**Review Article**

**Phytopharmaceutical Potential of Turmeric: Bridging Traditional Wisdom and Modern Medicine**

**Abstract:**

Turmeric (Curcuma longa), a perennial herb of the Zingiberaceae family, has held a prominent place in traditional medicine systems such as Ayurveda, Unani, and Traditional Chinese Medicine for centuries. Its principal bioactive constituent, curcumin, along with other curcuminoids and essential oils, contributes to a broad spectrum of pharmacological effects, including anti-inflammatory, antioxidant, antimicrobial, anticancer, neuroprotective, antidiabetic, analgesic, hepatoprotective, and immunomodulatory activities. Medicinally, turmeric has been used for the treatment of wounds, skin disorders, respiratory ailments, digestive complaints, and liver diseases. Despite its promising bioactivities, curcumin’s poor aqueous solubility, rapid metabolism, and limited systemic bioavailability have posed significant challenges for its clinical application. In response, advanced drug delivery systems—including nanoparticles, liposomes, Niosomes, phytosomes, and curcumin analogs—have been developed to enhance its bioefficacy, stability, and therapeutic potential. The integration of turmeric-derived compounds into functional foods, dietary supplements, and topical formulations has further expanded its role in both preventive and therapeutic healthcare. This review explores turmeric’s transformation from an ethnomedicinal remedy to a modern phytopharmaceutical agent, highlighting recent advancements in formulation technologies, outcomes of contemporary clinical trials, and regulatory considerations. By bridging traditional knowledge with modern science, turmeric continues to emerge as a promising, safe, and affordable candidate in the development of next-generation therapeutic agents.

Keywords:
Turmeric, Curcumin, Phytopharmaceuticals, Traditional Medicine, Bioavailability, Drug Delivery Systems, Clinical Trials, Anti-inflammatory, Antioxidant, Herbal Therapeutics

1. **Introduction:**

Turmeric (*Curcuma longa* L.), a perennial herbaceous plant belonging to the *Zingiberaceae* family, has been extensively utilized in traditional medicine, culinary applications, and cosmetic formulations for centuries. Native to South Asia, particularly India, turmeric is renowned for its vibrant yellow pigment and diverse pharmacological properties. The rhizome of turmeric is the most valuable part of the plant, as it contains a rich array of bioactive compounds, among which curcuminoids are the most significant. The most well-known curcuminoid, curcumin, has been identified as the primary contributor to turmeric’s therapeutic potential, exhibiting a wide range of biological activities, including anti-inflammatory, antioxidant, antimicrobial, anticancer, and neuroprotective effects (Gupta et al., 2013; Hewlings & Kalman, 2017). Curcuma longa L. (C. longa), commonly known as “Indian Saffron” or “The Golden Spice of India,” is a tall herbaceous plant that thrives in tropical climates and various regions across India (Fuloria et al., 2022). Widely valued in Indian households, it is used not only as a culinary spice and natural food colorant but also as a traditional remedy for a variety of ailments. The plant develops from a tuberous rhizome, which possesses a rough, segmented outer surface. These rhizomes mature underground beneath the foliage and are yellowish-brown on the exterior with a dull orange interior. Small, pointed tubers emerge from the main rhizome, typically measuring between 2.5 and 7.0 cm in length and about 2.5 cm in diameter (Prasad and Aggarwal, 2011). Once dried, the rhizome is ground into a yellow powder characterized by a distinct combination of bitter and sweet taste. Its most notable bioactive constituent is **curcumin** [1,7-bis (4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione], a yellow pigment composed of a resin-oil complex. This compound imparts flavor and color to food and exhibits significant therapeutic benefits. Traditionally, turmeric rhizome powder has been employed in treating a wide array of conditions, including inflammation, jaundice, menstrual irregularities, hemorrhages, flatulence, and various skin diseases through topical application. Indian varieties of C. longa are particularly esteemed for their high curcumin content, making them superior to those from other regions in terms of therapeutic efficacy (Verma et al., 2018). Curcumin, a lipophilic polyphenolic compound belonging to the flavonoid class, is virtually insoluble in water but exhibits high stability in the acidic environment of the stomach (Dave et al., 2017). Both aqueous and lipid-based extracts of C. longa and curcumin demonstrate antioxidant activity comparable to that of vitamins C and E, reinforcing their value in traditional and modern therapeutic applications. Turmeric has played a vital role in traditional medicine systems such as Ayurveda, Traditional Chinese Medicine (TCM), and Unani medicine. Ayurvedic practitioners have long used turmeric to treat a variety of ailments, including digestive disorders, respiratory conditions, and skin diseases. In TCM, turmeric is often employed for its ability to promote blood circulation, alleviate pain, and reduce inflammation. Additionally, Unani medicine has recognized turmeric as a potent remedy for liver disorders and infections. Given its extensive historical use, turmeric continues to be a subject of scientific interest, with modern research exploring its pharmacological mechanisms and therapeutic potential. Among the most interesting qualities of turmeric is its strong anti-inflammatory effect. Many diseases, including diabetes, cardiovascular disease, neurodegenerative disorders, and arthritis, are often caused by chronic inflammation. By blocking important molecules like nuclear factor-kappa B (NF-\u03ba), tumor necrosis factor-alpha (TNF-\u03b1), and interleukins, curcumin has been shown to modulate several inflammatory pathways (Aggarwal et al., 2007). These processes help curcumin to be effective in controlling inflammatory diseases including asthma, rheumatoid arthritis, and inflammatory bowel disease. Furthermore, studies suggest that curcumin may offer an alternative to non-steroidal anti-inflammatory drugs (NSAIDs) by providing similar benefits with fewer side effects (Gupta et al., 2013). In addition to its anti-inflammatory activity, turmeric possesses remarkable antioxidant properties. Oxidative stress, which results from an imbalance between free radicals and antioxidants, is a major contributor to aging and various chronic diseases, including cancer, cardiovascular diseases, and neurodegenerative conditions. Curcumin demonstrates its antioxidant properties by neutralizing free radicals, augmenting the function of endogenous antioxidant enzymes like superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px), and diminishing lipid peroxidation (Hewlings & Kalman, 2017). These actions safeguard cells from harm and enhance overall well-being. Turmeric’s antimicrobial properties have also been widely recognized, making it a valuable natural remedy for bacterial, viral, and fungal infections. *Staphylococcus aureus, Escherichia coli,* and *Candida albicans* among others have all been shown to be broadly susceptible to curcumin (Gopinath et al., 2018). Several processes, including bacterial cell membrane disruption, suppression of quorum sensing, and alteration of microbial virulence factors, explain its capacity to prevent bacterial growth. Furthermore, turmeric’s antimicrobial effects extend to its potential role in managing antibiotic resistance, as curcumin has been shown to enhance the efficacy of conventional antibiotics and reduce bacterial resistance (Tyagi et al., 2015). The anticancer potential of turmeric has garnered significant scientific interest, with numerous studies highlighting its ability to inhibit tumor growth and induce apoptosis in cancer cells. Curcumin has been found to exert anticancer effects through multiple mechanisms, including inhibition of cell proliferation, induction of cell cycle arrest, suppression of angiogenesis, and modulation of oncogenic signaling pathways (Gupta et al., 2013). Curcumin's capacity to improve the efficacy of chemotherapy and radiotherapy while lowering their adverse effects has also helped it to be a promising complementary treatment for cancer. Another area where turmeric has shown great promise is in neuroprotection and cognitive health. Neurodegenerative disorders such as Alzheimer’s disease, Parkinson’s disease, and Huntington’s disease are characterized by progressive neuronal damage and cognitive decline. Curcumin has been reported to mitigate neurodegenerative processes by reducing oxidative stress, inhibiting neuroinflammation, and promoting the clearance of amyloid-beta plaques (Mishra & Palanivelu, 2008). Furthermore, emerging research suggests that curcumin may enhance neurogenesis and improve synaptic plasticity, thereby supporting cognitive function and mental well-being. Beyond its medicinal benefits, turmeric is widely used in culinary applications across various cultures. In Indian cuisine, turmeric is a staple spice, used in curries, rice dishes, and beverages such as golden milk. The spice imparts a distinct flavor and color to foods while also providing health benefits. Turmeric is also used in Middle Eastern, Southeast Asian, and African cuisines, where it is valued for its aromatic and preservative properties. In addition to its culinary uses, turmeric is incorporated into traditional beauty and skincare regimens, where it is applied topically to improve skin complexion, treat acne, and reduce pigmentation. Despite its numerous health benefits, turmeric faces challenges related to bioavailability. Curcumin has poor solubility in water and undergoes rapid metabolism and elimination, limiting its absorption and therapeutic effectiveness. Various strategies have been explored to enhance curcumin’s bioavailability, including the use of adjuvants such as piperine (a component of black pepper), nano-formulations, liposomal encapsulation, and curcumin-phospholipid complexes (Anand et al., 2007). These approaches have shown promise in improving curcumin’s systemic availability and enhancing its pharmacological effects. Given the growing interest in natural remedies and plant-based medicine, turmeric continues to be a focal point of scientific research and clinical studies. Ongoing investigations aim to elucidate the molecular mechanisms underlying curcumin’s therapeutic actions and explore its potential applications in treating various health conditions. Moreover, the development of novel formulations and drug delivery systems is expected to further optimize the efficacy of curcumin-based therapies.

