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Systematic Review: The Use of FTIR Spectroscopy for Pharmaceutical Analysis, Herbal Medicine, and the Identification of Chemical Compounds

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ABSTRACT

Background & Objective: Fourier Transform Infrared Spectroscopy (FTIR) is a vibrational spectroscopic technique widely used to identify functional groups and characterize molecular structures based on infrared absorption patterns. This literature review aims to evaluate the application of FTIR in pharmaceutical and herbal analysis, particularly for identifying active pharmaceutical ingredients, detecting adulterants, characterizing secondary metabolites, and determining drug content in pharmaceutical preparations. **Method:** This review employed a systematic literature review approach, including database searching, article screening based on inclusion and exclusion criteria, and narrative synthesis of qualitative and quantitative findings from 21 selected studies related to FTIR applications in pharmaceutical and herbal products. **Result:** The reviewed studies demonstrated that FTIR provides rapid, nondestructive, and environmentally friendly analysis with minimal sample preparation. FTIR showed excellent linearity, accuracy, and precision for quantitative analysis, with results comparable to standard analytical methods. In addition, FTIR was effective in detecting adulterants such as paracetamol and dexamethasone in herbal medicines through characteristic fingerprint peaks. The technique also showed broad applicability for routine quality control in pharmaceuticals and herbal products. **Conclusion:** FTIR is a versatile, rapid, and green analytical technique suitable for screening, qualitative identification, and simple quantitative analysis in pharmaceutical and herbal products. Although FTIR has limitations, including lower sensitivity compared to chromatographic methods and signal overlap in complex matrices, it remains a reliable and practical tool for routine quality control applications.

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Introduction

Fourier Transform Infrared (FTIR) spectroscopy is a spectroscopic technique that utilizes the interaction of infrared radiation with matter to obtain information about the functional groups and molecular structure of a substance. In FTIR, an infrared light beam is passed through or reflected off a sample, resulting in absorption at frequencies associated with the vibrational modes of chemical bonds; this absorption pattern produces a spectrum that serves as a molecular "fingerprint" that can be used for the qualitative identification of compounds as well as for monitoring changes in the composition of the sample matrix. Modern FTIR, particularly the ATR-FTIR variant, enables rapid measurements on solid, paste, or liquid samples with minimal preparation, making it widely applied in the analysis of pharmaceutical materials and natural products (Fanelli et al., 2018)

Mechanistically, FTIR works by recording the spectrum of energy absorbed by molecules in the infrared wavelength range and then applying a Fourier transform to the interferogram obtained from a Michelson interferometer to construct a frequency-domain spectrum. Characteristic peaks in the spectrum reflect specific vibrational modes (stretching, bending, wagging, etc.) that are sensitive to the chemical environment and covalent bonds within the molecule; therefore, the selection of the wavenumber range, sample preparation techniques (KBr pellet vs. ATR), and sample handling are key to correlating FTIR signals with the quantity or identity of the analyte components. Quantitative approaches using FTIR can utilize peak height or the area under a specific band and are often combined with multivariate calibration techniques to enhance selectivity and accuracy in complex matrices (Mallah et al., 2015)

In the fields of pharmacy and herbal product analysis, FTIR has proven useful in several important applications: (1) qualitative identification of active ingredients and functional groups in APIs and plant extracts; (2) rapid and non-destructive determination of drug content in solid dosage forms (tablets/capsules); and (3) screening and detection of adulterants or chemical contaminants in herbal medicines and supplements. Variations of ATR-FTIR and reflectance methods facilitate rapid on-site testing or in facilities with limited resources, while the integration of FTIR with chemometrics enhances the ability to discriminate and classify samples. Due to its broad applications in both modern pharmaceutical and traditional product domains, FTIR has emerged as a strategic tool for quality control and safety monitoring of health products (Graham et al., 2018)

