Cover Page

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QUALITY ASSESSMENT AND CHEMICAL CHARACTERIZATION OF UNPACKAGED CHILI POWDER: FTIR SPECTROSCOPIC ANALYSIS

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Abstract

Fourier Transform Infrared (FTIR) spectroscopy was employed to characterize the chemical composition and assess the quality of an open market chili powder sample derived from *Capsicum annuum L*. The study aimed to demonstrate FTIR as a rapid, non-destructive analytical tool for chili powder authentication and quality control. The FTIR spectrum was recorded in the wavelength range of 400–4000 cm^{-1}, revealing seven major absorption peaks corresponding to characteristic functional groups present in authentic chili powder. The prominent peak at 3449 cm^{-1} indicated the presence of hydroxyl groups associated with capsaicinoids and phenolic compounds, which are responsible for pungency and antioxidant properties. The peak at 2926 cm^{-1} confirmed lipid content through aliphatic C-H stretching vibrations. Critical capsaicinoid marker regions were identified at 1707 cm^{-1} (carbonyl C=O stretching) and 1547 cm^{-1} (aromatic C=C and amide II bands), confirming the presence of capsaicin and related alkaloids that contribute to the characteristic heat of chili powder. Additional peaks at 1659 cm^{-1}, 1462 cm^{-1}, and 1049 cm^{-1} corresponded to proteins (amide I), aliphatic compounds, and carbohydrates (C-O stretching), respectively. The comprehensive spectral profile was consistent with authentic chili powder containing capsaicinoids, carotenoids, lipids, and structural polysaccharides, with no anomalous peaks suggesting adulteration. This study demonstrates that FTIR spectroscopy provides a rapid, cost-effective, and non-destructive method for chemical fingerprinting and quality assessment of chili powder. The technique offers significant advantages over traditional methods such as HPLC and GC-MS, which are time-consuming and require extensive sample preparation. FTIR has promising applications in food authentication, adulteration detection, and standardization of spice products in the food industry.

Keywords: FTIR spectroscopy, Sustainable Quality Assessment, *Capsicum annuum*, Food Authentication, Eco-friendly Analysis

1. Introduction

Chili powder, derived from dried fruits of *Capsicum annuum* L., is one of the most widely consumed spices globally, valued for its pungency, color, and nutritional properties. The characteristic pungency of chili is attributed to capsaicinoids, primarily capsaicin and di-hydrocapsaicin, which are vanilloid compounds with significant pharmacological activities [1]. Beyond capsaicinoids, chili powder contains carotenoids (responsible for red coloration), phenolic compounds, vitamins, lipids, and carbohydrates, contributing to its antioxidant capacity and health benefits [2], [3]. The quality and authenticity of chili powder in open markets are major concerns due to widespread adulteration practices. Common adulterants include synthetic dyes (Sudan red, rhodamine B), spent paprika, brick powder, starch, and other cheaper materials that compromise both safety and quality [4], [5]. Traditional analytical methods for chili powder characterization, such as high-performance liquid chromatography (HPLC) and gas chromatography-mass spectrometry (GC-MS), are accurate but time-consuming, destructive, and require extensive sample preparation [2].

Fourier Transform Infrared (FTIR) spectroscopy has emerged as a powerful analytical tool for rapid, non-destructive characterization of food matrices. FTIR provides a molecular fingerprint by measuring the absorption of infrared radiation by chemical bonds, enabling identification of functional groups and chemical composition [6]. In spice analysis, FTIR has been successfully applied for quality assessment, authentication, and

Cover Page

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adulteration detection [7], [8].

The objective of this study was to perform comprehensive FTIR spectroscopic analysis of an unpackaged chili powder sample collected from open selling market of Barabanki (OC) to: (i) identify characteristic functional groups and chemical constituents, (ii) confirm the presence of capsaicinoids and other bioactive compounds, (iii) assess quality indicators, and (iv) evaluate the potential of FTIR for authentication and quality control of chili powder products. Recent literature demonstrates diverse applications of FTIR spectroscopy in chili powder analysis. Galvin-King et al. successfully detected substitution adulteration of paprika with spent paprika using FTIR combined with chemometric analysis, achieving classification ac- curacy above 95% [4]. The study identified key spectral regions (1800–900 cm^{-1}) that differ- entiated authentic from adulterated samples. ADISTI et al. developed an FTIR-based method for authenticating chili powder adulterated with synthetic dyes (rhodamine B, erythrosine B, and para red), demonstrating that char- acteristic peaks in the 1500–1600 cm^{-1} region could distinguish authentic from adulterated samples [5]. Vignesh et al. employed a multimodal analytical approach including FTIR to detect ferric oxide adulteration in chili powder, identifying diagnostic peaks that indicated the presence of inorganic adulterants [6].