**Taxonomy:**

Turmeric (*Curcuma longa* L.) is classified within the plant kingdom as follows:

* **Kingdom:** Plantae
* **Clade:** Tracheophytes
* **Clade:** Angiosperms
* **Clade:** Monocots
* **Order:** Zingiberales
* **Family:** *Zingiberaceae*
* **Genus:** *Curcuma*
* **Species:** *Curcuma longa* L.

Turmeric belongs to the *Curcuma* genus, which comprises over 100 species. It is closely related to other medicinal plants such as ginger (*Zingiber officinale*). The species *Curcuma longa* is the most commonly cultivated and utilized variety for medicinal and culinary purposes.

1. **Botanical Description:**

Turmeric is a rhizomatous herbaceous perennial plant that grows up to 1 meter (3.3 feet) in height (Figure 1). The plant has the following distinguishing features:

* *Rhizomes:* The underground stem (rhizome) is cylindrical, orange-yellow in color, and covered with a brownish outer layer. The rhizomes have a balmy smell and bitter in taste (Puteri et al., 2020). It is highly aromatic and contains curcuminoids, the primary bioactive compounds. Table 1 represent the biochemical content in dried turmeric rhizomes (Niranjan et al., 2003).

**Table 1. Biochemical content in dried turmeric rhizomes (Niranjan et al., 2003)**

|  |  |
| --- | --- |
| Curcumin  | 3.1-3.4 % |
| Anthocyanin  | 18.9-37.0 g/g |
| Phenols | 0.15- 0.62 %  |
| Sugars | 20.5-43.4 % |
| Protein content | 3.6-6.8 % |
| Oil | 3.7-5.3 % |
| Tannins | 0.32-0.76 % |
| Ash | 6.9-9.8 % |
| Moisture  | 90.2-91.3 % |

* *Leaves:* The plant produces large, oblong, lanceolate leaves that are arranged alternately along the stem. They have a bright green color and can grow up to 70 cm in length.
* *Flowers:* The flowers are pale yellow with a reddish border, arranged in dense, spike-like inflorescences that emerge from a central shoot. They are mostly sterile, meaning the plant primarily reproduces through its rhizomes.
* *Fruits and Seeds:* Turmeric rarely produces seeds under cultivated conditions. Instead, it propagates vegetatively through rhizome division.



1. **Cultivation:**

Turmeric thrives in tropical and subtropical climates, preferring well-drained loamy or sandy soils. Optimal growth conditions include ample annual rainfall and average temperatures ranging between 20°C and 30°C. The plant performs best under consistently moist conditions. The typical harvest period spans from January to March or April. Early-maturing varieties are ready for harvest in 7 to 8 months, whereas medium-duration types take about 8 to 9 months. Harvesting usually begins once the foliage turns yellow and starts to wither (Soudamini and Kuttan, 1989). At maturity, the leaves are cut close to the ground, the soil is ploughed, and the rhizomes are either hand-harvested or carefully lifted using a spade. The ideal soil for turmeric cultivation should be rich, friable, and contain minimal sand content. Irrigation requirements depend on both the soil texture and climatic conditions. Medium-heavy soils generally need about 15–25 irrigations, while lighter red soils may require 35–40 irrigations, influenced by local rainfall and drainage capacity. Post-harvest, rhizomes are typically heaped under the shade of trees or stored in well-ventilated shelters, often wrapped in turmeric leaves to preserve freshness. For seed preservation, mature rhizomes can also be stored in sawdust-filled pits (Aggarwal et al., 2004).

