

# A Comprehensive Review On Biochemical Makeup And Bioactive Components Of Turmeric

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## ABSTRACT

Turmeric is a perennial herb and belong to family Zingiberaceae. It is well known for its use in cooking and medicine. This review collects recent findings from 2010 to 2025 from Google Scholar, Web of Science, Scopus, and Springer databases. It focuses on the chemical profile and biological potential of turmeric. The main bioactive compounds, called curcuminoids (curcumin, demethoxycurcumin, and bisdemethoxycurcumin), make up 3 to 6% of turmeric, with curcumin being the most researched. Turmeric also contains volatile oils (2 to 7%) like turmerone, zingiberene, and cineole. Additionally, it has polysaccharides, phenolic compounds, proteins, and minerals that contribute to its medicinal properties. Curcumin shows strong anti-inflammatory, antioxidant, anticancer, antimicrobial, neuroprotective, cardio protective, and antidiabetic effects. It works through processes such as NF- $\kappa$ B inhibition and ROS scavenging. Recent studies emphasize turmeric's role in managing chronic diseases like cancer, diabetes, and neurodegenerative disorders. However, its effectiveness in clinical settings is limited by poor bioavailability. Recent advances in Nano formulations and delivery systems have improved curcumin's solubility and therapeutic potential. Safety studies confirm that turmeric is safe at doses up to 1.5 g per day with minimal toxicity. Still, special clinical trials are necessary to determine the best dosage and long-term effectiveness. This review highlights turmeric's varied therapeutic potential and the need for ongoing research to make use of its bioactive compounds for medicinal and nutritional purposes.

**KEYWORDS:** Curcuma longa, curcumin, bioactive compounds, pharmacological activities, bioavailability, Nano formulations.

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## INTRODUCTION

It has a perennial herbaceous plant belong to the family Zingiberaceae that is well known as Spices & herbal medicine. Ancient root crop noted for its culinary, medicinal, and cultural value in a variety of societies worldwide. It was a longstanding ingredient in conventional medicine such as the Ayurveda and the Chinese Medicine, where its brilliant yellow colour and wide therapeutic range are very much appreciated (Ahmad et al., 2020; Zhu et al., 2023).

The plant rhizome is the most widely used, as a condiment, a natural dye, and the most powerful medicament (Shirley et al., 2008). Besides its role in the kitchen, *Curcuma longa* is grown in many Asian countries for its medicinal values (Labban, 2014) and leaves and flowers which are known for their volatile constituents, essential in perfumery, medicinal studies (Agarwal et al., 2018). Due to its long-term use in traditional medicine, scientific research of phytochemical and pharmacological properties of *J. gangetica* has intensified in recent years and many such properties have now been proven scientifically (Ahmad et al., 2020). This review compiles new information on the chemical composition and biological properties of *Curcuma longa* by discussing various bioactive compounds and their modes of action. In particular, curcuminoids (i.e., curcumin, demethoxycurcumin, and bisdemethoxycurcumin) as well as non-curcuminoid compounds (e.g., terpenoids and polysaccharides) present in turmeric, are well known for the various biological activities which have gained increasing interest and warranted more exhaustive reviews (Zhang & Kitts, 2021) (Cozmin et al., 2024). However, curcumin (CUR), the principal bioactive moiety, has poor water solubility, low bioavailability, rapid metabolism, and its direct clinical use is practically reduced (Cozmin et al., 2024) (Labban, 2014). This natural low bioavailability requires that effective drug formulation strategies should be developed to increase its in vivo treatment efficacy (Bahrami et al., 2021). As a result, in the recent years, new delivery systems, such as nanoparticles, liposomes, or phospholipid complexes for the improvement of the absorption and systemic availability of these useful compounds have been considered. Similarly, curcumin-the major component in turmeric-is a multifunctional molecule and broad range of biological activities, but it suffers from photosensitivity, is prone to alkaline degradation, and rapid excretion, which limit the therapeutic profile, and so it is a Bio pharmaceuticals Classification System (BCS) Class four drug since it has very low solubility and permeability (Al-Jameel et al., 2024). These inherent physicochemical limitations emphasize the necessity of sophisticated pharmaceutical approaches to increase its therapeutic effectiveness and extend its clinical application. The composition of turmeric may vary depending on the growing environment, which presents a challenge in the standardization as Indian turmeric has been known for its relatively higher curcumin content (Zhang & Kitts, 2021). Notwithstanding this wealth of research to

