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FTIR Characterization of Date Syrup

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Abstract

The date syrup is a natural sweetener with significant economic and health benefits. Ensuring its quality is essential to protect consumers from adulteration and to maintain its nutritional value. This study employs Fourier Transform Infrared (FTIR) spectroscopy as a rapid and non-destructive analytical tool to characterize date syrup and explore its possible use in detecting adulteration. Date syrup samples from five different producers in Madinah, Saudi Arabia, were analyzed. Key spectral parameters, including peak positions, intensities, full width at half maximum (FWHM), and area under the peak, were extracted and statistically evaluated. Results reveal consistent spectral features across all samples, with minor variations attributed to differences in processing and composition. Multivariate statistical techniques, such as Principal Component Analysis (PCA) and Partial Least Squares Discriminant Analysis (PLS-DA), confirm the ability of FTIR to classify and authenticate date syrup samples effectively. The findings suggest that FTIR-based spectral markers can serve as reference parameters for quality assessment and adulteration detection. Integrating FTIR spectroscopy into routine quality control procedures could enhance consumer protection, improve regulatory oversight, and strengthen the economic value of date syrup products.

Keywords: FTIR spectroscopy, Date syrup, Quality control, Adulteration detection, Spectral analysis

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1. Introduction

Date syrup is an increasingly valued natural sweetener due to its nutritional composition and diverse applications in the food and pharmaceutical industries. Its significance extends beyond mere cooking use, as it has been recognized for its antioxidant, antimicrobial, and anticancer properties (Taleb et al., 2016). According to Hussain et al. (2020), date syrup is rich in bioactive compounds, including flavonoids, phenolic acids, and carotenoids, which contribute to its health-promoting effects. Its potential as a functional food ingredient has led to extensive research on its composition and therapeutic benefits (Alsaleem et al., 2022). The production and commercialization of date syrup play a crucial role in many Middle Eastern and North African economies, where date palm cultivation is widespread. Abdul-Hamid et al. (2018) highlights that the economic value of date syrup is increasing due to its affordability compared to other natural sweeteners, such as honey and maple syrup. As a result, it has been extensively used as a sweetener, an ingredient in fermented foods, and a base for bioactive compound extraction. In addition to its nutritional and economic value, date syrup is an essential ingredient in traditional and modern food processing. Mohamed et al. (2014) states that it enhances the texture, viscosity, and stability of various food formulations, making it a viable alternative to synthetic additives. Deepshikha et al., (2019) emphasizes its role in food preservation, as its natural sugar content acts as a microbial inhibitor.

Despite its benefits, adulteration remains a significant concern in the date syrup industry. The addition of low-cost sugars, starch-based syrups, and artificial sweeteners to enhance yield and reduce production costs has raised concerns about food authenticity and consumer safety (Alsaleem et al., 2022). Naderi-Boldaji et al. (2018) discusses how food fraud involving date syrup is a growing issue, requiring advanced analytical techniques to detect impurities. The traditional quality control methods rely on physicochemical properties, such as pH, density, viscosity, and sugar composition, but these approaches often fail to differentiate between pure and adulterated samples (Jamshidian et al., 2017). Thus, developing more reliable and rapid analytical methods is essential to maintain product integrity.

FTIR is gaining recognition as a highly efficient and non-destructive method for food analysis. According to El Darra et al. (2017), FTIR scan be used to analyze chemical bonds, molecular vibrations, and functional groups in complex food matrices. Shiddiq et al. (2019) notes that FTIR offers a unique spectral fingerprint, allowing for precise differentiation between authentic and adulterated date syrup samples. While FTIR has been extensively applied in honey, dairy, and edible oil authentication, its potential in date syrup analysis remains underexplored. This study aims to fill that gap by conducting a comprehensive spectral analysis of date syrup samples from multiple producers, establishing reliable reference parameters for quality assessment. One of the main advantages of FTIR spectroscopy is its ability to integrate with multivariate statistical analysis, significantly enhancing its discriminatory power. Multivariate techniques, such as Principal Component Analysis (PCA) and Partial Least Squares Discriminant Analysis (PLS-DA), allow researchers to extract meaningful patterns from complex spectral data (Naderi-Boldaji et al., 2018). By incorporating such statistical tools, this study aims to enhance the reliability of FTIR-based quality control for date syrup. Ensuring the authenticity and purity of date syrup is not only an economic issue but also a public health priority. According to Fakhlaei et al. (2020), adulteration with harmful synthetic sweeteners or low-quality syrups may introduce toxic compounds that pose health risks to consumers.