1. **Geographical Distribution:**

Turmeric is believed to have originated from South or Southeast Asia, more likely in Vietnam, China, or western India. India is the biggest producer, consumer, and supplier, but it is also cultivated extensively in Cambodia, Bangladesh, Nepal, Indonesia, Thailand, Malaysia, West Bengal, Madagascar, Tamil Nadu, Maharashtra, Madras, Indonesia, and Philippines (Royal Botanic Gardens Kew, 2021) for its medicinal and commercial value.

1. **Nutritive Value:**

Turmeric is major source of macro and micronutrients (Mishra and Goel, 2020). Table 2 shows that it is rich in dietary fibre, vitamins, minerals content, and good source of energy. The vitamins and minerals content in the turmeric are significant. In ancient times turmeric is known as “Golden Spice” because of its various nutritional and medicinal properties, which helps in prevention of many diseases and also enriching the taste and color of the food (Longvah et al., 2017).

 **Table 2. Nutritive value of turmeric per 100 g**

|  |  |
| --- | --- |
| Constituents | Amounts |
| Carbohydrate | 49.22 g |
| Protein | 7.66 g |
| Total fat | 5.03 g |
| Total dietary fibre | 21.38 g |
| Ash | 6.13 g |
| Energy | 1174 KJ |
| Riboflavin | 0.01 mg |
| Thiamine | 0.06 mg |
| Pantothenic acid | 0.13 mg |
| Niacin | 1.55 mg |
| Iron | 46.08 mg |
| Calcium | 122 mg |
| Sodium | 24.41 mg |
| Potassium | 2374 mg |
| Copper | 0.44 mg |
| Zinc | 2.64 mg |
| Phosphorus | 276 mg |

 (Source- Indian Food Composition Table, 2017)

**6. Historical and Cultural Significance of Turmeric**

Turmeric (*Curcuma longa*) is more than just a botanical treasure—its rich legacy stretches back millennia, woven intricately into the spiritual, medicinal, culinary, and cultural tapestries of human civilization. Revered not only for its vibrant hue and earthy aroma, turmeric has also served as a symbol of purity, vitality, and transformation across ancient traditions and healing sciences.

**6.1 Traditional and Holistic Medical Systems**

Turmeric’s role in ethnomedicine spans diverse geographies and philosophies of health, highlighting its universal appeal and multifaceted healing potential.

* *Ayurvedic Medicine:*

Within Ayurveda, the ancient Indian system of holistic medicine, turmeric is exalted as a potent *Rasayana*—a rejuvenative tonic known to nourish life force (*ojas*), fortify immunity, and promote longevity. It has been used to balance *doshas* (bodily energies), especially *Kapha* and *Pitta*, and to treat a wide array of ailments such as indigestion, jaundice, skin diseases, respiratory infections, and chronic inflammation. Additionally, it has been traditionally prescribed for internal cleansing, wound healing, and enhancing liver function (Chattopadhyay et al., 2004).

* *Traditional Chinese Medicine (TCM):*

In TCM, turmeric is recognized under the name *Jiang Huang* and is used to activate blood flow, dissipate stasis, and relieve pain. It is commonly employed in managing arthritis, dysmenorrhea, and trauma-induced swelling. Its wider applications include treatment and prevention of chronic disorders such as cancer, coughs, diabetes, ulcers, psoriasis, and hepatobiliary dysfunctions. The warming and stimulating nature of turmeric aligns with its ability to remove stagnation and regulate *Qi* (life energy) (Li et al., 2011; Tung et al., 2019).

* *Unani Medicine:*

Practitioners of the Greco-Arabic Unani system have long embraced turmeric for its anti-inflammatory, carminative, and hepatoprotective qualities. It is a common constituent in herbal formulations aimed at treating jaundice, respiratory distress, hepatic congestion, and digestive anomalies. Its warming nature is believed to harmonize bodily humors (*Akhlat*) and expel phlegmatic imbalances (Pancholi et al., 2020).

* *Folk Remedies and Ethnobotanical Uses:*

Across generations and continents, rural and indigenous communities have relied on turmeric as a versatile household remedy. Its paste is ubiquitously applied to minor wounds, burns, boils, insect bites, and skin irritations due to its antiseptic and anti-inflammatory attributes. Consuming turmeric-infused milk—popularly known as “golden milk”—is a well-rooted tradition in many cultures to enhance immunity, ease respiratory ailments, and calm the nervous system. Folk medicine recognizes turmeric as a supportive agent in treating liver disorders, digestive imbalances, leukemia, arthritis, menstrual irregularities, eye infections, and respiratory tract inflammation. It is also trusted to soothe mucosal linings of the throat, stomach, and lungs, especially during infections or allergic responses.

**6.2. Cosmetic and Beauty Rituals**

In the realm of beauty and self-care, turmeric has been a cherished elixir for radiant skin and youthful vitality. Its use transcends aesthetic appeal, deeply embedded in rituals of purification and celebration.

* + 1. *Skin Care and Bridal Rituals:*

In South Asian bridal traditions, the *Haldi* ceremony—a ritual where turmeric paste is applied to the bride and groom—is believed to bless the couple, cleanse their skin, and bring a golden glow symbolic of prosperity and fertility. Turmeric is regularly used in face masks and body scrubs to reduce pigmentation, clear acne, tighten pores, and delay signs of aging.

* + 1. *Anti-Aging and Brightening:*

Curcumin’s antioxidant richness combats oxidative stress and free radical damage, making turmeric a natural defense against premature aging. When applied topically, it enhances skin tone, soothes inflammation, and promotes scar healing.

