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Pharmaceutical Analysis and Practical Applications of Curcumin Derived from Curcuma longa

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Abstract. Curcumin is a natural polyphenolic compound derived from the rhizome of Curcuma longa. It has gained great attention due to its varied pharmacological actions, particularly anti-inflammatory, antioxidant, and anticancer effects. With increasing interest in plant-derived natural products, reliable pharmaceutical analysis of curcumin is essential to ensure the quality, safety, and efficacy of related products. This review summarizes recent advances in the pharmaceutical analysis of curcumin and discusses its practical applications in modern medicine and industrial fields. Various analytical procedures are presented, including sample preparation techniques, chromatographic approaches such as high-performance liquid chromatography (HPLC), and sophisticated techniques such as liquid chromatography–mass spectrometry (LC–MS). In addition, the applications of curcumin in herbal medicine quality control, disease treatment research, and nutraceutical product development are reviewed. Although curcumin shows promising application potential, challenges such as low bioavailability and poor stability continue to limit its practical use. Future developments in analytical methodologies and formulation technologies are expected to promote further the application of curcumin in pharmaceutical and health-related fields.

Keywords: Curcumin, Pharmaceutical analysis, Chromatographic analysis, Herbal medicine quality control

1. Introduction

Natural products derived from medicinal plants have long served as an important source of therapeutic agents and continue to play a significant role in modern drug discovery and development [1,2]. Of the different plant-derived bioactive compounds, curcumin, a principal bioactive component isolated from the rhizome (root) of Curcuma longa (turmeric) has received significant interest for its variety of biological and pharmacological activities [3]. Various investigations have revealed that curcumin possesses anti-inflammatory, antioxidant, antibacterial, and anticancer activities, thereby presenting a tremendous promise for further pharmaceutical and nutraceutical development [3-5].

Despite these beneficial biological properties, the practical application of curcumin is limited by several challenges, including poor water solubility, low bioavailability, and instability under certain environmental conditions [6,7]. Therefore, accurate and reliable pharmaceutical analysis is crucial for the identification, quantification, and quality control of curcumin and related products. To date,

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numerous analytical methods have been developed for curcumin detection, comprising chromatographic techniques such as high-performance liquid chromatography (HPLC) and sophisticated analytical methods like liquid chromatography–mass spectrometry (LC–MS) [8,9].

This review aims to summarize the sources and chemical properties of curcumin systematically, outline commonly used pharmaceutical analytical methods, and discuss its practical applications in the pharmaceutical and industrial fields. By reviewing recent research advances, this study highlights the importance of reliable analytical strategies in promoting the development and application of curcumin-related products.

2. Source and chemical characteristics of curcumin

2.1. Botanical source

Curcuma longa is a perennial herbaceous plant belonging to the Zingiberaceae family. It is widely dispersed in tropical and subtropical countries, particularly in South and Southeast Asia, including India, China, Thailand, and Indonesia [10]. Turmeric has an extensive record of use in conventional and traditional medical systems, especially in Ayurvedic and traditional Chinese medicine, where it is used to treat inflammation, infections, and digestive issues [3].

Curcumin is a natural polyphenolic compound, and the rhizome of turmeric is the primary source of curcumin and related compounds collectively known as curcuminoids. These compounds are responsible not only for turmeric's characteristic yellow color but also for its pharmacological activities [3,10]. In addition to curcumin, turmeric rhizomes contain two structurally related compounds, demethoxycurcumin and bisdemethoxycurcumin, which together constitute the major bioactive components of turmeric extracts [11].

2.2. Chemical structure and physicochemical properties

Curcumin, also known as diferuloylmethane, has a molecular formula of C21H20O6 and a molecular weight of approximately 368.38 g/mol. Its molecular structure consists of two aromatic phenolic rings joined by a seven-carbon linker bearing an α,β-unsaturated carbonyl group [3,11]. This highly conjugated structure contributes to its strong antioxidant activity and enables interactions with various biological targets [4].

A notable feature of curcumin is the presence of functional groups, such as phenolic hydroxyls and methoxy groups, on its aromatic rings. These functional groups play a crucial role in determining its biological activities, including free radical scavenging and anti-inflammatory effects [4]. In addition, curcumin exhibits keto–enol tautomerism, allowing reversible interconversion between two structural forms depending on the surrounding environment [11].

In terms of physicochemical properties, curcumin typically appears as a bright yellow crystalline powder. It is poorly soluble in water but readily soluble in organic solvents such as ethanol, methanol, acetone, and dimethyl sulfoxide (DMSO). This low aqueous solubility significantly limits its absorption in biological systems and is a major factor contributing to its low bioavailability [6,7].