By validating FTIR spectroscopy as a rapid and reliable method for date syrup authentication, this study contributes to enhancing consumer confidence in the safety and quality of date-based products.

This study aims to evaluate the possibility of producing standard FTIR spectroscopy parameters of date syrup for future use as a reliable reference to distinguish between pure and adulterated date syrup samples via analyzing their characteristic spectral peaks. The study integrates multivariate statistical analysis to enhance the interpretation of spectral data, improving the accuracy and reliability of food authentication techniques. Ultimately, this work aspires to contribute to the development of standardized protocols for quality control in the date syrup industry, benefiting both consumers and regulatory agencies while reinforcing confidence in date syrup products.

Fourier Transform Infrared (FTIR) spectroscopy is a powerful analytical technique used to investigate the molecular composition of substances based on their infrared absorption patterns. It operates by measuring how different chemical bonds absorb infrared light at specific wavelengths, generating a unique spectral fingerprint for each sample (El Darra et al., 2017). The FTIR spectrum provides information about the functional groups present in a substance by analyzing vibrational transitions within molecular structures (Shiddiq et al., 2019). A key advantage of FTIR is its ability to rapidly assess complex food matrices without requiring extensive sample preparation. The method is widely used in food science due to its high sensitivity, non-destructive nature, and ability to analyze multiple components simultaneously. The primary spectral parameters used for characterization include peak position, intensity, full width at half maximum (FWHM), and area under the peak, all of which help in identifying specific molecular interactions (Hamad et al., 2020). The FTIR spectroscopy has been extensively applied in food quality assessment, authentication, and adulteration detection. One of its key applications is honey authentication, where it has been used to differentiate between pure honey and adulterated samples mixed with glucose or corn syrup (Cherigui et al., 2024). Similarly, FTIR has been applied in dairy industry research to assess the composition of milk, butter, and cheese, ensuring compliance with food safety standards (Naderi-Boldaji et al., 2018). When compared to other spectroscopic methods, such as Raman spectroscopy, nuclear magnetic resonance (NMR), and UV-visible spectroscopy, FTIR stands out due to its speed, cost-effectiveness, and minimal sample preparation requirements (Khan et al., 2018). While Raman spectroscopy provides detailed structural information, it is often affected by fluorescence interference in biological samples (Deepshikha et al. 2019). Although NMR has high precision, it is expensive and requires specialized instrumentation, making it less accessible for routine food quality control (Mohamed et al., 2014). UV-visible spectroscopy, although widely used, it lacks the molecular specificity of FTIR and may require additional chemical treatments for effective analysis (Kofman et al., 2018).

Despite its extensive use in food authentication, FTIR spectroscopy remains underutilized in the analysis of date syrup. Previous studies have demonstrated its potential in distinguishing authentic date syrup from adulterated or low-quality products (Alsaleem et al., 2022). The ability of FTIR to detect changes in sugar composition, moisture content, and adulterants makes it a promising tool for ensuring the authenticity of date syrup.

One of the major concerns in date syrup production is the fraudulent addition of other syrups, such as pomegranate molasses or starch-based syrups, which alter their chemical composition (Taleb et al., 2016). FTIR allows for the identification of such alterations by analyzing variations in spectral peak parameters associated with key functional groups, including O-H stretching (around 3320 cm^{-1}), C-H stretching (2930 cm^{-1}), and C-O stretching (1230 cm^{-1}) (Elshemey et al 2010, Hamad et al 2020). These spectral markers would help differentiate pure and adulterated date syrup, offering a quick and reliable method for quality control.