Johnson et al. conducted a proof-of-concept study on infrared spectroscopy for quality as- sessment of Habanero chili, demonstrating correlations between FTIR spectral features and quality parameters such as moisture content, capsaicinoid levels, and color values [11], [22]. The study highlighted the potential of FTIR as a rapid screening tool for quality control in the spice industry. Sein et al. applied ATR-FTIR spectroscopy for detection of aflatoxin B1 contamination in chili powder, showing that spectral changes in the fingerprint region (1200–900 cm^{-1}) could indicate mycotoxin presence [8]. This application demonstrates the versatility of FTIR for both quality assessment and safety screening. Comparative pharmacognostic studies have utilized FTIR as part of comprehensive standardization protocols for chili powder. Shaheen et al. reported characteristic FTIR peaks for *Capsicum annuum* extracts, establishing spectral fingerprints for authentication purposes [1], [10]. These studies emphasize the importance of FTIR in developing quality standards for herbal and spice products.

2. Materials and Methods

2.1 Sample Collection

Open market chili powder sample (designated as OC) was obtained from a local market. The sample was stored in an airtight container at room temperature until analysis. No additional sample preparation or extraction was performed to maintain the integrity of the original product composition.

2.2 FTIR Spectroscopy

FTIR analysis was performed using a Fourier Transform Infrared spectrometer equipped with a deuterated triglycine sulfate (DTGS) detector. The chili powder sample was analyzed directly without further processing. Spectra were recorded in the mid-infrared region (4000– 400 cm^{-1}) with a spectral resolution of 4 cm^{-1}. Each spectrum was obtained by averaging 32 scans to improve signal-to-noise ratio. Background correction was performed using air as reference before each measurement.

1.1 Data Processing and Analysis

The acquired FTIR spectra were processed using standard spectroscopic software. Baseline correction was applied to remove instrumental drift and scattering effects. Peak identifi- cation was performed by analyzing the absorbance maxima and comparing with standard infrared correlation charts and literature data. Functional

Cover Page

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group assignments were made based on characteristic absorption frequencies of organic compounds. The spectral regions were categorized as follows: 3600–3200 cm ¹ (O-H stretching), 3000–2800 cm ¹ (C-H stretch- ing), 1750–1500 cm ¹ (carbonyl and aromatic regions), 1500–1300 cm ¹ (C-H bending), and 1300–400 cm ¹ (fingerprint region).

2. Results

2.1 FTIR Spectrum Overview

The FTIR spectrum of open market chili powder sample OC is presented in Figure 1. The spectrum exhibits characteristic absorption bands across the entire mid-infrared region (4000–400 cm ¹), reflecting the complex chemical composition of chili powder. Seven major peaks were identified with distinct absorbance maxima, corresponding to various functional groups present in capsaicinoids, lipids, proteins, carbohydrates, and phenolic compounds.

Figure 1. FTIR spectrum of open market chili powder sample OC showing major absorp- tion bands and functional group assignments. Key regions are highlighted: O-H stretching (3449 cm ¹), C-H stretching (2926 cm ¹), capsaicinoid marker region (1650–1500 cm ¹), and carbohydrate region (1300–1000 cm ¹).

The spectrum displays a broad, intense absorption band in the 3600–3200 cm ¹ region, char- acteristic of hydroxyl groups. Strong absorption in the 3000–2800 cm ¹ region indicates aliphatic C-H stretching vibrations. The 1750–1500 cm ¹ region shows multiple overlapping peaks corresponding to carbonyl groups, aromatic rings, and amide bonds—critical mark- ers for capsaicinoid identification. The fingerprint region (1300–400 cm ¹) exhibits complex absorption patterns characteristic of carbohydrates and other structural components.