**6.3 Household, Culinary, and Spiritual Roles**

Turmeric’s importance is not confined to medicine or beauty—it has held a sacred and utilitarian role in daily life for centuries.

* + 1. *Culinary Use:*

Turmeric plays a crucial role in global cuisine, particularly in South Asian, Middle Eastern, and Southeast Asian culinary traditions. Its unique flavor, color-enhancing properties, and health benefits make it a staple in many dishes.

* *Indian Cuisine:* Turmeric is an essential component of spice blends such as garam masala and curry powder. It is used in lentil dishes (dal), rice preparations (biryani, pulao), and vegetable curries. Turmeric is also a key ingredient in pickles and chutneys.
* *Southeast Asian Cuisine:* In Thai and Indonesian cuisine, turmeric is used in soups, stews, and traditional spice pastes like Thai yellow curry paste. It is also an integral part of satay marinades and rendang dishes.
* *Middle Eastern Cuisine:* Turmeric is used in Persian and Arabic dishes such as saffron rice, kebabs, and stews. It is often combined with other spices like cinnamon and cumin for a rich, aromatic flavor.
* *Western Cuisine:* Turmeric has gained popularity in Western diets, particularly in health-conscious recipes. It is commonly used in smoothies, teas, lattes (golden milk), and salad dressings. Turmeric-infused honey and vinegar are also growing in popularity.
* *Baking and Beverages:* Turmeric is used in baking, adding color and mild spice to bread and pastries. It is also a key ingredient in health drinks such as turmeric tea and turmeric-infused juices.
* *Fermented Foods:* Turmeric is incorporated into fermented products like kimchi and sauerkraut for its antimicrobial properties, enhancing shelf life while providing health benefits.
	+ 1. *Preservation and Hygiene:*

Owing to its antimicrobial qualities, turmeric has been used historically to preserve food, purify drinking water, and disinfect household surfaces. It was often sprinkled in storage vessels to deter bacterial and fungal growth.

* + 1. *Spiritual and Ritual Significance:*

Turmeric holds deep religious and spiritual significance, especially in Hindu culture. It is commonly used in rituals, ceremonies, and festivals. Turmeric paste is used on the bride and groom in Hindu weddings to signify purification and blessing (Krishna et al., 2011). Turmeric is also associated with goddess Lakshmi, the deity of wealth and prosperity, and is used to sanctify religious idols and altars. In Buddhism, monks have traditionally dyed their robes with turmeric due to its vibrant yellow-orange color, which symbolizes renunciation and spiritual enlightenment (Kumar & Jain, 2015). Similarly, in Southeast Asia, turmeric is used in spiritual and protective rituals, often applied as a paste on newborns to ward off evil spirits.

* + 1. *Natural Dye and Decoration:*

Its vivid yellow pigment has been used to dye fabrics, especially for traditional garments and religious vestments. It also serves in painting religious icons and festive decorations during ceremonies.

**Figure 2. Traditional uses of turmeric (*Curcuma longa* L.)**

* 1. **Medicinal Applications:**

Turmeric has been thoroughly researched for its therapeutic properties, chiefly because of its active component, curcumin. The following are some of its key therapeutic applications:

* *Anti-Inflammatory Properties:* Curcumin is a potent anti-inflammatory agent that inhibits pro-inflammatory cytokines such as TNF-α, IL-6, and NF-κB (Aggarwal et al., 2009). It is beneficial in managing chronic inflammatory conditions such as arthritis and inflammatory bowel disease.
* *Antioxidant Effects:* Turmeric exhibits strong antioxidant activity by scavenging free radicals and enhancing the body's natural antioxidant defenses, reducing oxidative stress-related diseases (Gupta et al., 2013).
* *Antimicrobial and Antiviral Properties:* Curcumin has demonstrated antimicrobial activity against bacteria, fungi, and viruses. It is effective against *Helicobacter pylori*, *Staphylococcus aureus*, and other pathogenic microbes (Ghosh et al., 2018).
* *Anticancer Potential:* Research suggests that curcumin induces apoptosis, inhibits tumor growth, and suppresses metastasis in various cancers, including breast, lung, prostate, and colorectal cancers (Goel et al., 2010).
* *Cardioprotective Effects:* Turmeric helps lower cholesterol, reduce blood pressure, and prevent atherosclerosis, contributing to heart health (Hewlings & Kalman, 2017).
* *Neuroprotective Properties:* Curcumin has been studied for its ability to prevent neurodegenerative diseases like Parkinson's and Alzheimer's. It reduces amyloid plaque accumulation and oxidative stress in the brain (Mishra & Palanivelu, 2008).
	1. **Historical Trade and Economic Importance:**

Turmeric has played a significant role in international trade since ancient times. It was a valuable commodity along the Silk Road and was exported from India to the Middle East, Africa, and Europe (Menon & Sudheer, 2007). The demand for turmeric increased during the colonial era when European traders recognized its culinary and medicinal value.

Today, India remains the largest producer, consumer, and exporter of turmeric, accounting for approximately 80% of the world's supply (FAO, 2020). Major turmeric-producing states in India include Andhra Pradesh, Tamil Nadu, Maharashtra, and Odisha. Other significant producers include China, Indonesia, Bangladesh, and Thailand (Jiang et al., 2018).

**6.6 General Health Benefits:**

Evidence suggests the benefits of turmeric in relieving acne, inflammation, joint pain, asthma, eczema, and tonic and acute allergies; in wound healing; in maintaining a balanced mood and blood sugar levels; and in immunomodulation (Ammon and Wahl, 1991; Reddy and Rao, 2002).