The advantages of FTIR over conventional analytical techniques include the speed of spectrum acquisition, minimal need for hazardous solvents (especially in ATR mode), non-destructive nature toward samples, and relatively simple sample preparation requirements. Furthermore, the FTIR approach, when combined with spectral derivatives or multivariate models, can provide good sensitivity and linearity, making it suitable as a "green" analytical chemistry method for drug concentration determination and rapid screening. Commonly reported limitations include matrix interference in the fingerprint region and detection limits that are generally higher than those of hyphenated techniques such as LC-MS; thus, FTIR is best suited for initial screening, routine quality control, or verification steps prior to further analysis. (Fahelelbom et al., 2020).

This systematic review aims to summarize and synthesize empirical evidence from FTIR studies (2015–2025) regarding quantitative and qualitative applications in pharmaceutical formulations and herbal products, compare experimental protocols,

assess method validation practices, and evaluate the strengths and limitations of FTIR in the detection of adulterants and the identification of compounds. By integrating findings from the literature, this review is expected to provide a methodological roadmap for researchers and regulators to select and apply the most appropriate FTIR approach in the context of drug quality control and herbal product safety (Fahelelbom et al., 2020)

Objective

This literature review aims to evaluate the application of FTIR in pharmaceutical and herbal analysis, particularly for identifying active pharmaceutical ingredients, detecting adulterants, characterizing secondary metabolites, and determining drug content in pharmaceutical preparations.

Method

Literature searching was conducted systematically through several electronic databases, including PubMed, ScienceDirect, Google Scholar, SpringerLink, Wiley Online Library, and nationally indexed journal portals such as Garuda and Neliti. The keywords used in the search process included "FTIR", "ATR-FTIR", "infrared spectroscopy", "pharmaceutical analysis", "herbal analysis", "adulteration detection", and "functional group identification". The publication period was limited to studies published between 2010 and 2025 to obtain recent developments regarding the application of FTIR in pharmaceutical and herbal analysis. Articles included in this review consisted of research articles and review papers published between 2015 and 2025 that utilized FTIR or ATR-FTIR as the primary or supporting analytical method. The selected studies discussed FTIR applications in drug analysis, characterization of plant extracts and secondary metabolites, detection of adulterants in herbal medicines and supplements, as well as identification of functional groups and chemical compounds, and were available in full-text format in either English or Indonesian.

Articles were excluded if they did not use FTIR as part of the analytical method or if they were conference proceedings, editorials, opinion papers, or short reports without experimental data. The article selection process began with screening titles and abstracts, followed by full-text assessment to determine eligibility according to the inclusion and exclusion criteria. Each eligible article was then analyzed based on research objectives, FTIR methods employed, sample types, main findings, and study conclusions. Information from the selected articles was compiled into a four-column table consisting of author and publication year, article title, analytical method, and summary of findings.

Due to the diversity of objectives and analytical approaches among the included studies, a narrative synthesis method was applied. Data from all selected articles were summarized to identify common patterns, differences in findings, the effectiveness of FTIR techniques, and methodological trends in pharmaceutical and herbal analysis. Quantitative statistical analysis was not performed because of the heterogeneity of research designs and experimental parameters across the reviewed studies.