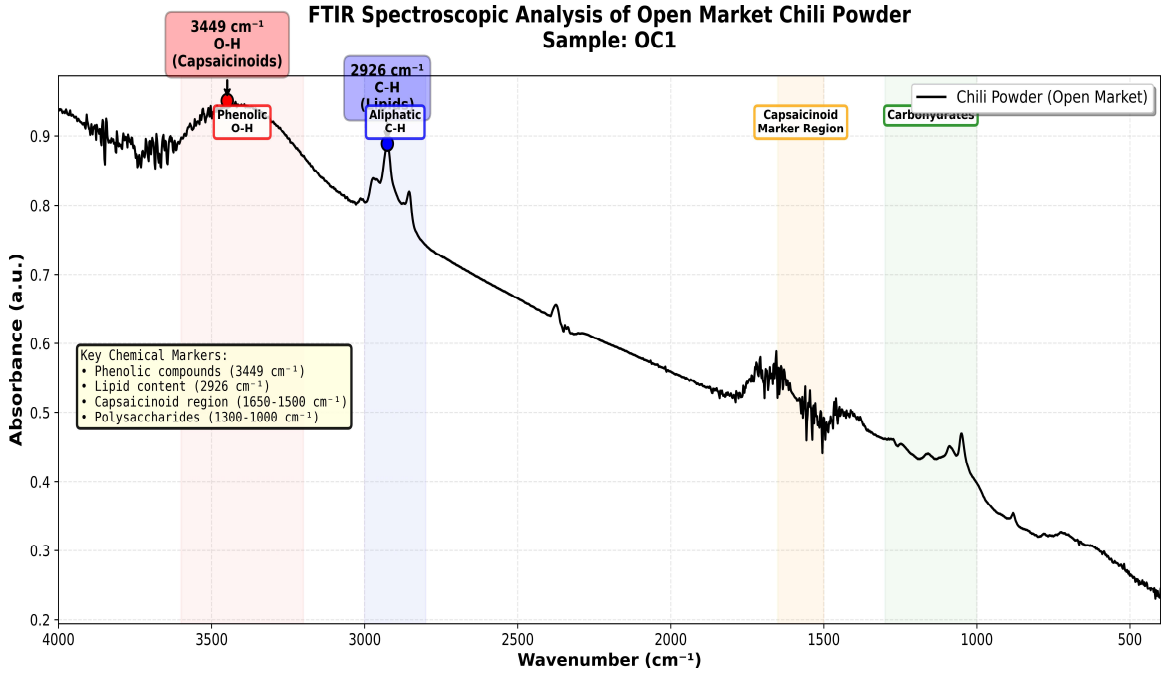

Figure 1: FTIR Spectrum of Chili Powder

Cover Page

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2.3 Peak Identification and Functional Group Assignments

Detailed analysis of the FTIR spectrum revealed seven major absorption peaks with specific functional group assignments (Table 1). Each peak was assigned to probable chemical constituents based on characteristic absorption frequencies and comparison with literature data.

Table 1. Major FTIR peaks identified in chili powder sample OC with functional group assignments and chemical significance.

Peak No.	Wavenumber (cm $^{-1}$)	Absorban(ccem $^{-1}$)	Spectral Range	Functional Group	Possible Compounds	Chemical Significance
1	3449	0.947	3600–3200	O-H stretching	Phenolic compounds (capsaicin, flavonoids), water, hydroxyl groups	Indicates presence of capsaicinoids and phenolic antioxidants
2	2926	0.888	3000–2800	C-H stretching (aliphatic)	Lipids, fatty acids, aliphatic chains in capsaicinoids	Indicates lipid content and capsaicinoid side chains
3	1707	0.567	1750–1680	C=O stretching	Esters, carbonyl groups in capsaici-noids, lipids	Characteristic of capsaicin amide bond and ester lipids
4	1659	0.569	1680–1600	C=C stretching, Amide I	Aromatic rings, proteins, capsaici-noid aromatic ring	Protein content and aromatic compounds

Cover Page

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Peak No.	Wavenumber (cm ⁻¹)	Spectral Range Absorbance (ccem ⁻¹)	Functional Group	Possible Compounds	Chemical Significance
5	1547	0.521	1600–1500	Aromatic C=C, Amide II, N-H bending	Capsaicinoids, proteins, phenolic compounds — Key region for capsaicin identification
6	1462	0.506	1500–1400	C-H bending (CH , CH)	Aliphatic compounds, lipids, carbohydrates — Structural components
7	1049	0.467	1200–1000	C-O stretching	Carbohydrates, polysaccha-rides, cellulose — Structural polysaccha-rides and sugars