1. **Phytochemical Constituents of Turmeric:**

Turmeric contains protein (6.3%), fat (5.1%), minerals (3.5%), carbohydrates (69.4%) and moisture (13.1%). Phenolic diketone, curcumin (Diferuloylmethane) (3-4%) is responsible for the yellow colour, and comprises curcumin I (94%), curcumin II (6%) and curcumin III (0.3%). Other chemicals compound is copper/zinc, campesterol, stigmasterol, beta-sitosterol, cholesterol, fatty acids and metallic elements potassium, sodium, magnesium, calcium, manganese, and iron (Satruhan and Patel, 2022). Turmeric contains a diverse array of bioactive compounds that contribute to its medicinal properties (Figure 3). The major phytochemicals found in turmeric include:

* *Curcuminoids:* These include curcumin, demethoxycurcumin, and bisdemethoxycurcumin, which provide anti-inflammatory, antioxidant, and anticancer properties (Nelson et al., 2017).
* *Essential Oils:* Comprising turmerone, ar-turmerone, atlantone, and zingiberene, these oils contribute to the aromatic and therapeutic qualities of turmeric, including antimicrobial and neuroprotective effects (Li et al., 2011).
* *Polysaccharides:* Such as starch, arabinogalactan, and ukonan, which enhance turmeric’s immune-modulatory activities and metabolic functions (Menon & Sudheer, 2007).
* *Phenolic Compounds:* These provide strong antioxidant capabilities, contributing to free radical scavenging and anti-aging effects (Hewlings & Kalman, 2017).
* *Flavonoids:* Found in small amounts, these compounds further enhance anti-inflammatory and cardiovascular protective properties (Gupta et al., 2013).
* *Alkaloids and Tannins:* Present in trace amounts, these compounds contribute to antimicrobial and hepatoprotective effects.
* *Saponins and Glycosides:* These compounds play a role in cholesterol regulation and have cardioprotective benefits.



 **Figure 3. Chemical structure of phytoconstituents present in turmeric**

1. **Pharmacological Properties of Turmeric:**

Turmeric (*Curcuma longa* L.) is a medicinal plant and it has various therapeutic and pharmacological activities (Figure 4).

* *Anti-Inflammatory Activity*

*Curcuma longa* contains volatile oils and curcumin, both known for their potent anti-inflammatory properties. Studies have shown that orally administered curcumin is as effective as cortisone and phenylbutazone in managing acute inflammation. Specifically, oral intake of C. longa has been reported to significantly reduce inflammatory swelling (Cronin, 2003). The anti-inflammatory action of C. longa is believed to stem from its ability to inhibit the biosynthesis of inflammatory prostaglandins from arachidonic acid and suppress neutrophil activity during inflammatory responses. Curcumin can also be applied topically to alleviate itching and inflammation associated with allergic and inflammatory skin conditions; however, its intense yellow pigment may stain clothing, requiring careful application. At the molecular level, curcumin is a strong modulator of inflammatory pathways. It inhibits nuclear factor-kappa B (NF-κB) and downregulates pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and interleukin-1β (IL-1β) (Aggarwal et al., 2007). Numerous studies have confirmed curcumin’s effectiveness in managing chronic inflammatory diseases such as arthritis, inflammatory bowel disease, and cardiovascular disorders (Chainani-Wu, 2003).

* *Antioxidant Properties*

Turmeric unveils formidable antioxidative prowess, dismantling volatile free radicals while amplifying the efficacy of innate enzymatic defenders like superoxide dismutase (SOD), catalase, and glutathione peroxidase (Mishra et al., 2011). This molecular vigilance positions curcumin as a sentinel compound, pivotal in warding off maladies tethered to oxidative debilitation, notably neurodegenerative afflictions and cardiovascular decay (Hewlings & Kalman, 2017). Both the hydrophilic and lipophilic extractions of turmeric, as well as its cornerstone compound curcumin, evince a formidable capacity to arrest oxidative degeneration—paralleling, if not rivaling, the antioxidative capacities of ascorbic acid and tocopherol. In experimental paradigms simulating ischemic trauma, preemptive administration of curcumin substantially tempered myocardial perturbations incited by restricted blood flow (Dikshit et al., 1995), illuminating its potential as a cardioprotective agent of notable merit.

* *Antimicrobial and Antiviral Effects*

Curcumin unfurls an expansive antimicrobial spectrum, wielding its potency against bacterial, fungal, and viral antagonists with multifaceted precision. Empirical inquiries reveal its inhibitory influence on formidable pathogens such as Staphylococcus aureus, Escherichia coli, and Candida albicans—primarily orchestrated through destabilization of microbial cell membranes and the sabotage of biofilm synthesis (Gunes et al., 2016). Beyond its bactericidal and fungicidal edge, curcumin asserts a formidable virostatic capability. It impedes the life cycles of formidable viral agents including the hepatitis C virus, influenza strains, and the novel SARS-CoV-2 by interrupting critical pathways of viral replication and transcription (Praditya et al., 2019). This tri-fold arsenal underscores curcumin’s therapeutic promise as a molecular adversary across microbial kingdoms.

* *Anticancer Potential*

Curcumin manifests potent anticancer aptitude by orchestrating a symphony of cellular signaling modulations—chief among them, the initiation of programmed cell death, throttling of neovascularization, and restraint of metastatic migration (Sharma et al., 2005). Its bioactive influence has been evidenced across a panorama of malignancies, demonstrating pronounced efficacy against breast, prostate, pulmonary, and colorectal carcinomas (Gupta et al., 2013). Moreover, insights gleaned from clinical investigations underscore curcumin’s role as a chemotherapeutic ally—amplifying the therapeutic thrust of conventional anticancer regimens while concurrently mitigating their cytotoxic aftermath (Ravindran et al., 2009). This dual action situates curcumin as a compelling adjunct in oncological therapeutics, bridging efficacy with tolerance.

* *Antifungal Property*

Ether and chloroform extracts and oil of turmeric have antifungal effects (Apisariyakul et al., 1995). Crude ethanol extract also possesses antifungal activity. Turmeric oil is also active against *A. parasiticus Aspergillus flavus Penicillium digitatum,* and*, Fusarium moniliforme* (Jayaprakasha et al., 2001).

* *Diabetes Mellitus*

Turmeric rhizome powder, when synergistically combined with amla juice and honey, has been traditionally extolled for its therapeutic potential in managing Madhumeha (diabetes mellitus) (Acharya, 1994). Ingestion of 6 grams of turmeric by healthy individuals elicited an elevation in postprandial serum insulin, albeit without notable shifts in plasma glucose or gastrointestinal dynamics—hinting at turmeric’s modulatory influence on pancreatic insulin release (Wickenberg et al., 2010). At the molecular frontier, the rhizome’s active arsenal—particularly the curcuminoids—attenuates lipid peroxidation, safeguarding cellular integrity by upregulating endogenous antioxidative sentinels such as superoxide dismutase, catalase, and peroxidase. The robust antioxidant character of Curcuma longa is primarily attributed to curcumin and its molecular congeners: demethoxycurcumin, bisdemethoxycurcumin, and diacetylcurcumin (Faizal et al., 2009). These compounds coalesce to fortify metabolic resilience and oxidative equilibrium.