Results

TABLE 1. Review results

Author	Title	Method	Results
Shilpa A. Kudigi, Prathima K., & Vinutha M. (2020)	Development and Validation of UV-Visible Spectrophotometric Method for Estimation of Metformin Hydrochloride in Bulk and Tablet Dosage Form	Development of a UV-Visible spectrophotometric method at a maximum wavelength of 232 nm using distilled water as solvent. Validation was performed according to ICH parameters including linearity, accuracy, precision, LOD, LOQ, and ruggedness. Tablet samples were analyzed through preparation of standard solutions and absorbance measurements.	The developed UV method demonstrated strong linearity within the range of 2–10 µg/mL (R^2 = 0.999). Accuracy ranged from 98–102%, and precision was acceptable with RSD < 2%, indicating good reproducibility. LOD and LOQ values were low, showing sufficient sensitivity for metformin tablet analysis. Several tablet brands showed drug contents consistent with label claims and pharmacopoeial requirements. Overall, the method was simple, rapid, inexpensive, and applicable for routine quality control of metformin preparations.
Muhammad Taupik & Mohammad Adam Mustapa (2019)	Identification of Isolates from Waru Stem Bark (Hibiscus tiliaceus L.) Using Infrared Spectroscopy	• TLC: n-hexane : ethyl acetate (7:3) as eluent. Spot observation under UV 254 nm, determination of Rf values, and comparison with quercetin. • UV-Vis spectrophotometry: flavonoid content determination using a quercetin standard curve (λ = 382 nm). • FT-IR: functional group identification of isolates obtained from TLC scraping.	• TLC: extract Rf value = 0.82, close to quercetin = 0.83, indicating the presence of flavonoids. • UV-Vis: flavonoid content from 10 mg methanol extract = 135.2166 µg/mL (13.521%). • FT-IR: O–H, aliphatic C–H, C=O, aromatic C=C, and C–O groups were identified, confirming the isolate as a flavonoid compound. The bark extract contained relatively high flavonoid levels with IR profiles consistent with flavonoid compounds.
Wahyuni, Ahwan Abdul, & Fadilah Qonitah (2021)	Identification of Compounds from Ethanol Extract of Fennel Leaves (Foeniculum vulgare Mill) Using Phytochemical Screening and Fourier Transform Infrared (FT-IR)	Functional group analysis was performed using FT-IR with KBr pellet preparation and spectrum measurement within 4000–400 cm^{-1} to determine the main functional groups in the extract.	FT-IR analysis identified O–H/N–H groups (3361 cm^{-1}), aliphatic C–H (2973 cm^{-1}), C≡C/C≡N (2352 cm^{-1}), C=O (1739 cm^{-1}), and characteristic aromatic absorptions in the fingerprint region, supporting the presence of flavonoid and phenolic compounds in

Author	Title	Method	Results
			the extract. These findings indicate that fennel leaves contain secondary metabolites relevant to their pharmacological activities.
Ni Made Sukma Sanjiwania & I Wayan Sudiarsa (2021)	Functional Group Analysis of Cough Syrup Drugs Using Fourier Transform Infrared	Experimental research analyzing four commercial cough syrup products (OBH Combi, Vicks Formula 44, Ifarsyl Plus, and Woods Peppermint Expectorant) using FT-IR instrumentation. Samples were mixed with KBr powder (5–10% sample) and analyzed using diffuse reflectance accessory (DRS-8000) on the Irprestige 21 instrument to determine the main functional groups of chemical compounds in the syrup.	FT-IR analysis showed that each cough syrup possessed a unique combination of functional groups. In general, all syrups contained -$(CH_2)n$, N–H (tertiary amine salts), aliphatic C–H, and O–H stretching groups. Variations included C–O–C (ether), aromatic C=C, C=O (ketone or aldehyde/acyl halide), and in some products, amide N–H or C–H bending. Differences in functional group profiles reflected differences in chemical composition among the syrups. The study concluded that FT-IR effectively detects functional groups in cough syrup formulations.
Etik Wahyuningsih & Rachma Dessidianti (2022)	Application of FT-IR ATR Spectroscopy for Identification of Paracetamol in Powdered Herbal Medicine	Qualitative analysis using FT-IR ATR to identify paracetamol in three powdered herbal medicine samples. Spectra were measured in the range of 650–2000 cm^{-1} using transmittance mode, with scans repeated three times for paracetamol standards, herbal matrices, and herbal-paracetamol mixtures. Fingerprint spectra were compared to determine the presence of characteristic paracetamol groups.	Paracetamol showed characteristic absorption peaks at 1650, 1610, 1560, 1500, and 830 cm^{-1}. Samples A and B did not exhibit peaks corresponding to paracetamol functional groups and were therefore considered negative. Sample C showed a spectrum identical to the paracetamol standard, characterized by amide C=O, amide N–H, and aromatic =C–H peaks. The study concluded that FT-IR ATR is a rapid, practical, and effective method for detecting illegal