2.3. Stability and bioavailability issues

Curcumin is light-sensitive and also sensitive to heat and alkaline conditions and is rapidly degraded. In neutral or alkaline aqueous solutions, curcumin can be easily hydrolyzed and subject to oxidative degradation to form the products, for example, ferulic acid, vanillin, etc. and other small

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phenolic substances [6,12]. Such instability may affect the accuracy of measurements made in such laboratory analyses and may also impair the therapeutic activity of curcumin formulations.

Furthermore, curcumin undergoes extensive metabolic transformation in the liver and intestinal tissues, primarily via glucuronidation and sulfation, further reducing its biological activity in vivo [7].

To overcome these limitations, various strategies have been developed to improve the stability and bioavailability of curcumin [7,13]. These include the creation of new delivery systems like nanoparticles, liposomes, polymeric micelles, and phospholipid complexes. These advanced formulations enhance solubility, reduce degradation, and improve absorption efficiency, thereby increasing curcumin's therapeutic potential.

3. Pharmaceutical analysis of curcumin

3.1. Sample preparation methods

Since curcumin is present in complex plant matrices, effective extraction and purification are required before analysis. Among various approaches, solvent extraction is the most widely used technique for sample preparation. Organic solvents such as ethanol, methanol, acetone, and ethyl acetate are commonly used due to their ability to efficiently dissolve curcuminoids [14]. Typically, turmeric rhizomes are first ground into a fine powder, then extracted under controlled conditions [14].

To improve extraction efficiency and reduce processing time, techniques such as ultrasonic-assisted extraction and reflux extraction are often employed. In addition to traditional methods, solid-phase extraction (SPE) is frequently used as a purification step to remove interfering substances through selective adsorption and elution, thereby enhancing analytical accuracy [9]. More advanced techniques, including microwave-assisted extraction and supercritical fluid extraction, have also been increasingly applied to improve efficiency and reduce solvent consumption.

3.2. Chromatographic analysis

Chromatographic techniques are among the most widely used methods for the separation, identification, and quantification of curcumin. Due to their high sensitivity, selectivity, and reproducibility, these techniques play a crucial role in pharmaceutical analysis and quality control [8].

High-performance liquid chromatography (HPLC) is the most commonly used method for curcumin analysis. It enables effective separation of curcumin and related curcuminoids such as demethoxycurcumin and bisdemethoxycurcumin. In many studies, HPLC systems are coupled to ultraviolet (UV) or diode-array detectors (DAD) to achieve accurate quantification based on characteristic absorption wavelengths. Reverse-phase columns, particularly C18 columns, are widely used due to their suitability for separating hydrophobic compounds [8,9].

Thin-layer chromatography (TLC) is a different approach utilised for turmeric analysis. Although less sensitive than HPLC, TLC remains useful for rapid qualitative analysis and preliminary screening due to its simplicity and low cost [8]. Gas chromatography (GC) may be applied to analyze volatile components in turmeric extracts. However, it is generally not suitable for direct analysis of curcumin due to its low volatility.

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3.3. Advanced analytical techniques

In recent years, advanced analytical techniques have been increasingly applied to improve sensitivity, accuracy, and structural characterization. Among these, liquid chromatography–mass spectrometry (LC–MS) is one of the most important methods. By combining chromatographic separation with mass spectrometric detection, LC–MS enables precise identification of curcumin and its metabolites based on molecular mass and fragmentation patterns [9]. LC–MS/MS systems offer even higher analytical performance and are widely used in pharmacokinetic and metabolic studies.

Nuclear magnetic resonance (NMR) spectroscopy is another important technique that provides detailed structural information on curcumin and related compounds. It plays a key role in structural confirmation and in the study of molecular interactions within complex systems [11].

In addition, metabolomics and chemometrics approaches have been increasingly applied in natural product research. These methods allow comprehensive profiling of multiple chemical components in turmeric extracts, enabling a more holistic evaluation of chemical composition and quality characteristics [15].

4. Practical applications of curcumin

4.1. Quality control of herbal medicines

Compared with synthetic drugs, the chemical composition of plant-derived medicinal materials is often significantly influenced by environmental factors, genetic variation, and agricultural practices, leading to considerable variability [1,2]. Geographical origin is one of the key factors affecting curcumin content. Turmeric is mainly cultivated in tropical and subtropical regions, and turmeric produced in Indian states such as Kerala, Tamil Nadu, and Andhra Pradesh is widely recognized for its relatively high curcuminoid content [10].

Studies have shown that turmeric grown under climatic conditions with an average annual temperature of approximately 20–30 °C and annual rainfall of 1500–2500 mm is more favorable for curcuminoid accumulation [10]. In addition, turmeric grows best in well-drained loamy or sandy loam soils, with an optimal soil pH range of 5.5–7.0 [10].