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support its use as a medicine, one of the greatest challenges in the medicinal use of curcumin chemical is its less bioavailability, which is related to its low water solubility and rapid first-pass metabolism (Cogle et al., 2024) (Gu et al., 2013). Therefore, novel strategies including the use of nanoparticulate systems are the focus of recent studies to improve the tissue penetration of curcumin and their efficacy (Ahmad et al., 2020). Some of the most effective alternative treatment strategies for various diseases are encompassing curcumin—a highly bioactive chemical compound present in turmeric that exist in keto-enol form (Yang et al., 2023). The keto tautomer is the major contributor in acidic and neutral media, although in an alkaline medium the enol form becomes the more stable configuration (Halevas et al., 2018). It is coping with multiple enzymatic CYP450 metabolism routes along with direct conjugation to glucuronidation mediated by UDP-glucuronosyltransferases that is hampering the therapeutic in vivo employment of curcumin, despite its low solubility, and why the pharmacological activities of curcumin remain untapped (Rahim-Mahdy & Seifert, 2025). Formation of conjugates and swift elimination, albeit being the matters of concern, kait the rise in renal and portable adjuncts operative towards betterment of its practical inadacondary in vitiated physiology (Rahim-Mahdy & Seifert, 2025) (Stojs et al., 2019). It's only suffering from the above mentioned deficiencies and the incessantly growing pharmacological multivalencies that might eventually destroy the conventional clinic ties of curcumin due to the possible restoratives of the antiinflammatory and adjunctive anti-cancer medicines (Labban, 2014). More importantly, curcumin readily undergoes metabolism and forms inactive conjugates, thereby culminating in the production of glucuronides and sulfates, which negatively impacts the systemic bioavailability due to the low aqueous solubility of the compound, making the curcumin peripheral to the therapeutic outcome. Thus, targeted Pharmaceutical intervention is a requisite. In recent studies, curcumin has attracted notable encounters for the innovation of encapsulation and stratified delivery systems. These systems include the use of liposomes, micellar polymers, and nanoparticles, which effectively address the issues surrounding curcumin's systemic bioavailability and therapeutic potency (Zhang & Kitts, 2021). This approach facilitates the bypassing of the advanced curcumin deliver systems limitations, thereby fostering its broader clinical usage to a range of diseases (Strimpakos & Sharma, 2007) (Shekarforoush, 2018). Also in terms of the interaction between curcumin and other plant bioactives like piperine we see that this has put forth promise in terms of improving its gastrointestinal absorption and permeability which in turn improves its therapeutic value (Zhang Kitts, 2021).

### HABITAT NATURE, TYPES AND DISTRIBUTION IN INDIA AND ABOARD

Also in terms of habitat, type and distribution Turmeric is a type of herb from the ginger family which grows mainly in tropical and sub-tropical regions, does best in well drained loamy or sandy soils and in warm humid climates. Although native to South East Asia it has wide scale cultivation which has grown globally, today India is the leading producer which puts them at over 80% of the world's turmeric supply (Rahban et al., 2020). This large scale distribution also puts into relief its economic value and which in turn brings to light the very many agro-climatic regions in which it does well, which in turn influences its phytochemical profile. By geography, soil type and culture methods we see great difference in curcuminoid content and the range of volatile compounds which in turn requires we have standardized cultivation practices for consistent health benefits.

These regional differences in growth which in turn play a role in the concentration of key bioactive compounds like curcumin which in turn requires we have in place very rigorous quality control measures for turmeric based products to put out consistent pharmacological action (Siudem et al., 2023). Also the issue of low production in India which has by large the market share plays a role in the fact that we must put in place integrated nutrient management strategies to improve yield and at the same time preserve the plant's phytochemical make up (Dikey et al., 2019). We see great wide scale growth of *Curcuma longa* in particular in countries like India, China and parts of Africa which is a reflection of its adaptability and economic value but also puts out issues in to standardizing the bioactive component profile due to variable environmental factors which is what we see in (Gupta et al., 2015).

### THE MORPHOLOGY OF TURMERIC:-

*Curcuma longa* is a rhizomatous herb that typically grows to a height of 1 meter. It has oblong, pointed leaves and pale yellow flowers that emerge from a spike (Cozmin et al., 2024). The plant's underground rhizomes are the main source of commercial turmeric. These rhizomes are fleshy and cylindrical, showing a bright orange-yellow color when cut, which comes from curcuminoids (Tilak et al., 2004). They have a strong aromatic smell and a pungent, slightly bitter taste. These qualities make them popular in cooking, medicine, and cosmetics (Bhowmik et al., 2009).

The internal structure has a dense network of parenchymal cells that store starch and oleoresins, including curcuminoids, essential oils, and other compounds. These components contribute to its health benefits and sensory traits. The bright colour and unique aroma come from various volatile compounds and curcuminoids, which vary by geographical origin and processing methods (Zhang & Kitts, 2021; Rahi et al., 2020).

Additionally, the physical features of the rhizome, especially its structure, affect how well extraction processes work and the yield of bioactive compounds. This highlights how important plant characteristics are for industrial uses. The rhizome's size, shape, and internal density are key factors in improving drying, grinding, and solvent extraction efficiencies. These factors directly affect the quality and quantity of extracted curcuminoids and essential oils (Tilak et al., 2004).

