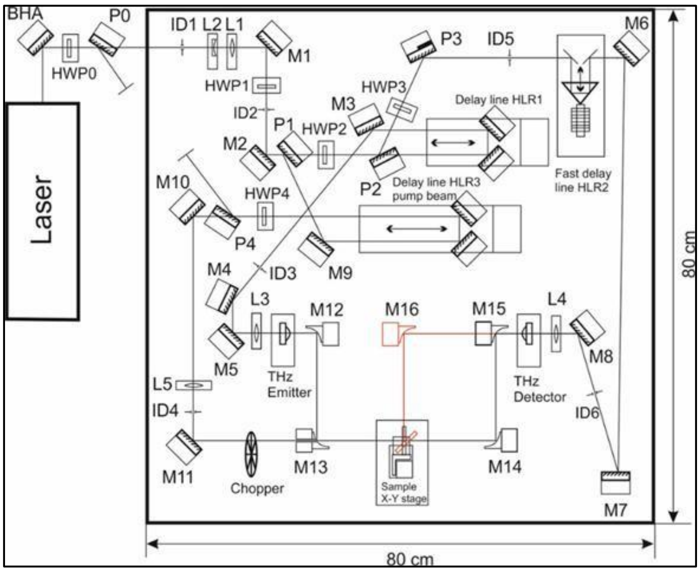

Fig. 1 The schematic diagram of the terahertz-time domain spectroscopy system

Measurements were conducted using a terahertz time-domain spectroscopy system operating in transmission mode. Fig. 1 shows the schematic diagram of the terahertz time-domain spectroscopy system used for the measurement. During these measurements, a terahertz pulse was directed through the rice sample positioned on the glass slide, with the transmitted signal recorded in the time domain. A reference measurement was taken first using the empty glass slide under identical experimental conditions. For each type of rice, five repeated measurements were performed to assess data reliability and repeatability. The setup remained unchanged throughout the experiment to guarantee accurate comparisons between samples.

The recorded time-domain signals were processed using Fast Fourier Transform to extract frequency-domain spectra. Absorption spectra were calculated by comparing the transmitted signal through the rice sample with the reference signal. In this technical report, analysis focuses on the frequency-domain spectra and absorption characteristics which provide useful information about how terahertz waves interact with the rice samples.

To investigate variation among all the rice samples, the absorption data was analysed according to Principal Component Analysis (PCA). PCA functioned as an exploratory method for visualizing patterns and clustering tendencies between local and imported rice varieties. The outcomes of PCA were interpreted qualitatively and not for classification or predictive purposes.