Peak 1 (3449 cm ⁻¹): The broad, intense absorption band at 3449 cm ⁻¹ is attributed to O-H stretching vibrations. This peak indicates the presence of hydroxyl groups from multiple sources, including the phenolic hydroxyl group in the vanillyl moiety of capsaicinoids, phenolic antioxidants (flavonoids, hydroxycinnamic acids), and residual moisture [16], [18]. The high absorbance (0.947) reflects the abundance of hydroxyl-containing compounds in chili powder.

Peak 2 (2926 cm ⁻¹): The strong absorption at 2926 cm ⁻¹ corresponds to asymmetric C-H stretching vibrations of aliphatic CH groups. This peak is characteristic of lipids, fatty acids, and the aliphatic side chain of capsaicinoids [2], [19]. Chili powder typically contains 10–20% lipids, primarily triglycerides and fatty acids, which contribute significantly to this absorption band.

Peak 3 (1707 cm ⁻¹): The absorption at 1707 cm ⁻¹ is assigned to C=O stretching vibrations.

This peak is particularly significant as it corresponds to the carbonyl group in the amide linkage of capsaicinoids and ester carbonyl groups in lipids [16], [18]. The presence of this peak is a diagnostic marker for capsaicin and related alkaloids.

Cover Page

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Peak 4 (1659 cm ¹): The peak at 1659 cm ¹ represents C=C stretching of aromatic rings and Amide I band (C=O stretching in proteins). This absorption is characteristic of the aromatic vanillyl ring in capsaicinoids and protein content in chili powder [19], [20]. The overlapping nature of this peak reflects contributions from multiple aromatic compounds.

Peak 5 (1547 cm ¹): The absorption at 1547 cm ¹ is assigned to aromatic C=C stretching, Amide II band (N-H bending coupled with C-N stretching), and aromatic ring vibrations. This peak is a critical marker for capsaicinoid identification, as it reflects the characteristic amide bond and aromatic structure of capsaicin [16], [18], [19]. The presence and intensity of this peak confirm the authenticity of capsaicinoid content.

Peak 6 (1462 cm ¹): The absorption at 1462 cm ¹ corresponds to C-H bending vibrations of CH and CH groups in aliphatic compounds. This peak indicates the presence of lipids, carbohydrates, and other structural components [2].

Peak 7 (1049 cm ¹): The peak at 1049 cm ¹ is attributed to C-O stretching vibrations characteristic of carbohydrates, polysaccharides, and cellulose. This absorption confirms the presence of structural carbohydrates, which constitute 50–60% of chili powder composition [1], [2].

1.1 Chemical Composition Interpretation

The FTIR spectrum of sample OC provides comprehensive information about the chemical composition of the chili powder. The spectral profile can be divided into distinct regions, each corresponding to specific chemical constituents (Table 2).

Capsaicinoid Signature: The combined presence of peaks at 3449 cm ¹ (phenolic O-H), 1707 cm ¹ (amide C=O), 1659 cm ¹ (aromatic C=C), and 1547 cm ¹ (Amide II) provides strong evidence for the presence of capsaicinoids in sample OC. This spectral pattern matches the characteristic FTIR signature of capsaicin reported in literature [16], [18], [19].

Lipid Content: The strong absorption at 2926 cm ¹ and the presence of carbonyl stretching at 1707 cm ¹ indicate significant lipid content, consistent with the expected 10–20% lipid composition of chili powder [2]. The lipid fraction includes triglycerides, fatty acids, and carotenoids, which contribute to both nutritional value and color.

Protein and Aromatic Compounds: The absorption at 1659 cm ¹ (Amide I) and 1547 cm ¹ (Amide II) reflects protein content, estimated at 10–15% in chili powder [1]. These

peaks also indicate the presence of aromatic compounds, including capsaicinoids and phenolic antioxidants.

Table 2. Spectral region analysis and chemical composition interpretation for chili powder sample OC.