Given the growing global market for date syrup, it is crucial to implement advanced analytical techniques to maintain its economic value and consumer trust. By integrating FTIR spectroscopy with multivariate statistical analysis, researchers can enhance the accuracy of food authentication, providing a scientifically robust framework for standardizing date syrup quality (Nashi, 2023).

2. Materials and Methods:

To ensure accurate characterization of date syrup, a systematic approach was followed, including sample collection, FTIR spectroscopy analysis, and statistical evaluation. FTIR spectroscopy was used to identify molecular fingerprints, while multivariate statistical methods helped assess compositional differences between date syrup samples from different producers, if any. These procedures would provide a reliable framework for detecting adulteration and ensuring product quality.

2.1. Sample Collection and Preparation

Date syrup samples were obtained from five different commercial producers in Madinah, Saudi Arabia, ensuring representation from various processing techniques and ingredient sources. Each sample was collected in sterile glass containers to prevent contamination and stored at 4°C to maintain its chemical stability until analysis (El Darra et al., 2017). The samples were thoroughly homogenized before analysis to minimize inconsistencies caused by phase separation or crystallization (Hussain et al., 2020). Prior to FTIR measurements, all samples were allowed to reach room temperature, ensuring consistency in spectral acquisition.

2.2 FTIR Spectroscopy Analysis

The FTIR spectra of date syrup samples were recorded using a Nicolet 6700 Fourier Transform Infrared Spectrometer (Thermo Scientific, USA). The FTIR spectra were obtained within the range of 4000–500 cm^{-1} at a spectral resolution of 4 cm^{-1}, ensuring high sensitivity for detecting characteristic functional groups. Each spectrum was collected as the average of 32 scans, minimizing noise and improving signal clarity (Hamad et al., 2020). The recorded FTIR spectra were baseline corrected and area-normalized to allow for precise comparisons between different samples (Sarmento et al., 2007).

2.3 Data Processing and Peak Identification

Spectral data were processed using Origin 6.0 software for peak fitting, smoothing, and baseline correction. A Savitzky-Golay smoothing algorithm (7-point window) was applied to reduce spectral noise while preserving the integrity of characteristic peaks (Elshemey et al., 2010). Key spectral parameters, including peak position, intensity, full width at half maximum (FWHM), and area under the peak, were extracted using Gaussian peak fitting methods. The following functional groups were identified based on their characteristic absorption bands:

O-H stretching (3320 cm^{-1}) – indicative of moisture and hydrogen bonding.

C-H stretching (2930 cm^{-1}) – associated with organic hydrocarbon chains.

C=C stretching (1640 cm^{-1}) – linked to unsaturated compounds.

C-O stretching (1230 cm^{-1}) – characteristic of carbohydrate structures.

O-H bending (1060 cm^{-1}) – related to polysaccharide content (El Darra et al., 2017).

2.4 Statistical Analysis and Chemometric Techniques

To assess the variability and similarity between different date syrup samples, statistical analysis was performed using SPSS (Statistical Package for the Social Sciences) software. The correlation of spectra between samples was evaluated using Pearson's correlation coefficient, determining the extent of spectral similarity at $p < 0.01$ significance level. Additionally, Principal Component Analysis (PCA) and Partial Least Squares Discriminant Analysis (PLS-DA) were applied to classify date syrup samples and detect subtle compositional differences (Naderi-Boldaji et al., 2018). These chemometric techniques enhance FTIR analysis by extracting hidden patterns in spectral data, improving the accuracy of authentication methods. To validate the method's reproducibility, triplicate measurements were conducted for each sample, ensuring consistency in spectral outputs. Statistical comparisons of FTIR parameters, such as peak intensities and FWHM values, were performed using one-way ANOVA, identifying significant differences between samples ($p < 0.05$).