3. Results and Discussion

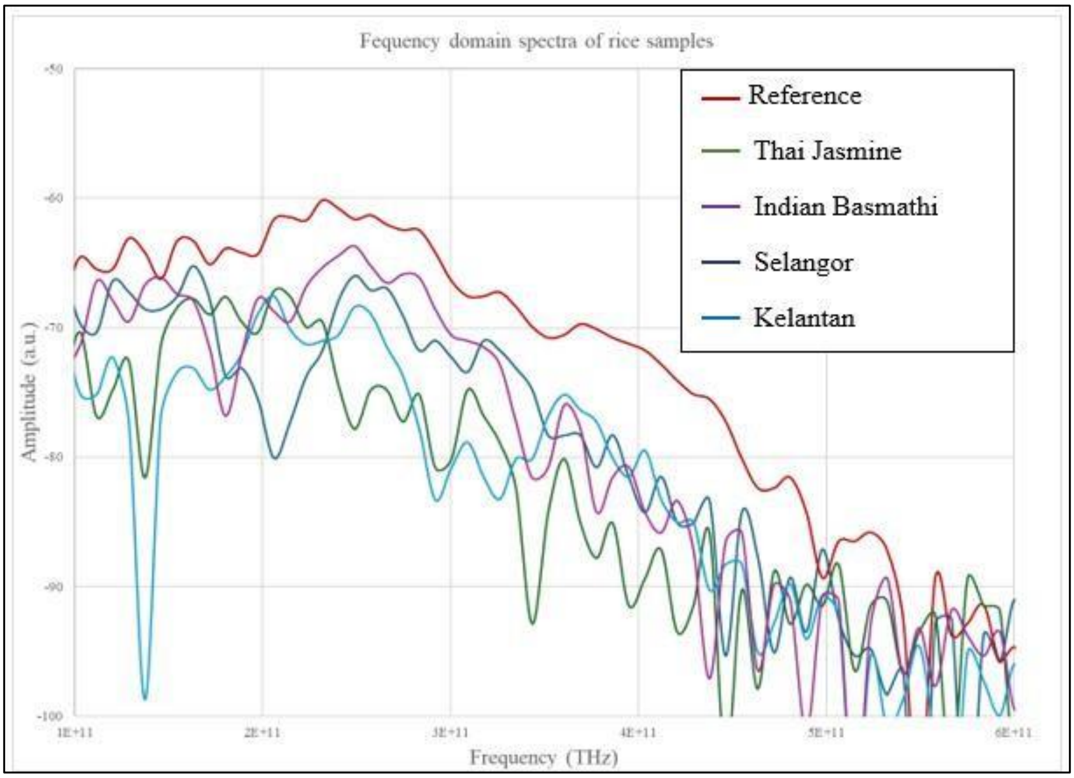

Fig. 2 Frequency domain spectra of rice samples

Fig. 2 shows that the frequency-domain spectra obtained for all rice samples show smooth and continuous patterns throughout the measured terahertz frequency range. Differences in signal amplitude are observed between rice samples of different origins and varieties. Frequency is shown on the horizontal axis and signal amplitude is plotted on the vertical axis. The red curve represents the reference spectrum, which corresponds to the system response recorded without a rice sample and it is used as a baseline for comparison.

The reference spectrum shows the highest amplitude across most of the observed frequency range, indicating significant signal attenuation. In contrast, all rice samples exhibit smaller amplitudes, indicating that terahertz waves are attenuated during transmission through the rice grains. This attenuation results from absorption and scattering effects related to the internal structure of the rice.

At lower frequencies, the rice samples' spectral typically follow the shape of the reference spectrum but with lower amplitudes. As the frequency increases, stronger attenuation and greater spectral variations are observed, it is shown that higher terahertz frequencies are more sensitive to the rice grains' microstructural.

There are noticeable differences among the rice sample spectra are observed at specific frequency regions where different levels of amplitude reduction occur. These change show different terahertz responses, which could be explained by differences in the rice composition, origin, or processing conditions. The consistent deviation of the rice spectra from the reference over multiple samples suggests that the observed differences are systematic rather than noise-related.

Overall, the results show that frequency-domain terahertz spectroscopy is suitable for non-destructive discrimination of rice samples based on their physical and chemical characteristics and is sensitive to material dependent properties of rice.