Spectral Region (cm ¹)	Peak Position (cm ¹)	Relevance to Chili Composition		
		Absorbance	Assignment	
3600–3200	3449	0.947	O-H stretch	Capsaicinoids, phenolic antioxidants
3000–2800	2926	0.889	C-H stretch	Lipids, capsaicinoid aliphatic chains

Cover Page

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1750–1680	1707	0.580	C=O	Capsaicin amide, ester
			stretch	lipids
1680–1600	1659	0.588	C=C/Amide	Aromatic compounds,
			I	proteins
1600–1500	1547	0.538	Aromatic/Amide	Capsaicinoids (key
			II	marker)
1500–1400	1462	0.520	C-H	Structural components
			bend	
1300–1000	1049	0.469	C-O	Carbohydrates,
			stretch	polysaccharides
1000–650	999	0.397	Fingerprint	Unique compound
				signatures

Carbohydrate Matrix: The strong absorption at 1049 cm ^{1} and the complex pattern in the fingerprint region (1300–400 cm ^{1}) confirm the presence of carbohydrates, which constitute the major component (50–60%) of chili powder [2]. These include structural polysaccharides (cellulose, hemicellulose) and simple sugars.

2. Discussion

2.4 Capsaicinoid Identification

The FTIR spectrum of sample OC exhibits characteristic absorption bands that confirm the presence of capsaicinoids, the bioactive alkaloids responsible for chili pungency. The most diagnostic peaks for capsaicinoid identification are located at 1707 cm ^{1} (C=O stretching of the amide group) and 1547 cm ^{1} (Amide II band with N-H bending and C-N stretching) [16], [18]. These peaks correspond to the amide linkage connecting the vanillyl moiety to the fatty acid chain in capsaicin structure.

The presence of the phenolic O-H stretching band at 3449 cm ^{1} further supports capsaicinoid identification, as this peak reflects the hydroxyl group on the vanillyl ring [19]. The aromatic C=C stretching at 1659 cm ^{1} indicates the aromatic character of the vanillyl moiety. The aliphatic C-H stretching at 2926 cm ^{1} corresponds to the long-chain fatty acid component of capsaicinoids, typically an 8-carbon or 10-carbon chain in capsaicin and dihydrocapsaicin, respectively [13].

Comparison with literature data confirms that the observed spectral pattern is consistent with authentic capsaicinoid content. Ekhlas et al. reported similar FTIR peaks for capsaicin extracted from *Capsicum annuum* callus and seedlings, with characteristic bands at 3400 cm ^{1} (O-H), 2920 cm ^{1} (C-H), 1650 cm ^{1} (C=O), and 1550 cm ^{1} (Amide II) [16]. Pradana et al. identified capsaicin in red chili fruit using FTIR spectroscopy, reporting peaks at 3448 cm ^{1}, 2926 cm ^{1}, 1707 cm ^{1}, and 1547 cm ^{1}, which closely match the peaks observed in sample OC [7].

Cover Page

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The intensity and sharpness of the capsaicinoid marker peaks in sample OC suggest that the chili powder contains appreciable levels of capsaicinoids, indicating good quality and pungency. The absence of unusual peaks or spectral distortions in the capsaicinoid marker region (1750–1500 cm ^{1}) suggests that the sample is free from major adulterants that would alter this characteristic signature [4], [5].

2.5 Lipid and Carotenoid Content

The strong absorption at 2926 cm ^{1} (C-H stretching) and the carbonyl peak at 1707 cm ^{1} indi- cate significant lipid content in sample OC. Chili powder typically contains 10–20% lipids, including triglycerides, phospholipids, and fatty acids [2]. The lipid fraction is important for several reasons: (1) it serves as a solvent for lipophilic compounds such as capsaicinoids and carotenoids, (2) it contributes to the flavor and mouthfeel of chili powder, and (3) it affects the bioavailability of bioactive compounds [12].

Carotenoids, particularly capsanthin and capsorubin, are responsible for the characteristic red color of chili powder and possess antioxidant properties [3]. While carotenoids do not exhibit strong, distinct peaks in the FTIR spectrum due to their low concentration (0.1– 0.5%), they contribute to the overall absorption in the C-H stretching region (2926 cm ^{1}) and the C=C stretching region (1659 cm ^{1}) [20]. The presence of these peaks, combined with the visual red color of the sample, suggests that carotenoid content is preserved in sample OC.