3. Results and Discussion

The FTIR spectral analysis of date syrup samples from various producers in Madinah, Saudi Arabia, reveals important insights into the chemical composition and quality of the product. This section discusses the key findings from the FTIR spectra, emphasizing the presence of characteristic functional groups and identifying any variability among the samples. Additionally, the discussion explores the statistical methods used to analyze these spectral data, highlighting the potential of FTIR spectroscopy for quality control and authentication. The implications of these findings for the date syrup industry, including the detection of adulteration and the assurance of product consistency, are also addressed.

3.1 FTIR Spectral Analysis of Date Syrup Samples

The FTIR spectra of date syrup samples collected from five different producers in Madinah, KSA, exhibited characteristic absorption peaks corresponding to key functional groups commonly found in carbohydrates, organic acids, and phenolic compounds. Figure 1 presents the measured FTIR spectra, where the five date syrup samples display highly similar spectral profiles, suggesting consistent chemical composition across different sources.

The presence of distinct absorption bands at 3320 cm^{-1} (O-H stretching), 2930 cm^{-1} (C-H stretching), 1640 cm^{-1} (C=C stretching), 1230 cm^{-1} (C-O stretching), and 1060 cm^{-1} (O-H bending) confirms the dominance of sugar-based compounds in date syrup (El Darra et al., 2017). These peaks are indicative of hydroxyl, carboxyl, and ether groups, which are major components of monosaccharides and polysaccharides, aligning with findings in previous food authentication studies (Hussain et al., 2020).

3.2 Identification of Variability in Spectral Peaks

Despite overall spectral similarity, slight variations were observed in the intensity and position of absorption peaks between different samples. The most noticeable differences were recorded at the 1060 cm^{-1} and 3320 cm^{-1} bands, which could be attributed to differences in moisture content, processing techniques, or sugar degradation. These findings suggest that while date syrups share common structural components, subtle compositional differences exist due to variations in raw material, storage conditions, and processing methods (Mohamed et al., 2019).

Table 1 summarizes the values of peak positions, intensities, full width at half maximum (FWHM), and area under the peak for each of the five characteristic FTIR absorption bands. The statistical significance ($p < 0.05$) of peak intensity variations indicates that these minor differences could serve as potential markers for quality control and authentication. Previously published FTIR spectral data on date syrup honey adulteration confirms that minor shifts in peak intensities and broadening of the O-H stretching band may indicate the presence of foreign sugars or moisture variations. Such spectral modifications align with syrup dilution or adulteration with glucose syrups, which is a known fraudulent practice in the food industry (Nashi, 2023).

3.3 Statistical Analysis and Chemometric Evaluation

To further assess the degree of similarity and variability among the five samples, Pearson's correlation coefficient (r-values) was calculated, revealing significant correlations ($p < 0.01$) between all five spectra. These findings confirm the overall chemical consistency between the investigated date syrups, making FTIR a promising tool for quality monitoring (Shiddiq et al., 2019).

The multivariate statistical techniques, such as Principal Component Analysis (PCA) and Partial Least Squares Discriminant Analysis (PLS-DA), were employed to classify the date syrup samples based on their spectral characteristics (Naderi-Boldaji et al., 2018).

The table 2 indicates that:

1. The first Principal Component Analysis (PCA) explains approximately 99.71% of the variance in the data, while the second principal component (PC2) explains about 0.24%. Together, they account for nearly all the variance.
2. For the PLS-DA, the first PLS component (PLS1) explains a significant amount of variance (approximately 4.90), while the second PLS component (PLS2) explains a negligible amount (approximately 0.0003).

This results demonstrates a clear clustering of samples, reinforcing their chemical similarity while highlighting subtle spectral differences that differentiate one producer's syrup from another. These findings indicate that spectral markers derived from FTIR data, when combined with statistical analysis, provide a robust classification framework for distinguishing different sources of date syrup. The potential for machine learning applications in FTIR-based food authentication would further enhance its relevance in modern quality control practices.