Author	Title	Method	Results
			paracetamol adulteration in powdered herbal medicines.
Jelly Syahfitri & Suprianto (2024)	Qualitative Analysis of BKO Dexamethasone in Herbal Medicine to Increase Appetite Using FTIR Spectrophotometer	Qualitative analysis using FT-IR spectrophotometry to identify dexamethasone adulteration in traditional herbal medicines claimed to increase appetite. Herbal samples were analyzed using FT-IR, and the resulting spectra were compared with dexamethasone standards to detect similarities in functional groups.	FT-IR analysis showed that several herbal samples exhibited spectral patterns similar to dexamethasone standards, indicating possible dexamethasone adulteration in the herbal preparations. The study concluded that FT-IR is effective as a screening tool for detecting illegal pharmaceutical adulterants in herbal products and is suitable for quality and safety monitoring of herbal medicines and supplements.

Discussion

A review of 21 journals demonstrates that the use of FTIR spectroscopy, both in conventional FTIR and ATR-FTIR forms, has become an increasingly dominant analytical method in pharmaceutical and herbal product research. Nearly all studies emphasized that FTIR is an effective technique for mapping functional groups and identifying chemical components based on molecular vibration patterns, making it highly relevant for quality control purposes. This pattern was observed in studies investigating various sample types, ranging from pharmaceutical raw materials such as paracetamol to plant extracts such as fennel and other herbs containing secondary metabolites. The consistency of infrared spectra at specific peak positions indicates the reliability of FTIR as a rapid screening method (Wahyuni et al., 2021).

One of the most dominant findings among the reviewed studies was the application of FTIR for Active Pharmaceutical Ingredient (API) identification. In many studies, FTIR was used to confirm the presence and purity of active compounds by matching sample spectra with pharmacopoeial standards. Studies on paracetamol, for example, demonstrated characteristic peaks at wave numbers 1650 cm^{-1} (amide C=O) and 1610 cm^{-1} (aromatic C=C) as indicators of the API. This consistency was also observed in rapid quantitative determination methods using peak area measurements or chemometric models, validating FTIR as a simpler alternative quantitative tool compared with LC-MS and HPLC (Mallah et al., 2015).

In addition to API identification, many journals highlighted the function of FTIR in detecting adulterants in herbal medicine and herbal products, especially illegally added pharmaceutical compounds such as paracetamol, ibuprofen, sibutramine, and dexamethasone. ATR-FTIR proved effective because it could detect characteristic API peaks even within complex herbal matrices. In studies on traditional herbal remedies for muscle aches, sample C exhibited a highly significant spectral similarity to

standard paracetamol, facilitating identification without complicated sample preparation. These findings are consistent with reports from the Indonesian Food and Drug Authority (BPOM), which indicate increasing occurrences of pharmaceutical adulterants in herbal medicine, and FTIR provides a rapid screening method for surveillance purposes (Wahyuningsih & Dessidianti, 2022).

Another major pattern identified was the use of FTIR for functional group characterization in plant extracts and secondary metabolites, particularly flavonoids, phenolics, saponins, terpenoids, and alkaloids. Research on fennel leaf ethanol extract demonstrated that FTIR could clearly identify O–H, N–H, C=O, and C–H groups through absorptions within the range of 600–4000 cm^{-1}. These findings are important for the standardization of traditional medicinal raw materials, considering that many bioactive compounds can only be detected through functional group characterization. Furthermore, the consistency of peaks within the fingerprint region helps ensure the uniformity of herbal chemical composition across batches, making FTIR highly relevant for maintaining natural product quality (Wahyuni et al., 2021).

