Multi-Spectral techniques for detecting adulterants in turmeric powder

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ABSTRACT

The deliberate tampering of turmeric powder with potentially dangerous substances is a serious risk to the health and welfare of consumers. In this work, we sought to create a reliable technique for identifying a prevalent adulterant in turmeric powder—ferrous sulfate heptahydrate. Using the weight-to-weight approach, samples of turmeric powder were gathered from different sources and combined with ferrous sulfate heptahydrate in varying quantities (0 %, 1 %, 5 %, 10 %, 15 %, and 20 %). The mixed samples were analyzed using spectroscopic methods such as Raman spectroscopy and Fourier-transform infrared spectroscopy (FTIR). The ferrous sulfate heptahydrate's distinctive peaks were detected at 1060 cm^{-1} in Fourier transform infrared spectra (FTIR). On the other hand, turmeric showed clear peaks at 1630 cm^{-1}, 1745 cm^{-1}, 2930 cm^{-1}, and 3720 cm^{-1} in FTIR, in addition to peaks at 250 cm^{-1}, 328 cm^{-1}, and 420 cm^{-1} in Raman spectroscopy. In addition, elemental mapping was applied to guarantee that the adulterant was evenly distributed throughout the mixture. Principal component analysis and Soft Independent Modelling Class Analogy (SIMCA) models, when used in conjunction with this technique, allowed for the successful separation of tainted and pure turmeric samples. Our results show that elemental mapping and spectroscopy are useful tools for identifying ferrous sulfate heptahydrate adulteration in turmeric powder. This approach has the potential to guarantee the security and caliber of turmeric-related products sold.

1. Introduction

Turmeric powder is a widely used spice known for its culinary, medicinal, and therapeutic properties. It plays a significant role in traditional and modern medicine due to its anti-inflammatory, antioxidant, and antimicrobial effects. However, the demand for turmeric powder has also led to its adulteration with harmful substances to enhance appearance, weight, and profitability. One such adulterant is ferrous sulphate heptahydrate, whose addition poses significant public health risks. Consumption of turmeric powder adulterated with ferrous sulphate heptahydrate may lead to iron overload, oxidative stress, and gastrointestinal issues, potentially resulting in severe health complications such as liver and cardiovascular damage. Despite the societal impact, limited studies have been conducted on its prevalence and specific health implications, underscoring the need for comprehensive research in this area [4].

Various analytical techniques have been developed to detect adulterants in turmeric powder. For instance, UV–Visible Spectroscopy has been employed to identify color-based adulterants such as metanil yellow with a detection limit of 1.5 ppm and a precision of ± 3 % [1], Similarly, Raman spectroscopy demonstrated high specificity (~95 %) in detecting Sudan dye but faced limitations due to false positive rates [10]. Fourier Transform Infrared Spectroscopy (FTIR) has proven effective in identifying lead chromate with a sensitivity of 97 % [11], Fourier Transform Infrared Spectroscopy (FTIR) has proven effective in identifying lead chromate with a sensitivity of 97 % [7], and Advanced methods like terahertz spectroscopy achieved detection thresholds of ~ 2 % (w/w) for structural adulterants [14]. Furthermore, chromatographic methods and electrochemical detection have also been utilized to identify certain adulterants with high precision but are time-intensive and unsuitable for rapid screening. Despite these advancements, existing studies have largely focused on detecting specific adulterants such as metanil yellow, lead chromate, and Sudan dye, with limited applicability to ferrous sulfate heptahydrate. Additionally, reliance on single analytical techniques often fails to address complex adulteration scenarios or the coexistence of multiple adulterants Quantitative methods such as HPLC and chromatography offer high accuracy but lack the ability to visualize the distribution of adulterants within samples.
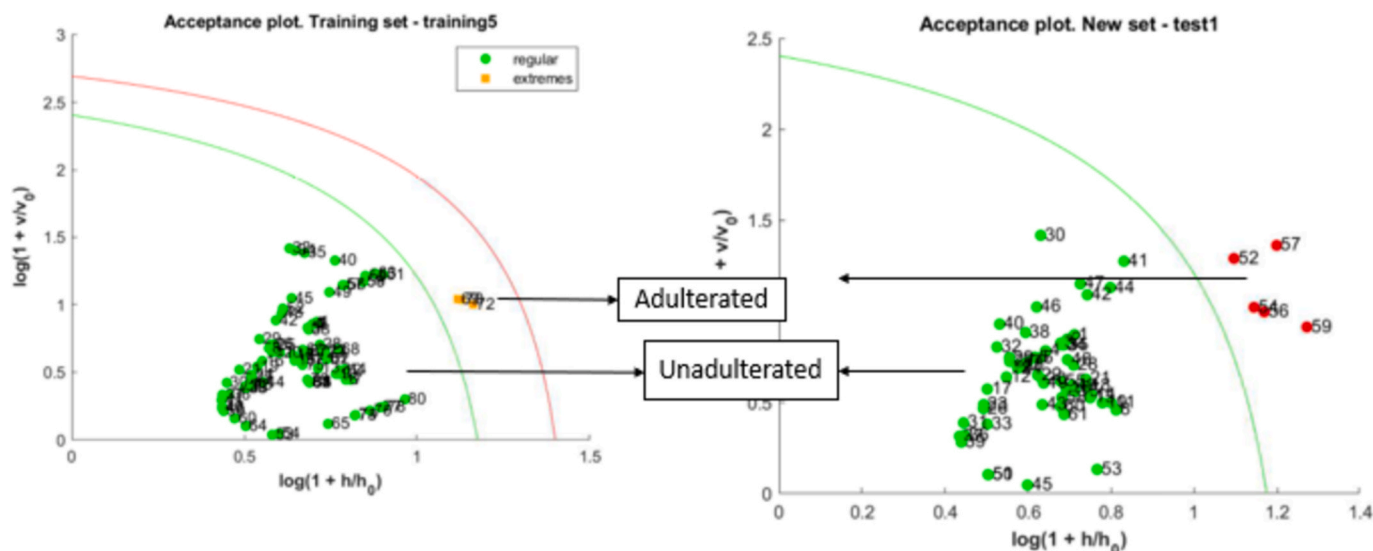