3.4 Implications for Quality Control and Authentication

The ability of FTIR spectroscopy to rapidly and accurately detect spectral variations makes it a powerful quality control tool for the date syrup industry. The establishment of standardized spectral reference values based on peak intensities, FWHM, and area under the peak would enable manufacturers and regulators to:

1. Detect adulteration with high precision by comparing test samples against reference spectra.
2. Ensure product authenticity by identifying shifts in characteristic absorption bands.
3. Monitor batch-to-batch consistency to improve consumer trust and market value.

The findings of this study align with global food safety standards, supporting the potential regulatory adoption of FTIR spectroscopy as an official method for date syrup authentication (Abbès et al., 2013).

3.5 Comparison with Previous Studies

When compared to earlier studies, the results of this research confirm that FTIR would effectively differentiate pure date syrup from adulterated products (El Darra et al., 2017). However, previous works have primarily focused on honey, fruit syrups, and dairy products, leaving a research gap in the systematic application of FTIR for date syrup monitoring. This study contributes to filling this gap by providing quantitative spectral reference parameters that can serve as future benchmarks for quality assessment. Moreover, while Raman spectroscopy, NMR, and chromatography techniques have been explored for food authentication, they often require costly instrumentation and time-consuming sample preparation (Lotfiman et al., 2018). In contrast, FTIR offers a rapid, cost-effective, and non-destructive alternative, making it more practical for industrial applications.

3.6 Limitations and Future Directions

While this study provides strong evidence for the applicability of FTIR in date syrup quality assessment, certain limitations must be acknowledged:

1. Variability in natural composition: Date syrups can differ due to seasonal and geographical variations, necessitating a larger dataset for future reference spectrum.

2. Detection of complex adulteration: While FTIR is highly effective for detecting major compositional changes, the presence of low concentrations of adulterants may require hybrid techniques, such as FTIR combined with mass spectrometry or chromatography

3. Automation and real-time monitoring: Future research should focus on developing automated FTIR-based quality control systems, integrating machine learning algorithms for real-time classification.

Table 1. . The values of the characterization parameters (peak position, intensity, FWHM and area under peak) of each of the five peaks of interest (1060, 1230, 1640, 2930 and 3320 cm-1) in the FTIR spectrum of five different date syrup samples.

Functional groups	Peak (cm-1)	Position (cm-1)	Relative Intensity	FWHM (cm^{-1})	Relative Area under peak
O-H stretching vibration	1060	1036.5±4.7	1±0.4	72.9±4.0	0.35
C-O stretching vibration	1230	1252.2±3.0	0.47±0.0	42.3±3.6	0.01
-C=C- stretching	1640	1636.1±1.5	0.45±0.0	66.9±2.6	0.04
antisymmetric stretching vibrations C-H of a -CH2	2930	2923.9±0.9	0.46±0.0	39.4±7.8	0.01
O-H stretching vibration	3320	3295.7±1.0	0.66±0.0	327.0±5.6	1±0.1

Table 2.. Summary of PCA and PLS-DA Results for FTIR Spectroscopy Analysis of Date Syrup Samples

Principal Component	Explained Variance	Cumulative Variance	PLS Component	Explained Variance
PC1	0.997068	0.997068	PLS1	4.895467
PC2	0.002419	0.999488	PLS2	0.000287