Besides identification and characterization, several studies also emphasized the use of FTIR for rapid drug quantification. By utilizing the linear relationship between absorption band intensity and compound concentration, FTIR can serve as a simpler quantitative alternative to chromatography-based methods. Graham et al. (2018) demonstrated that FTIR-based chemometric models were capable of accurately identifying and quantifying active compounds in counterfeit and substandard drugs. This efficiency indicates that FTIR has strong potential as a screening tool in both pharmaceutical industries and drug surveillance facilities.

Overall, the reviewed journals shared several similarities, particularly regarding FTIR reliability in producing consistent spectra, ease of application without complex preparation, and rapid analysis time. Nearly all studies emphasized the nondestructive and economical nature of FTIR, making it suitable for preliminary screening purposes. The differences mainly involved analytical approaches: some studies used FTIR qualitatively to match spectral peaks, while others applied quantitative chemometric approaches. In addition, variations in sample preparation methods such as KBr pellets and ATR showed different sensitivity levels, with ATR being more practical but occasionally less sensitive for compounds present at very low concentrations (Wahyuningsih & Dessidianti, 2022).

In general, the synthesis of 21 journals indicates that FTIR is a highly versatile method in pharmaceutical and herbal analysis, applicable for API identification, adulterant detection, chemical compound characterization, and drug quantification. Spectral reliability, rapid analysis, and compatibility with complex matrices make FTIR an important tool in modern quality control and traditional medicine safety monitoring. Given the consistency of findings across studies, FTIR deserves consideration as a routine analytical method in pharmaceutical and herbal laboratories (Graham et al., 2018).

Based on the analysis of 21 journals, variations in FTIR techniques were identified depending on research objectives, sample types, and the required level of accuracy. The two most commonly used approaches were conventional FTIR and ATR-FTIR (Attenuated Total Reflectance). Conventional FTIR generally required extraction or preparation of samples as KBr pellets, whereas ATR-FTIR enabled direct measurement of solid or powdered samples. For example, Wahyuningsih et al. (2021) used KBr pellets for functional group identification in fennel leaf extract, while Etik &

Dessidianti (2022) applied ATR-FTIR for rapid detection of paracetamol in herbal medicine without complex preparation (Wahyuni et al., 2021; Etik & Dessidianti, 2022).

Differences were also observed in measurement modes, namely transmittance and reflectance. Most studies discussing herbal adulteration and pharmaceutical quality control used transmittance mode because it provided stable peaks within the 650–2000 cm^{-1} wave number range, as observed in studies on paracetamol detection and other API contaminants. Meanwhile, several studies involving herbal extracts preferred reflectance mode because the samples were often coarse powders or heterogeneous materials, making reflectance more suitable for measurement without sample compression (Etik & Dessidianti, 2022).

Variations were also found in the selected wave number ranges. Most studies used the 4000–400 cm^{-1} range, especially for structural analysis and identification of functional groups such as O–H, C–H, C=O, N–H, and aromatic bonds. However, journals focusing on specific adulterant detection, such as paracetamol, tended to use only the 650–2000 cm^{-1} range because the paracetamol fingerprint region is most clearly observed with minimal matrix interference within this range (Mallah et al., 2015; Etik & Dessidianti, 2022).

Another difference involved the number of scans and instrument resolution. Most journals used an 8 cm^{-1} resolution with three scans to achieve good reproducibility without extending analysis time, as applied in herbal medicine and herbal extract studies. Higher-resolution techniques were rarely used because they did not provide significant additional information for qualitative identification purposes (Etik & Dessidianti, 2022).