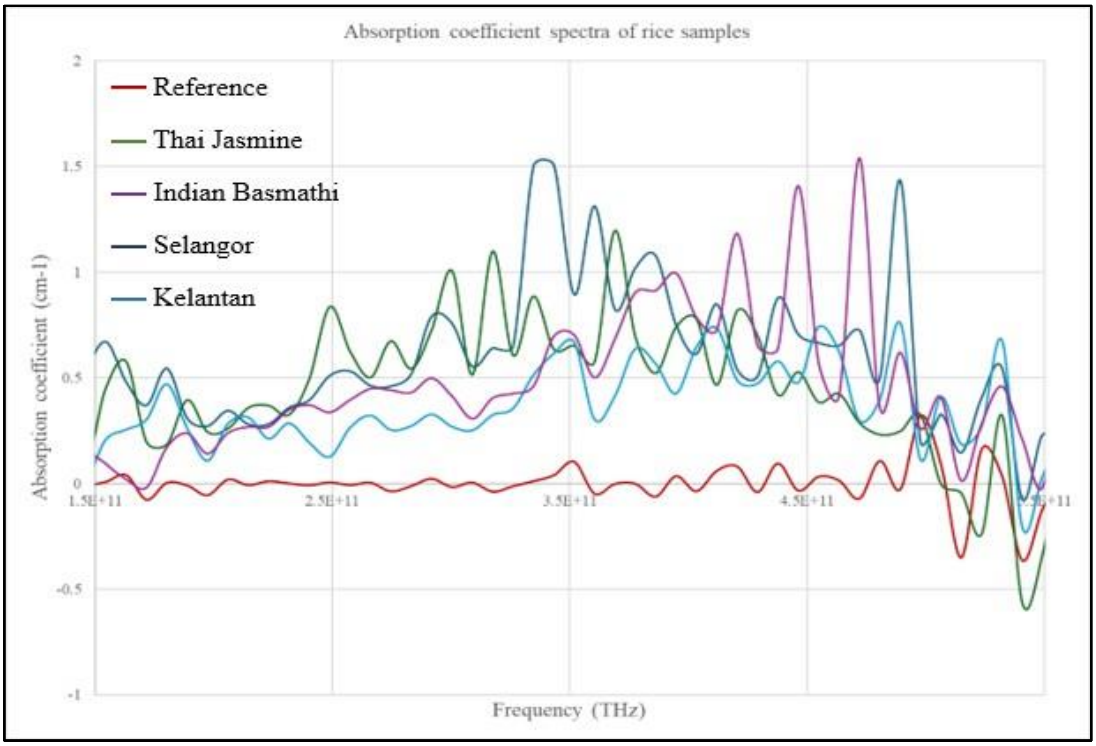

Fig. 3 Absorption coefficient spectra of rice samples

Fig. 3 represented absorption coefficient spectra of rice samples. Absorption analysis shows more noticeable differences among the rice samples. The imported rice samples, Thai Jasmine and Indian Basmathi, shows absorption trends are different from the local rice samples from Kelantan and Selangor. These differences indicate that rice samples from different origins are attenuated to different degrees.

The horizontal axis displays frequency while the absorption coefficient (cm^{-1}) is shown on the vertical axis. The red curve represents the reference measurement obtained without a rice sample and is served as a baseline. The reference spectrum remains close to zero across the majority of the frequency range and indicates negligible absorption. In contrast, all rice samples show greater absorption coefficients indicating that terahertz waves are absorbed as they pass through the rice grains. Terahertz radiation and interior components of the rice interact to produce this absorption.

The increased absorption observed in the rice samples is mostly relevant to their compositional and structural characteristics, including starch content, molecular bonding, and residual moisture. The absorption coefficient generally increases with frequency, indicating that the rice material and terahertz radiation interact more strongly at higher frequencies.

Distinct absorption characteristics and variations are observed among the rice samples at several frequency regions, suggesting differences in terahertz absorption behaviour. These changes are probably caused by differences in grain structure, chemical composition, and growing or processing conditions, which might differ depending on the rice origin. At higher frequencies, fluctuations and occasional negative values are observed in both reference and sample spectra, which are caused by system noise, reduced signal-to-noise ratio, and phase uncertainty. Despite this, rice samples consistently showing higher absorption than the reference and maintaining a clear overall trend.

Overall, the absorption spectra demonstrates that terahertz spectroscopy is sensitive to material-dependent properties of rice and indicate its potential as a non-destructive technique for differentiating rice samples based on origin.