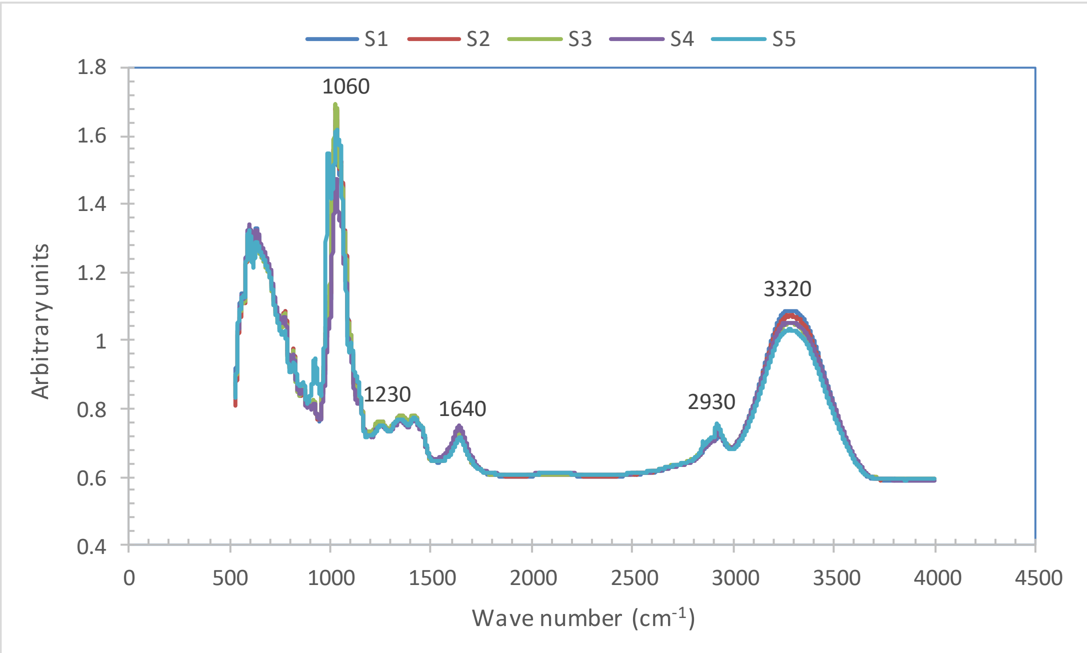

Figure 1. Measured FTIR spectra of the five investigated date syrup samples.

4. Conclusion

FTIR spectroscopy has demonstrated its effectiveness as a reliable and non-destructive method for analyzing date syrup composition and authenticity. The spectral characterization parameters established in this study—peak intensity, full width at half maximum (FWHM), and area under the peak—provide valuable markers for assessing product quality and for possible detection of potential adulteration. Minor variations in spectral peaks were observed among samples, likely due to differences in production methods, moisture content, or raw material origins. However, the overall consistency in spectral profiles confirms that FTIR spectroscopy can serve as a robust tool for distinguishing authentic date syrup from adulterated or substandard products. By integrating FTIR spectroscopy with statistical methods such as Pearson's correlation coefficient, principal component analysis (PCA), and partial least squares discriminant analysis (PLS-DA), this study has enhanced the accuracy and efficiency of quality assessment. These techniques allow for precise classification of date syrup samples, making FTIR-based analysis a promising approach for routine food authentication and regulatory compliance. The adoption of FTIR spectroscopy in the date syrup industry can strengthen consumer confidence, improve market transparency, and prevent fraudulent practices.

Given the increasing demand for natural sweeteners, implementing standardized FTIR protocols can support quality assurance efforts and regulatory frameworks. Future studies should aim to expand the spectral database by analyzing a broader range of date syrup samples from diverse geographical regions and production processes. Additionally, integrating FTIR spectroscopy with complementary analytical techniques, such as chromatography and mass spectrometry, could further improve the detection of complex adulterants. Advances in artificial intelligence and machine learning could also enhance the automation and accuracy of FTIR-based quality control systems. Ensuring the authenticity and safety of date syrup is not only a commercial priority but also a public health necessity. The findings of this study reinforce the need for innovative, science-driven approaches in food quality assessment. By leveraging FTIR spectroscopy as a primary analytical tool, food manufacturers, regulators, and researchers can uphold the integrity of date syrup products and promote sustainable industry practices.

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