The lipid profile of chili powder can be affected by processing conditions, storage, and adul- teration. Oxidation of lipids during storage can lead to the formation of carbonyl compounds, which would increase absorption in the 1750–1680 cm ^{1} region [12]. The relatively sharp car- bonyl peak at 1707 cm ^{1} in sample OC, without significant broadening or additional peaks at higher wavenumbers, suggests that lipid oxidation is minimal, indicating proper storage conditions.

2.6 Protein and Carbohydrate Components

The FTIR spectrum reveals the presence of proteins through the Amide I (1659 cm ^{1}) and Amide II (1547 cm ^{1}) bands. Chili powder contains 10–15% protein, primarily in the form of enzymes, structural proteins, and storage proteins [1]. The protein content contributes to the nutritional value of chili powder and can serve as a quality indicator, as protein levels are relatively stable and less susceptible to adulteration compared to other components [10].

The strong absorption at 1049 cm ^{1} and the complex pattern in the 1300–1000 cm ^{1} region confirm the presence of carbohydrates, which constitute the major component (50–60%) of chili powder [2]. These carbohydrates include structural polysaccharides (cellulose, hemicel- lulose, pectin) and simple sugars. The C-O stretching vibrations in this region are charac- teristic of glycosidic bonds and hydroxyl groups in carbohydrate structures [9].

The carbohydrate profile can be used to detect certain types of adulteration. For example, addition of starch or flour would increase the intensity of peaks in the 1300–1000 cm ^{1} region and alter the spectral pattern [5], [6]. The carbohydrate signature in sample OC appears consistent with authentic chili powder, without unusual intensification that would suggest starch adulteration.

2.7 Quality Indicators and Authentication

The FTIR spectrum of sample OC provides several quality indicators that can be used to assess the authenticity and quality of chili powder:

Cover Page

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1. Capsaicinoid Marker Presence: The clear presence of capsaicinoid marker peaks (1707 cm ¹ and 1547 cm ¹) confirms that the sample contains authentic capsaicinoids, indicating genuine chili powder rather than adulterated or substituted material [4], [5].

2. Spectral Integrity: The absence of unusual peaks or spectral distortions suggests that the sample is free from major adulterants such as synthetic dyes (Sudan red, rhodamine B), which would produce characteristic peaks in the 1500–1600 cm ¹ region [5]. Similarly, the absence of strong peaks in the 800–600 cm ¹ region suggests that inorganic adulterants (brick powder, ferric oxide) are not present in significant quantities [6].

3. Lipid Quality: The sharp carbonyl peak at 1707 cm ¹ without significant broadening indicates that lipid oxidation is minimal, suggesting proper storage and handling [12].

4. Moisture Content: The broad O-H stretching band at 3449 cm ¹ includes contributions from residual moisture. While FTIR cannot provide precise moisture quantification without calibration, the moderate intensity of this peak suggests that moisture content is within acceptable limits (typically 8–12% for chili powder) [11], [22].

5. Overall Spectral Profile: The FTIR spectrum of sample OC exhibits a profile consistent with authentic chili powder, with all expected functional groups and chemical constituents present. The spectral pattern matches those reported in literature for genuine *Capsicum annuum* products [1], [10], [16].

2.8 Comparison with Literature

The FTIR spectrum of sample OC shows excellent agreement with published spectra of authentic chili powder and capsaicinoid-containing materials. Shaheen et al. reported characteristic FTIR peaks for *Capsicum annuum* at 3448 cm ¹ (O-H), 2926 cm ¹ (C-H), 1707 cm ¹ (C=O), and 1547 cm ¹ (Amide II), which closely match the peaks observed in this study [1], [10]. Pasha conducted comparative analysis of *Capsicum annuum* from Pakistan using FTIR and reported similar spectral features, confirming the consistency of FTIR signatures across different chili varieties [2].

Ciulu-Costinescu et al. performed preliminary FTIR analysis of *Capsicum annuum* extracts and identified characteristic peaks in the 3400–3200 cm ¹ (O-H), 2950–2850 cm ¹ (C-H), 1750– 1650 cm ¹ (C=O), and 1600–1500 cm ¹ (aromatic) regions, consistent with the findings of this study [12]. The similarity in spectral patterns across different studies and geographical origins suggests that FTIR provides a robust fingerprint for chili powder authentication.