Cultivation practices also significantly affect the accumulation of curcuminoids in turmeric rhizomes. Adequate sunlight exposure and proper nutrient management are essential for improving rhizome yield and curcumin content [10]. Agronomic studies indicate that applying balanced nitrogen, phosphorus, and potassium (NPK) fertilizers can significantly enhance biomass production and increase curcuminoid levels [10]. Furthermore, maintaining appropriate soil moisture through effective irrigation management supports plant growth and promotes the biosynthesis of secondary metabolites [15].

The harvesting stage is another critical factor affecting curcumin content. Generally, turmeric reaches maturity approximately 7–9 months after planting. As the aerial parts of the plant turn yellow and senesce, the accumulation of curcuminoids in the rhizomes typically reaches a relatively high level [10]. Therefore, this stage is considered optimal for harvesting. Timely harvesting not only increases the content of active compounds but also improves the chemical stability of the raw material [10].

Following harvesting, post-harvest processing—including boiling, drying, polishing, and storage—can significantly influence the final quality of turmeric products [10]. Traditional processing methods typically involve boiling fresh rhizomes for 30–45 minutes, followed by drying at 50–60

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°C to reduce moisture content. Excessive drying temperatures or prolonged exposure to strong light, high humidity, or air during storage may accelerate curcumin degradation [6]. Therefore, establishing standardized processing procedures and controlled storage conditions is essential for maintaining the chemical stability and medicinal value of turmeric-derived herbal products [6].

4.2. Therapeutic applications

One of the most important and extensively studied therapeutic effects of curcumin is its anti-inflammatory activity. Studies have showed that curcumin can alter numerous inflammation-related signaling pathways, including suppressing nuclear factor kappa B (NF-κB) and reducing the production of other inflammatory mediators, thereby exhibiting anti-inflammatory actions [4,7]. This mechanism suggests its potential for treating inflammatory diseases, including rheumatoid arthritis and inflammatory bowel disease [4].

In addition, curcumin has high antioxidant capabilities, enabling it to scavenge reactive oxygen species (ROS) and reduce oxidative stress in biological systems [4]. Oxidative stress is closely associated with the development of various chronic diseases, including cardiovascular diseases and neurodegenerative disorders [4].

Curcumin has also garnered considerable interest in cancer work. This compound may impact tumor cell proliferation, affect apoptosis, and regulate many pathways in various cancer cell lines. Although much of this needs to be tested in vivo, this compound may be viable as a 'nutraceutical' in modern cancer medicine [5].

4.3. Industrial applications

In addition to its pharmaceutical and therapeutic potential, curcumin has been widely applied in various industrial fields, particularly in the food, cosmetic, and nutraceutical industries [3,10]. Due to its natural origin and favorable safety profile, curcumin has increasingly been used as an alternative to synthetic additives and colorants [3].

In the food industry, curcumin is widely used as a natural coloring agent, imparting an intense yellow hue to various products such as sauces, beverages and candies. It has antioxidant properties, which also contributes to the stability of food and prolongation of shelf life [3]. In many countries, this compound has been approved for use as a food additive and often is identified by the designation E100 [12].

In the nutraceutical industry, curcumin is widely incorporated into dietary supplements and functional foods due to its potential health-promoting effects [3,7]. These products are often marketed for their anti-inflammatory and antioxidant properties, supporting overall health and well-being [7].

Furthermore, curcumin has gained increasing attention in the cosmetic industry. Owing to its antioxidant and anti-inflammatory activities, it is incorporated into various skincare products and is believed to contribute to improved skin health and anti-aging effects [3,13].

5. Conclusion

The study of curcumin not only highlights the pharmacological potential of a single natural compound but also reflects the broader significance of plant-derived natural products in modern pharmaceutical science [1,2]. As a representative link between traditional herbal knowledge and contemporary analytical technologies, curcumin demonstrates the wide-ranging applications of

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natural products in medicine, functional foods, and related industrial fields [3]. The growing interest in curcumin also reflects a global trend toward integrating natural medicines into evidence-based medical systems and modern industrial applications.

Curcumin research highlights key development challenges for natural products: source variability, compound instability, and low bioavailability necessitate overcoming technical and quality control barriers prior to application [6,7]. Pharmacological studies are therefore insufficient; systematic pharmaceutical analysis and standardized production are essential for ensuring consistent product quality and safety [14]. Pharmaceutical analysis bridges natural product chemistry with real-world applications. Advances in chromatography and mass spectrometry enable precise identification and quantification of curcumin and related compounds, allowing effective quality control from cultivation through final product manufacturing [14]. This promotes herbal medicine modernization and enhances global natural product acceptance. Future progress will rely on interdisciplinary collaboration integrating analytical chemistry, formulation science, biotechnology, and agriculture to address stability, bioavailability, and standardization limitations [13,14]. Curcumin research may establish a model for developing other plant-derived natural products, advancing their applications in modern medicine and industry [1].