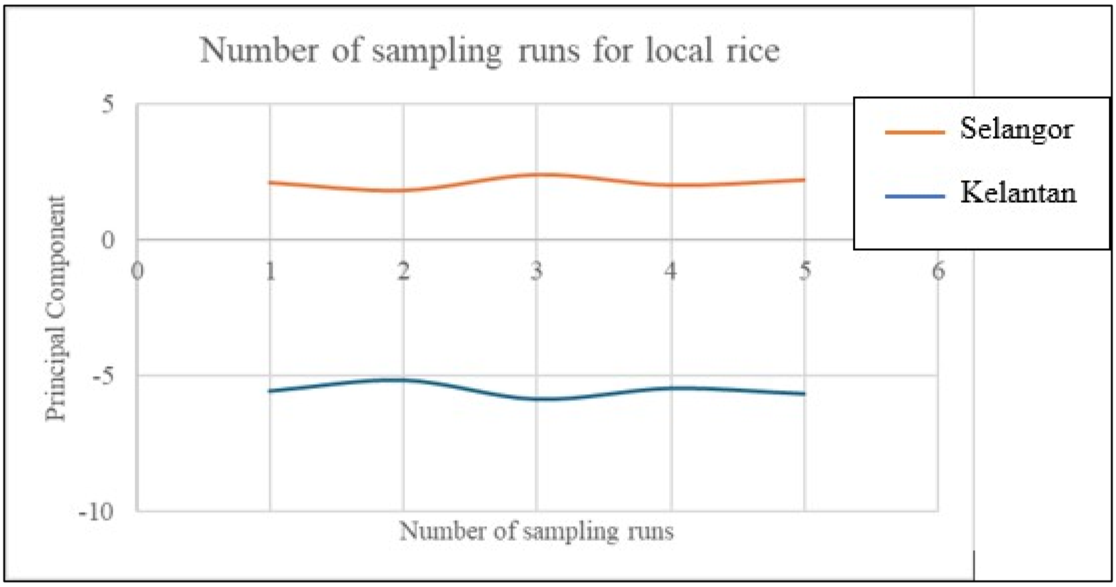

Fig. 4 Number of samplings runs for the local rice

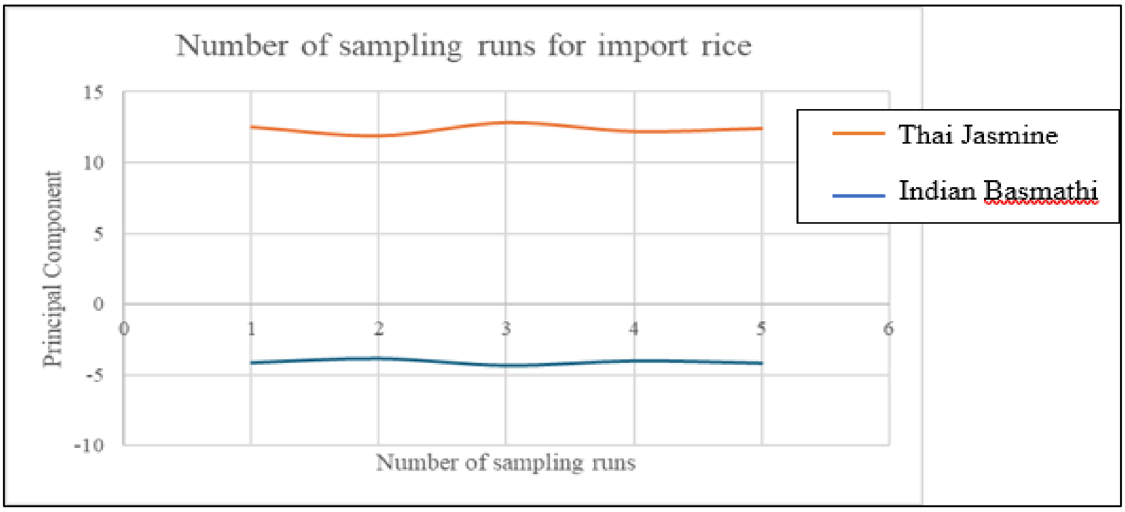

Fig. 5 Number of samplings runs for the import rice

Fig. 4 and Fig. 5 present the absorption spectra obtained from five repeated terahertz measurements for local and imported rice samples. All rice samples show good consistency throughout repeated measurements but with just a slight difference between runs. This confirms the stability of the experimental setup, and the absorption data is accurate. The absorption curves in both situations show strong overlap and stable trends across all measurement runs with only slight differences observed.