* *Osteoarthritis*

Emerging evidence underscores the efficacy of turmeric extracts—administered independently or in tandem with other botanicals—in mitigating pain and enhancing joint functionality in individuals grappling with knee osteoarthritis. In select clinical inquiries, turmeric mirrored the analgesic potency of ibuprofen. However, it fell short in efficacy when measured against diclofenac regarding pain alleviation and mobility restoration (Mishra and Goel, 2019).

* *Gastrointestinal Disorders*
Curcumin, revered for its potent anti-inflammatory dynamics, has displayed therapeutic merit across a spectrum of gastrointestinal disturbances. These range from functional dyspepsia and *Helicobacter pylori* infections to more intricate pathologies such as peptic ulcers, irritable bowel syndrome, Crohn’s disease, and ulcerative colitis (Labban, 2014).
* *Neurological Disorders*

Experimental models of Alzheimer’s disease (AD) reveal curcumin’s capacity to attenuate amyloid plaque accumulation—one of the neuropathological hallmarks of AD (Ringman et al., 2005). Accumulated data highlight curcumin’s neuroactive versatility, positioning it as a promising agent for addressing disorders like major depressive disorder, tardive dyskinesia, and diabetic neuropathy (Kulkarni et al., 2010).

* *Pregnancy and Neonatal Considerations*

Investigations by Singh and Aggarwal (1995) demonstrated that curcumin modulates hepatic detoxification pathways, significantly enhancing levels of glutathione S-transferase (GST), sulfhydryl compounds, cytochrome b5, and cytochrome P450 enzymes. These findings suggest that curcumin’s bioactive constituents—or their metabolites—may be bioavailable to neonates through maternal lactation.

* *Irritable Bowel Syndrome (IBS)*

Individuals contending with IBS frequently endure abdominal cramping, bloating, altered stool consistency, and increased bowel frequency. In an eight-week exploratory trial, turmeric supplementation yielded a remarkable drop in IBS prevalence—53% and 60% across the intervention cohorts. Post-intervention analysis showed reductions in pain and discomfort indices by 22% and 25%, respectively (Barbara et al., 2002), marking curcumin as a potential agent in IBS symptom management.

* ***Skin Treatments***

Turmeric delivers an array of dermatological boons—accelerating wound closure, pacifying inflamed pores, and diminishing acne outbreaks. Thanks to its potent antioxidative and anti-inflammatory arsenal, turmeric stands as a natural ally in addressing a variety of skin afflictions (Verma et al., 2018).

* ***Obesity Management***

For those striving to shed excess weight or combat metabolic imbalance, turmeric serves as a botanical boon. Its active constituents catalyze the release of bile—a vital fluid in emulsifying and breaking down dietary fats—thus supporting weight regulation and metabolic efficiency (Verma et al., 2018).

* ***Respiratory Disorders***

Curcuma longa exerts a calming effect on bronchial musculature, hinting at its bronchodilatory potential in respiratory ailments like asthma and obstructive pulmonary conditions. It modulates inflammatory pathways, safeguards lung tissue, regulates airway sensitivity, and fine-tunes immune responses (Boskabady et al., 2020). Curcumin’s antiasthmatic efficacy has been validated through both laboratory and clinical lenses. Traditional applications include rhizome juice for bronchitis, rhizome-infused milk for rhinitis and cough, and decoction gargles or smoked rhizome for sore throat and catarrhal cough. Active phytochemicals—curcuminoids, turmerones, and tetrahydrocurcumin—amplify its respiratory benefits, while Haridradhumvarti fumes are traditionally inhaled for congestion and asthma relief.

* ***Cardiovascular Health***

Cardiovascular diseases, the harbingers of global morbidity, have found a natural adversary in curcumin. It exhibits lipid-lowering, anti-atherosclerotic, and cardioprotective effects—both in ischemic heart episodes and post-reperfusion injury (Gao et al., 2019; Wang et al., 2018). Curcumin improves lipid profiles, enhances endothelial function, and can synergize with standard cardiovascular drugs (Qin et al., 2017). Studies also reveal its anticoagulant capacity and its ability to protect against coronary heart disease (Li H. et al., 2020). It alleviates heart failure symptoms by modulating cellular signaling (Cao et al., 2018), and recent innovations explore curcumin-based nanomedicine as a targeted therapeutic (Salehi et al., 2020).

* ***Liver Protection (Hepatoprotective Action)***

Used traditionally with amla juice for jaundice, Curcuma longa shows substantial hepatoprotective promise. It counters liver damage caused by toxicants such as carbon tetrachloride, galactosamine, and acetaminophen (Rao et al., 1995). Ethanolic rhizome extracts containing curcumin, turmerone, atlantone, and zingiberene protect liver tissue at significant dosages (Park et al., 2000). Curcumin enhances apoptosis in damaged hepatocytes, mitigates inflammation and fibrosis, and accelerates detoxification via free radical scavenging and glutathione augmentation. Notably, it outperformed ascorbic acid by tenfold in protecting hepatocytes from tacrine-induced cytotoxicity (Song et al., 2001).

* ***Anti-Allergic Properties***

Curcumin blunts histamine release by hindering mast cell degranulation, reducing allergic inflammation. It boosts intracellular cAMP and blocks immune overreaction, suppressing both IgE-mediated systemic anaphylaxis and the release of pro-inflammatory compounds such as leukotrienes, prostaglandins, and histamine (Choi et al., 2010; Li et al., 2014). Additionally, curcumin downregulates antigen-presenting molecules and inflammatory cytokines (IL-1β, IL-6, TNF-α), highlighting its potential as an anti-allergic pharmacological scaffold.