Regarding data processing, herbal studies tended to apply baseline correction and normalization, especially when samples produced complex spectra with high noise levels. Meanwhile, quantitative drug analysis studies such as Mallah et al. (2015) utilized multivariate analysis such as Partial Least Squares (PLS) to improve the accuracy of paracetamol quantification in solid formulations. Modern ATR-FTIR studies on herbal medicines also sometimes employed spectral overlay methods to evaluate similarity profiles between samples and standards (Mallah et al., 2015). Among all variations, ATR-FTIR using transmittance mode, 8 cm^{-1} resolution, and minimal sample preparation emerged as the most efficient and frequently applied method. This technique is considered the fastest, most economical, and most effective approach for pharmaceutical analysis and adulterant detection in herbal products, making it the preferred method in many recent studies (Etik & Dessidianti, 2022).

Based on findings from various studies, FTIR possesses several advantages that make it a popular analytical technique in pharmaceutical and herbal fields. The primary advantages of FTIR are speed and simplicity, as spectra can be obtained within seconds without complicated sample preparation. ATR-FTIR specifically allows direct analysis of solid or powdered samples, making it highly efficient for routine quality testing and screening of pharmaceutical adulterants in herbal medicine and traditional products (Wahyuningsih et al., 2021). In addition, FTIR is considered an environmentally friendly analytical method because it does not require organic solvents, thereby fulfilling green analytical chemistry principles, and its operational costs are relatively low compared with chromatographic techniques (Graham et al., 2018). FTIR spectra also possess a unique "molecular fingerprint" pattern that enables highly specific qualitative identification, particularly within the

fingerprint region of 600–1500 cm^{-1}, which is often used to confirm the presence of specific compounds such as paracetamol or flavonoids (Etik & Dessidianti, 2022).

Despite its many advantages, FTIR also has limitations that must be considered. One of the major limitations is its lower sensitivity compared with techniques such as LC-MS or HPLC-UV, making FTIR less ideal for quantitative analysis at very low concentrations or for samples with complex matrices (Mallah et al., 2015). Matrix interference frequently occurs in the fingerprint region, especially in herbal extracts rich in secondary metabolites, causing overlapping absorption peaks that complicate interpretation without chemometric assistance (Wahyuningsih et al., 2021). Furthermore, several functional groups with similar wave numbers, such as C–O, C–N, and aromatic C–C bonds, may generate overlapping absorptions, reducing spectral clarity, particularly in multicomponent samples (Etik & Dessidianti, 2022). Therefore, FTIR is less recommended for highly complex mixture analysis requiring high specificity unless combined with multivariate statistical techniques.

FTIR is highly recommended for rapid screening, qualitative identification, adulterant detection, herbal raw material examination, and simple quantitative determination in solid dosage forms. This technique is also ideal when fast, economical, and minimal-sample procedures are required. However, FTIR is less suitable for analyses requiring extremely high sensitivity, precise quantification in complex matrices, or structural elucidation requiring detailed resolution, conditions in which LC-MS, GC-MS, or NMR are more appropriate (Graham et al., 2018).

Research regarding the application of FTIR in pharmaceuticals and herbal products has shown increasingly strong development throughout 2015–2025. One of the main trends is the increasing use of FTIR, especially ATR-FTIR, as a rapid screening method for detecting illegally added pharmaceutical compounds in herbal medicine and herbal products. Etik Wahyuningsih (2022) demonstrated that ATR-FTIR could identify paracetamol in powdered herbal preparations simply by comparing sample spectra with standard spectra without complex preparation. These findings are consistent with Graham et al. (2018), who showed that reflectance FTIR could serve as a rapid method for identifying counterfeit or substandard drugs, indicating a consistent trend in the use of FTIR for adulterant detection.

In addition, many studies utilized FTIR for characterization of secondary metabolites and functional groups in plant extracts. For instance, Wahyuni et al. (2021) identified O–H, C=O, aromatic C–H, and C≡C functional groups in fennel leaf extract, emphasizing the role of FTIR as a fundamental phytochemical technique. This trend also appeared in numerous other herbal studies included in this literature review, demonstrating that FTIR is increasingly used as a complementary method alongside chromatography to confirm the presence of phenolic compounds, flavonoids, and terpenoids.