References

[1] Newman, D. J., & Cragg, G. M. (2016). Natural Products as Sources of New Drugs from 1981 to 2014. Journal of Natural Products, 79(3), 629–661. https: //doi.org/10.1021/acs.jnatprod.5b01055
[2] Genet, Z. (2021). Discovery and Resupply of Pharmacologically Active Plant-Derived Natural Products. 7(1), 1–2.
[3] Hewlings, S., & Kalman, D. (2017). Curcumin: A Review of Its Effects on Human Health. Foods, 6(10), 92. https: //doi.org/10.3390/foods6100092
[4] Kunnumakkara, A. B., Bordoloi, D., Padmavathi, G., Monisha, J., Roy, N. K., Prasad, S., & Aggarwal, B. B. (2016). Curcumin, the golden nutraceutical: multitargeting for multiple chronic diseases. British Journal of Pharmacology, 174(11), 1325–1348. https: //doi.org/10.1111/bph.13621
[5] Tomeh, M. A., Hadianamrei, R., & Zhao, X. (2019). A Review of Curcumin and Its Derivatives as Anticancer Agents. International Journal of Molecular Sciences, 20(5). https: //doi.org/10.3390/ijms20051033
[6] Wang, Y.-J., Pan, M.-H., Cheng, A.-L., Lin, L.-I., Ho, Y.-S., Hsieh, C.-Y., & Lin, J.-K. (1997). Stability of curcumin in buffer solutions and characterization of its degradation products. Journal of Pharmaceutical and Biomedical Analysis, 15(12), 1867–1876. https: //doi.org/10.1016/s0731-7085(96)02024-9
[7] Nelson, K. M., Dahlin, J. L., Bisson, J., Graham, J., Pauli, G. F., & Walters, M. A. (2017). The Essential Medicinal Chemistry of Curcumin. Journal of Medicinal Chemistry, 60(5), 1620–1637. https: //doi.org/10.1021/acs.jmedchem.6b00975
[8] Jadhav, B.-K., Mahadik, K.-R.., & Paradkar, A.-R. . (2007). Development and Validation of Improved Reversed Phase-HPLC Method for Simultaneous Determination of Curcumin, Demethoxycurcumin and Bis-Demethoxycurcumin. Chromatographia, 65(7-8), 483–488. https: //doi.org/10.1365/s10337-006-0164-8
[9] Carolina Alves, R., Perosa Fernandes, R., Fonseca-Santos, B., Damiani Victorelli, F., & Chorilli, M. (2019). A Critical Review of the Properties and Analytical Methods for the Determination of Curcumin in Biological and Pharmaceutical Matrices. Critical reviews in analytical chemistry, 49(2), 138–149. https: //doi.org/10.1080/10408347.2018.1489216
[10] Cooksey, C. (2017). Turmeric: old spice, new spice. Biotechnic & Histochemistry, 92(5), 309–314. https: //doi.org/10.1080/10520295.2017.1310924
[11] Priyadarsini, K. (2014). The Chemistry of Curcumin: From Extraction to Therapeutic Agent. Molecules, 19(12), 20091–20112. https: //doi.org/10.3390/molecules191220091
[12] Tonnesen, H. (1989). Studies on curcumin and curcuminoids. XIV. Effect of curcumin on hyaluronic acid degradation in vitro. International Journal of Pharmaceutics, 50(2), 91–95. https: //doi.org/10.1016/0378-5173(89)90132-4
[13] Zong, D. (2019). Delivery carrier of curcumin based on nanotechnology : A review. IOP Conference Series: Earth and Environmental Science, 332(3), 032016. https: //doi.org/10.1088/1755-1315/332/3/032016

DOI: 10.54254/2753-8818/2026.AU33454

[14] Chemat, F., Abert-Vian, M., Fabiano-Tixier, A. S., Strube, J., Uhlenbrock, L., Gunjevic, V., & Cravotto, G. (2019). Green extraction of natural products. Origins, current status, and future challenges. TrAC Trends in Analytical Chemistry, 118, 248–263. https: //doi.org/10.1016/j.trac.2019.05.037

[15] Kotra, V. S. R., Satyabanta, L., & Goswami, T. K. (2019). A critical review of analytical methods for determination of curcuminoids in turmeric. Journal of food science and technology, 56(12), 5153–5166. https: //doi.org/10.1007/s13197-019-03986-1