Studies on adulteration detection have demonstrated that FTIR can distinguish authentic chili powder from adulterated samples. Galvin-King et al. showed that spent paprika substitution in paprika powder could be detected using FTIR spectroscopy, with key dis- criminating features in the 1800–900 cm ¹ region [4]. ADISTI et al. successfully identified synthetic dye adulteration in chili powder using FTIR, with characteristic peaks appearing in the 1500–1600 cm ¹ region for rhodamine B and erythrosine B [5]. The absence of such anomalous peaks in sample OC supports its authenticity.

Johnson et al. demonstrated that FTIR spectroscopy could be used for quality assessment of Habanero chili, with correlations between spectral features and quality parameters such as capsaicinoid content, moisture, and color [11], [22]. This proof-of-concept study highlighted the potential of FTIR as a rapid screening tool for quality control in the spice industry, supporting the approach used in this study.

Recent comprehensive reviews have emphasized the growing importance of non-targeted analytical methods, including FTIR spectroscopy, for authentication of spices and herbs [18]. Oliveira et al. reviewed various analytical

Cover Page

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approaches for spice authentication and concluded that FTIR, particularly when combined with chemometric analysis, provides a powerful tool for detecting adulteration and assessing quality [18]. Johnson et al. provided a comprehensive review of analytical techniques for spice quality and safety assessment, highlighting FTIR as a key technology for rapid, non-destructive analysis [14].

The application of FTIR spectroscopy for capsaicinoid analysis has been validated in multiple studies. A et al. reviewed extraction and quantification methods for capsaicin and noted that FTIR spectroscopy, while not as quantitatively precise as HPLC, provides valuable qualitative information about capsaicinoid presence and can serve as a screening tool [13]. Khuriyati et al. demonstrated the use of near-infrared (NIR) spectroscopy for non-destructive measurement of antioxidant activity and water content in chili powder, showing that infrared- based methods can predict quality parameters with good accuracy [23].

1. Conclusion

This study demonstrates that FTIR spectroscopy is a powerful, rapid, and non-destructive analytical tool for chemical characterization and quality assessment of chili powder. The FTIR spectrum of open market chili powder sample OC revealed seven major absorption peaks corresponding to characteristic functional groups of capsaicinoids, lipids, proteins, carbohydrates, and phenolic compounds.
The presence of diagnostic capsaicinoid marker peaks at 1707 cm^{-1} (amide C=O) and 1547 cm^{-1} (Amide II) confirms the authenticity of the sample and indicates the presence of capsaicin and related alkaloids. The spectral profile is consistent with genuine chili powder containing expected levels of bioactive compounds, with no evidence of major adulteration.
Key findings include:

1. **Capsaicinoid Confirmation:** The characteristic FTIR signature of capsaicinoids (peaks at 3449, 2926, 1707, 1659, and 1547 cm^{-1}) confirms the presence of authentic pungent compounds.
2. **Chemical Composition:** The spectrum reveals the complex chemical composition of chili powder, including lipids (2926 cm^{-1}), proteins (1659, 1547 cm^{-1}), and carbohy- drates (1049 cm^{-1}).
3. **Quality Indicators:** The spectral profile suggests good quality with minimal lipid oxidation and no evidence of common adulterants.
4. **Authentication Potential:** The FTIR fingerprint provides a basis for authentication and quality control applications in the spice industry.
5. **Literature Consistency:** The observed spectral pattern shows excellent agreement with published FTIR data for authentic *Capsicum annuum* products.

FTIR spectroscopy offers significant advantages over traditional analytical methods, includ- ing minimal sample preparation, rapid analysis (minutes vs. hours), non-destructive nature, and the ability to provide comprehensive chemical fingerprinting. When combined with chemometric techniques, FTIR can achieve high accuracy in classification, authentication, and semi-quantitative analysis of chili powder.

Future research directions include: (1) development of calibration models for quantitative determination of capsaicinoid content using FTIR, (2) expansion of spectral databases for different chili varieties and geographical origins, (3) integration of FTIR with other analytical techniques (HPLC, GC-MS) for comprehensive quality assessment, and (4) application of advanced chemometric methods (machine learning, artificial neural networks) for improved classification and prediction.
This study contributes to the growing body of evidence supporting FTIR spectroscopy as a valuable tool for

Cover Page

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quality control, authentication, and safety assessment of spice products, with important implications for food industry, regulatory agencies, and consumer protection.

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Conflict of Interest

The authors declare no conflict of interest.

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Cover Page

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