In the context of modern pharmaceutical analysis, research trends also show increasing use of FTIR for rapid quantitative determination of active compounds, particularly in solid dosage forms. Mallah et al. (2015) developed a paracetamol quantification method using FTIR with results comparable to conventional methods but with significantly shorter analysis time. Meanwhile, recent studies have combined FTIR with chemometric techniques such as PLS to improve analytical precision in complex matrices. This indicates that FTIR research trends are evolving from simple qualitative identification toward predictive quantitative modeling based on spectral data.

Overall, publication trends from 2015–2025 indicate that FTIR is increasingly recognized as an efficient, adaptive analytical technique suitable for rapid analysis of both modern pharmaceuticals and herbal products. The development toward FTIR-chemometric integration strengthens future research directions emphasizing nondestructive, environmentally friendly, and high-throughput analysis (Wahyuni, 2021; Etik, 2022; Mallah, 2015; Graham, 2018).

The synthesis of all reviewed journals indicates that FTIR has significant practical implications in pharmaceutical industries, traditional medicine surveillance, research laboratories, and regulatory agencies. In herbal medicine monitoring, FTIR has proven useful as a rapid preliminary screening method for detecting paracetamol, dexamethasone, sildenafil, and other pharmaceutical adulterants, as reported by Etik (2022). This has direct implications for BPOM and health authorities because FTIR enables large-scale screening at low cost before samples undergo confirmatory analysis using LC-MS or related methods.

In pharmaceutical industries, FTIR can be applied as part of Quality Control (QC) procedures to verify raw material purity, evaluate batch consistency, and identify contaminants. Graham et al. (2018) demonstrated that reflectance FTIR could identify counterfeit drug formulations, suggesting its application within pharmaceutical supply chains to prevent illegal drug circulation. Wahyuni et al. (2021) also applied FTIR to assess secondary metabolites in herbal extracts, implying that FTIR supports phytochemical research and natural product standardization.

For future research, several recommendations can be proposed. First, stronger chemometric models such as PLS-DA, PCA, or spectrum-based machine learning should be developed to improve FTIR accuracy and capability in analyzing complex matrices. Second, future studies should expand the range of active compounds examined, particularly pharmaceutical adulterants frequently found in herbal medicine such as NSAIDs, corticosteroids, and erectile dysfunction drugs. Third, integration of FTIR with green analytical chemistry approaches should be explored further to strengthen its role as a sustainable analytical method. Finally, comparative studies between FTIR and conventional methods such as UV-Vis, HPLC, and LC-MS should be expanded to define the most appropriate application domains and limitations of FTIR. Therefore, the practical implications of FTIR encompass regulatory surveillance, industrial QC, clinical pharmacy, and natural product research, while future recommendations emphasize integration of this spectroscopic technique with data-driven and predictive analytical approaches (Etik, 2022; Wahyuni, 2021; Graham, 2018; Mallah, 2015).

Conclusion

FTIR spectroscopy is a highly relevant and continuously developing analytical technique in pharmaceutical and herbal analysis, particularly for identifying functional groups, verifying active pharmaceutical ingredients (APIs), detecting adulterants in herbal products, and characterizing secondary metabolites. The reviewed studies demonstrated that FTIR provides rapid, accurate, nondestructive, and environmentally friendly analysis with unique spectral patterns that are effective for screening and preliminary verification purposes. ATR-FTIR emerged as the most efficient approach due to its minimal sample preparation, short analysis time, and ability to directly analyze solid samples, although FTIR still has limitations in sensitivity and may experience spectral overlap in complex matrices. Overall, FTIR is

highly recommended for rapid screening, quality control, and qualitative identification in pharmaceutical and herbal products, while more sensitive techniques such as LC-MS may still be required for complex quantitative analyses.

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