Fig. 5. Acceptance plots for authenticity of sample test data and Acceptance plots for authenticity of sample training data.

quantification (LOQ) for ferrous sulfate heptahydrate in turmeric powder. The LOD and LOQ were calculated based on the signal-to-noise ratio (S/N), where the LOD was defined as the concentration level yielding a signal three times the noise, and the LOQ was defined as the concentration level yielding a signal ten times the noise.

FTIR Spectroscopy: The LOD and LOQ were found to be 0.5 % and 1.5 % (w/w) respectively, based on characteristic absorption peaks around 1020 cm^{-1} and 1120 cm^{-1}, corresponding to Fe-S stretching vibrations.

Raman Spectroscopy: With a 532 nm laser and 10 mW power, the LOD was 0.3 %, and the LOQ was 1.0 %, highlighting the technique's superior sensitivity for detecting vibrational modes specific to adulterants.

UV–Vis Spectroscopy: Absorption bands at 520 nm provided an LOD of 0.7 % and an LOQ of 2.0 %. This technique was particularly effective in identifying color-based changes induced by adulterants.

Cyclic Voltammetry: Electrochemical signals showed an LOD of 0.8 % and an LOQ of 2.5 %, with peak current variations providing quantifiable insights into redox activity of ferrous ions.

These metrics demonstrate the enhanced sensitivity of the combined multi-spectral approach compared to single-method analyses, allowing for precise detection even at low adulteration levels. The combined techniques not only increased reliability but also provided complementary insights into the chemical and structural properties of the adulterated samples.

3.8. Novelty and Mechanism

The novelty of this study lies in its integration and optimization of multiple advanced analytical techniques to establish a comprehensive framework for detecting food adulteration. Unlike previous approaches that rely on a single method, this research combines FTIR spectroscopy, Raman spectroscopy, UV–visible spectroscopy, cyclic voltammetry, and elemental mapping through SEM to enable precise and detailed characterization of ferrous sulfate heptahydrate adulteration in turmeric powder. This multi-technique approach significantly enhances detection sensitivity and accuracy while providing complementary insights into the adulteration process. Furthermore, the study leverages advanced statistical methods, including Principal Component Analysis (PCA) and SIMCA modelling, to classify and differentiate between adulterated and unadulterated turmeric samples. These tools not only improve boundary determination but also quantify adulterant levels with greater predictive reliability. The integration of elemental mapping ensures the uniform distribution of adulterants within samples, adding another layer of rigor to the methodology.

The findings of this study highlight the potential of a multi-spectral approach for practical food safety applications. This method can be particularly beneficial in resource-limited settings, where access to advanced laboratory facilities may be restricted. By combining cost-effective spectroscopic techniques such as FTIR, Raman, UV–Vis, and elemental analysis with robust statistical models, the proposed approach offers a reliable and adaptable solution for on-site quality control. It enables quick detection of food adulterants, ensuring the authenticity and safety of food products and protecting consumer health.

This work is pioneering in its real-time detection potential, validated through independent datasets, showcasing practical applications for on-site quality control and food safety monitoring. By addressing a critical gap in the detection of ferrous sulfate heptahydrate adulteration, this study sets a benchmark for ensuring the safety and authenticity of turmeric powder in food and pharmaceutical industries.

CRediT authorship contribution statement

T. Vignesh: Writing – original draft, Methodology, Formal analysis, Conceptualization. **D. Selvakumar:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **R. Jayavel:** Writing – review & editing, Validation, Resources, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.microc.2025.112830.

Data availability

Data will be made available on request.

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