* ***Digestive Relief and Gastric Protection***

Administering 600 mg of curcumin five times daily over 12 weeks was shown to both prevent and alleviate symptoms of gastric ulcers. Patients reported diminished abdominal discomfort within one to two weeks. In preclinical studies, ethanolic C. longa extract reduced acid secretion and ulcer formation by inhibiting H2 histamine receptors, mimicking the action of ranitidine (Kim et al., 2005). It also fortified the gastric mucosa under stress conditions and lowered lesion severity from ulcerogenic agents.

* ***Mood and Depression Disorders***

Curcuma longa exhibits antidepressant potential by restraining monoamine oxidase buildup in the brain (Yu et al., 2002). It helps stabilize mood by modulating neurotransmitter levels—restoring serotonin, dopamine, and noradrenaline balance while controlling stress markers like cortisol and CRF (Xia et al., 2007). Its mood-elevating effects paralleled those of imipramine in stressed animal models, suggesting curcumin as a viable phytotherapeutic candidate for depression (Mohammed et al., 2019; Qi et al., 2020).

* ***Combating Drug Resistance***

Curcumin counters multidrug resistance in cancer by curbing the expression of P-glycoprotein and enhancing intracellular drug retention (Xu et al., 2011). It sensitizes resistant tumor cells by inhibiting NF-κB activation, amplifying the potency of chemotherapeutics like adriamycin. When used alongside tamoxifen, curcumin re-sensitizes tamoxifen-resistant breast cancer cells, paving a path for its use in reversing drug resistance (Mimeault and Batra, 2011).

* ***Antifertility Potential***

Endorsed by WHO for cost-effective reproductive control, C. longa demonstrates antifertility action. In male mice, oral administration of aqueous rhizome extract suppressed spermatogenesis and altered seminiferous tubules, pointing to reversible infertility (Hembrom et al., 2015). In females, a combination of curcumin and andrographolide reduced implantation, litter size, estrus cycle duration, and ovarian follicles (Shinde et al., 2015). Both aqueous and petroleum ether extracts completely inhibited implantation in rats. Curcumin’s capacity to impair sperm motility supports its potential role in intravaginal contraceptive formulations.

**Figure 4. Pharmacological Properties of Turmeric (*Curcuma longa* L.)**

* ***Efficacy of Turmeric***

Turmeric and its principal bioactive constituent, curcumin, have been designated as GRAS (Generally Recognized As Safe) by the U.S. Food and Drug Administration. Owing to this safety profile, turmeric is widely integrated into various food products across the United States—including butter, mustard, cheese, and snack items like chips. Beyond its culinary inclusion, turmeric offers substantial therapeutic merit. It has demonstrated cardioprotective properties and contributes to improved tissue recovery following injury. A study administering 100 mg/kg of turmeric over a month revealed a marked reduction in cellular degeneration and death, highlighting its restorative and protective potential in cardiovascular health (Mohanty et al., 2006).

**9. Clinical Trials on the Therapeutic Efficacy of *Curcuma longa***

Over the past decades, the pharmacological potential of *Curcuma longa*, particularly its active compound curcumin, has been increasingly validated by rigorous clinical investigations. While preclinical studies have long supported its broad-spectrum medicinal value, emerging human trials are now offering concrete evidence of its therapeutic efficacy across diverse pathological conditions (Iweala et al., 2023).

* *Arthritic Disorders*

Among the most extensively studied applications of *Curcuma longa* is its role in the management of osteoarthritis (OA) and rheumatoid arthritis (RA)—both chronic, debilitating inflammatory joint diseases. Clinical trials have consistently demonstrated the anti-arthritic properties of orally administered turmeric extracts. In multiple randomized studies, administration of curcumin in varying doses was found to significantly alleviate hallmark symptoms of arthritis such as joint pain, stiffness, and swelling. Patients exhibited notable reductions in pro-inflammatory biomarkers like C-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α) (Dcodhar et al., 2013; Pinsornsak et al., 2012). Moreover, curcumin therapy led to a measurable improvement in disease activity scores, functional mobility, and overall quality of life, affirming its place as a promising adjunct or alternative to nonsteroidal anti-inflammatory drugs (NSAIDs), without their typical gastrointestinal side effects (Kulkarni et al., 1991; Kuptniratsaikul et al., 2014).

* *Neurodegenerative Diseases – Alzheimer’s Disease*

In the context of neurodegenerative disorders, particularly Alzheimer’s disease (AD), *Curcuma longa* has shown remarkable potential. A year-long clinical intervention involving oral administration of curcumin in AD patients revealed a significant rise in serum levels of Aβ40 peptides—a biochemical marker associated with the breakdown and clearance of amyloid-beta plaques (Ringman et al., 2012). These plaques are key pathological culprits in Alzheimer’s progression, and their disaggregation is considered a pivotal therapeutic target. The findings suggest that curcumin may exert neuroprotective effects through its ability to inhibit plaque aggregation, reduce oxidative stress, and attenuate neuroinflammation, thereby offering a multi-pronged approach in cognitive preservation and slowing disease progression.

* *Immune Modulation in Pediatric Respiratory Infections*

Another area where *Curcuma longa* has demonstrated noteworthy efficacy is in enhancing immune response in pediatric populations. A clinical study conducted on children suffering from recurrent upper respiratory tract infections showed that supplementation with curcumin significantly improved immune modulation (Zuccotti et al., 2009). The children experienced fewer episodes of infection, quicker recovery times, and reduced need for antibiotics—indicating curcumin’s role in fortifying innate immunity and downregulating inflammatory responses.

* 1. **Challenges in Turmeric-Based Therapeutics**

Although turmeric and its principal bioactive constituent, curcumin, have demonstrated extensive therapeutic benefits across various disease models, their clinical translation faces several significant pharmacological barriers. The most critical challenges hindering curcumin's effectiveness in human applications include poor water solubility, limited systemic bioavailability, low absorption rates, and rapid metabolic degradation in the liver and intestinal wall (Anand et al., 2007). Curcumin is hydrophobic in nature, meaning it has minimal solubility in aqueous environments such as gastrointestinal fluids. Consequently, when administered orally, only a small fraction of the compound reaches the systemic circulation in its active form. Additionally, curcumin undergoes extensive first-pass metabolism, resulting in the formation of various conjugated derivatives such as glucuronides and sulfates, which may possess reduced pharmacological activity. This rapid metabolism significantly limits the compound's therapeutic impact in vivo.