The small differences between repeated measurements are likely due to experimental factors such as slight differences in sample thickness and placement on the glass slide. Overall, the high level of consistency observed for both local and imported rice samples confirms the stability of the experimental apparatus and repeatability of the measuring process. This repeatability supports the validity of the absorption data used ensuring comparative analysis and exploratory techniques such as principal component analysis.

Principal component analysis (PCA) was a method implemented on terahertz spectroscopy data to assess whether extracted features can differentiate different rice types. PCA is widely used in spectral analysis to reduce the dimensional structure of the data, still preserving the most substantial variation in the dataset [3].

The PCA score plot is shown in Figure 6 with the first two principal components PC1 and PC2 that reveal the primary heterogeneity of terahertz measurements. The score plot shows clear clusters of samples by rice type, which means that the terahertz spectral features show clear discrimination even if dimensionality reduced. The Indian Basmathi rice samples are grouped together in the negative region of both PC1 and PC2, which indicates a good close intra-class resemblance and general terahertz behaviour. Such a narrow range indicates that compositional and structural traits are similar, which may affect the interference of terahertz waves throughout the material. The variant percentage of PC1 is 88%. Most of the difference between the samples were explained by this component, it differentiates the imported and local rice origins. The most important factor can be seen by the wide spread along the X-axis which is from -25 to +25. For the PC2, the variant percentage is 12% where it explains the secondary differences, which are probably associated with the specific rice variety which is Thai Jasmine vs. Indian Basmathi. These differences are smaller than the origin differences, as shown by the much smaller spread along the Y-axis which is from -7.5 to +12.5.

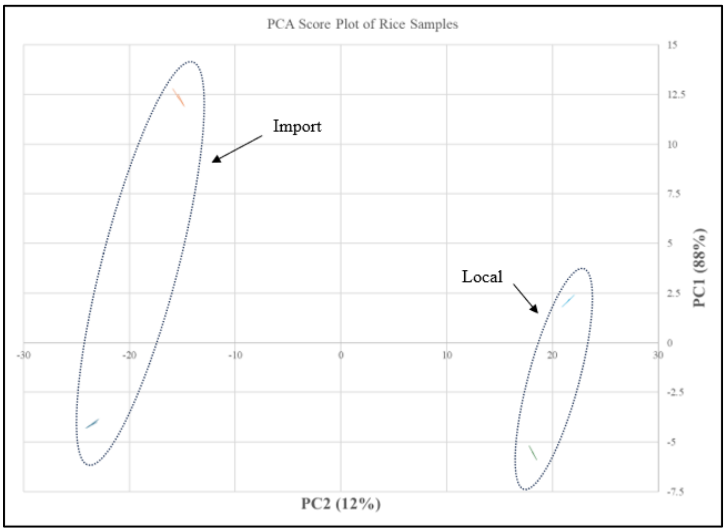

Fig. 6 Principal component analysis (PCA) of terahertz absorption data

On the other hand, Jasmine Thai rice samples are shown to be found in the negative PC1 and positive PC2 regions indicating that PC2 is a significant discriminative mechanism in distinguishing Jasmine Thai rice from Indian Basmathi rice. This separation indicates that the differences in terahertz absorption behaviour as well as dielectric response may be responsible for the observed discrimination between these two imported rice types.

Positive PC1 and negative PC2 quadrant represent clearly separated Kelantan rice samples meaning PC1 plays a significant role in separating Kelantan rice from other rice products. Hence, the PC1 dominated variance has to do with specific spectral features about internal structure or composition of the Kelantan rice. Samples from Selangor rice also cluster around positive region in PC1 and PC2 and form a different group from the remaining samples. PC2 also displays the separation of Kelantan and Selangor rice as a contributor indicating the relevance of this element in differentiating between rice types according to their regional origin.

The minimal overlap between the clusters in the PCA score plot illustrates the prominent discrimination performance of the terahertz spectroscopy data. Taken together, these findings establish the successful capturing of the intrinsic variations between rice types and origin with terahertz features, as extracted from the images. Also, the results show that PCA is a reliable multivariate method in classification and pattern recognition used for terahertz sensing systems for the purpose of terahertz detection [9]. The clear and straightforward separation of local and imported rice samples further corroborated the potential of combining terahertz spectrum studies with multivariate analysis as a non-destructive path for rice origin determination and is useful in quality control, authentications checks, import verification systems, and others.

4. Conclusion

This research explored the viability of utilizing terahertz time-domain spectroscopy (THz-TDS) in conjunction with principal component analysis (PCA) to distinguish between imported and locally sourced rice samples. Terahertz measurements taken in transmission mode indicated distinct differences in the absorbance spectra of the rice across the analysed frequency range. While individual spectral characteristics displayed some overlap, significant variations in absorbance intensity were noted between the imported and local varieties. The application of PCA on the absorbance spectra improved discrimination by highlighting clustering patterns related to the origin of the rice. These findings underscore that multivariate analysis is crucial for enhancing the interpretability of terahertz spectral data, especially when direct visual comparisons are inadequate. In summary, the results indicate that THz-TDS holds promise as a non-invasive method for identifying rice origins and validating food authenticity. It is advisable to conduct further research with an expanded sample size and controlled measurement conditions to enhance classification reliability and robustness.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Siti Norsyafiqah Muhammad Aridi, Noor Azura Awang;* ***data collection:*** *Siti Norsyafiqah Muhamad Aridi;* ***analysis and interpretation of results:*** *Siti Norsyafiqah Muhamad Aridi, Noor Azura Awang;* ***draft manuscript preparation:*** *Siti Norsyafiqah Muhamad Aridi, Noor Azura Awang. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Chen, T., Zhang, H., Liu, Y., Wang, J., & Zhou, Z. (2017). Discrimination of transgenic rice seeds using terahertz spectroscopy combined with chemometric methods. Food Chemistry, 217, 348–354. https://doi.org/10.1016/j.foodchem.2016.04.117

[2] Chen, X., Xue, Z., Wang, J., & Jiang, H. (2019). Identification of rice varieties and geographical origin using visible and near-infrared spectroscopy. Food Chemistry, 272, 144–151. https://doi.org/10.1016/j.jcs.2021.103322

[3] Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: A review and recent developments. Philosophical Transactions of the Royal Society A, 374(2065), 20150202. https://doi.org/10.1098/rsta.2015.0202

[4] Li, Z., Wang, J., Liu, Y., & Zhang, H. (2018). Feasibility of terahertz spectroscopy for hybrid purity identification of rice seeds. International Journal of Agricultural and Biological Engineering, 11(4), 215–221. https://doi.org/10.25165/j.ijabe.20181105.3898

[5] Liu, J., Chen, T., Wang, J., Zhang, H., & Zhou, Z. (2023). Identification of rice freshness using terahertz imaging combined with deep learning. Photonics, 10(5), 547. https://doi.org/10.3390/photonics10050547

[6] Siegel, P. H. (2002). Terahertz technology. IEEE Transactions on Microwave Theory and Techniques, 50(3), 910–928. https://doi.org/10.1109/22.989974

[7] Sun, Q., Zhang, H., Chen, T., & Wang, J. (2024). Recent developments and applications of terahertz spectroscopy in food analysis. Biosensors, 15(10), 677. https://doi.org/10.3390/bios15100677

[8] Tonouchi, M. (2007). Cutting-edge terahertz technology. Nature Photonics, 1(2), 97–105. https://doi.org/10.1038/nphoton.2007.3

[9] Zhang, C., Liu, F., Kong, W., He, Y., & Zhou, W. (2025). Quantification of cumin powder adulteration with rice by-products using NIR spectroscopy combined with chemometric and machine learning models. Journal of Food Composition and Analysis, 95, 103053. https://doi.org/10.1016/j.jfca.2025.108471

[10] Zhang, H., Chen, T., Liu, Y., & Wang, J. (2020). Applications of terahertz spectroscopy in agriculture and food engineering. ASABE. 61(2): 411-424. https://doi.org/10.13031/trans.12201