To overcome these limitations, researchers have explored and developed innovative drug delivery systems aimed at enhancing curcumin’s pharmacokinetics, stability, and targeted delivery. These strategies include:

* *Nanoparticle-based formulations*: Encapsulation of curcumin in polymeric or lipid nanoparticles enhances its solubility, prolongs its systemic circulation, and facilitates controlled drug release (Sun et al., 2013). These nanoformulations significantly increase curcumin’s bioavailability and tissue uptake.
* *Liposomal encapsulation*: Curcumin is incorporated into phospholipid bilayers (liposomes), which mimic cellular membranes, enabling better absorption through biological barriers and improved bio-distribution (Feng et al., 2017)
* *Niosome encapsulation:* Since ancient times, niosomes have been employed as therapeutic molecule carriers. Due to They are highly biocompatible and have little toxicity due to their nonionic nature. Niosome formulations can be administered intramuscularly, intravenously, peroral, or transdermally, and they have a number of applications. Additionally, it has been demonstrated that niosomes, which are drug delivery vesicles, improve drug absorption across cell membranes and localization in certain organs (Singh and Upadhyay., 2021).
* *Phytosomal technology:* In phytosomes, curcumin is complexed with phosphatidylcholine, enhancing its ability to cross lipid-rich cell membranes and increasing its absorption in the gastrointestinal tract (Chaudhary and Rajora., 2025).
* *Curcumin analogs and adjuvants*: Structural analogs of curcumin and the use of bio-enhancers such as piperine (from black pepper) have been shown to inhibit curcumin metabolism and enhance its bioavailability by up to 2000% (Joshi et al., 2021).
* *Hydrogels and micelles:* These novel carriers provide a stable aqueous dispersion of curcumin and allow sustained drug release, offering another promising route for therapeutic administration (Chelimela et al., 2024).
	1. **Modern Therapeutic Potential:**

Turmeric continues to be a subject of extensive scientific research for its modern therapeutic potential. Studies have identified its efficacy in various fields of medicine:

* *Chronic Disease Management***:** Turmeric is used in treating metabolic disorders such as diabetes and obesity. Curcumin improves the management of type 2 diabetes and obesity-related inflammation by increasing insulin sensitivity and regulating lipid metabolism (Daily et al., 2016).
* *Gastrointestinal Health:* Research indicates that curcumin aids in the treatment of gastrointestinal conditions, including irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), and gastric ulcers, by reducing gut inflammation and oxidative stress (Chainani-Wu, 2003).
* *Chemoprevention and Cancer Treatment:*Curcumin exhibits potential in cancer treatment by inhibiting tumor growth, reducing metastasis, and inducing apoptosis. Studies have underscored its role in the suppression of a variety of cancers, such as breast, prostate, lung, and colorectal cancers(Goel et al., 2010).
* *Neurodegenerative Disorders:* Turmeric has been investigated for its neuroprotective properties in conditions such as Alzheimer's disease and Parkinson’s disease. It reduces beta-amyloid plaque accumulation, oxidative stress, and neuroinflammation, potentially delaying cognitive decline (Mishra & Palanivelu, 2008).
* *Cardiovascular Health:* Curcumin promotes cardiovascular health by decreasing cholesterol, preventing atherosclerosis, and reducing hypertension. It functions as an anticoagulant, thereby decreasing the likelihood of stroke and heart disease (Hewlings & Kalman, 2017).
* *Wound Healing and Skin Health:* Due to its antimicrobial and anti-inflammatory effects, turmeric is widely used in dermatology for treating acne, psoriasis, and wound healing (Pancholi et al., 2020).

The increasing scientific validation of turmeric's medicinal properties has led to its incorporation into modern pharmaceuticals, nutraceuticals, and functional foods. However, challenges such as curcumin's low bioavailability have prompted research into novel delivery systems, including nanoparticles, liposomes, and phospholipid complexes.

* 1. **Safety and Adverse Effects:**

While turmeric is widely recognized for its medicinal benefits, its safety profile should be carefully considered, especially in high doses or prolonged use.

* *Gastrointestinal Issues***:** Excessive consumption of turmeric may lead to nausea, diarrhea, acid reflux, or stomach upset in some individuals (Lao et al., 2006).
* *Allergic Reactions***:** Some individuals may experience allergic responses such as skin rashes, itching, or contact dermatitis when using turmeric topically or orally (Rahman et al., 2019).
* *Bleeding Risks***:** Turmeric has mild anticoagulant properties, which may increase the risk of bleeding when taken with blood thinners like aspirin or warfarin (Chainani-Wu, 2003).
* *Liver and Gallbladder Concerns***:** High doses of turmeric may exacerbate existing liver conditions or gallbladder disease by increasing bile production (Cheng et al., 2001).
* *Drug Interactions***:** Curcumin may interact with medications such as antidiabetic drugs, chemotherapy agents, and immunosuppressants, potentially altering their efficacy (Sharma et al., 2005).
* *Pregnancy and Breastfeeding***:** While turmeric is safe in dietary amounts, high doses should be avoided during pregnancy due to potential uterine-stimulating effects (Takahashi et al., 2009).

Although turmeric is generally well-tolerated, it is essential to consult a healthcare provider before using it as a medicinal supplement, particularly for individuals with pre-existing conditions or those on medications.

* 1. **Conclusion:**

Turmeric remains an invaluable plant with extensive medicinal, culinary, and cultural significance. Its bioactive compounds, particularly curcumin, exhibit remarkable therapeutic properties, making it a promising candidate for disease prevention and treatment. Ongoing scientific research continues to validate its efficacy in modern medicine, yet challenges such as bioavailability and standardization require further investigation. As the global demand for natural and plant-based remedies increases, turmeric’s role in pharmaceuticals, functional foods, and healthcare is expected to expand. Future studies focusing on innovative delivery methods and clinical trials will help harness its full potential, ensuring its integration into mainstream medical practice.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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