The processing of these rhizomes, which includes cleaning, drying, milling, and packaging, significantly influences the stability and amount of curcuminoids. Careful control is needed to maintain their quality (Llano et al., 2022). Moreover, the grinding process can cause a considerable loss of volatile compounds due to heat, which shows the need for specialized milling methods that reduce thermal degradation (Shelake et al., 2017). This calls for specific size reduction techniques, like cryo-milling or air-cooled grinding systems, to keep heat-sensitive phytochemicals intact and maximize essential oil yield (Shelake et al., 2017). Ultimately, how effective

\**Curcuma longa*\* is as a therapeutic agent depends on closely managing its growing, processing, and extraction to maintain its powerful bioactive compounds (Gogoi et al., 2023).

## CHEMICAL COMPONENTS:

*Curcuma longa* is chemically rich and curcuminoids are regarded as the main bioactive constituents. Turmeric is a complex of different curcuminoids, the main one is curcumin (diferuloylmethane) which is 2-5% of the composition of turmeric; the rest are minor components - demethoxycurcumin and bisdemethoxycurcumin. In addition to curcumin, turmeric contains volatile oils (2-7%) such as turmerone, zingiberene, cineole, sabinene and borneol which contribute to turmeric's unique aroma and medicinal properties. Other components are polysaccharides (e.g. punte A, B, C, D and Ukonan), proteins, resins, phenolic compounds, trace vitamins contains C and E, minerals contains iron, potassium and small amounts of fibre and fatty acids. Collectively, these compounds are very responsible for many of the health benefits of turmeric, including following: Synergy among these multiple compounds, rather than any single compound, is reported to be responsible for many of the biological activities that have been identified for *Curcuma longa* (Nasri et al., 2014).

*Curcuma longa* contains numerous bioactive curcuminoids, of which the major is the diarylheptanoid curcumin, responsible for the therapeutic effects. The expression of all chemical component activities, by modulating the key signaling pathways for cell proliferation, inflammation and apoptosis, is a potential candidate agent for various treatments (Noorafshan & Ashkani-Esfahani, 2013). In addition to curcumin, the minor curcuminoids demethoxycurcumin and bisdemethoxycurcumin have been demonstrated to play a role in turmeric's biological activities and to, in fact, enhance the activity of curcumin by demonstrating synergistic interactions (Cozmin et al., 2024). Besides curcuminoids, the other compounds found in turmeric include volatile oils such as turmerone, zingiberene and cineole that lend turmeric its distinctive smell has high levels of anti-inflammatory and antioxidant activity (Chakraborty et al., 2021). More than 40 curcuminoids were isolated, of which 30 were unique (Zhu et al., 2023) were recently reported. Other constituents include omega-3 fatty acids, d-a-phellandrene, D-sabinene, cineole, borneol, sesquiterpenes such as germacrone, etc. Turmeric's complex chemical constituents provide a variety of medicinal properties (Aggarwal, 2010).

For example, *Curcuma longa* as a therapeutic agent is extremely chemically heterogeneous; it has been reported to have more than 326 biological activities, including at least 20 antibiotic, 14 anti-carcinogenic, 12 anti-tumor and 12 anti-inflammatory compounds (Ahmad et al., 2020). Curcumin (diferuloylmethane) exists in two tautomeric forms: as the enol form (predominantly in organic solvents) linked to increased membrane permeabilities and cell-cell interactions, and as the keto form (predominantly in aqueous media) linked to different enzymatic reactions and its bioavailability and biological interactions (Gogoi et al., 2023; Aggarwal and Sung, 2008). Such tautomerism is of crucial importance to understand the broad-spectrum pharmacological activity of curcumin. Also, *Curcuma longa* comprises sesquiterpenoids (ar-turmerone and turmerone) that contribute more to *Curcuma longa* therapeutic potential than the well-known curcuminoids that are the basis for *Curcuma longa* broad-spectrum biological activity (Zhang and Kitts, 2021; Gogoi et al., 2023).

Apart from curcuminoids, *Curcuma longa* is rich in numerous non-curcuminoid constituents with the volatile ones, like ar-turmerone, a-turmerone, a-curcumene and the like, playing a significant role in its therapeutic activity. These compounds display anti-swelling and neuroprotective activities and a variety of molecular mechanisms contribute to the medicinal value of the plant (Zhu et al., 2023; Alolga et al., 2022). A phytochemical profile attracted by some 50 polar and nonpolar molecules is testament to the synergy underlying turmeric's broad-spectrum health benefits and, therefore, an ideal focus of pharmacological studies (Nasri et al. 2014; Zhang & Kitts 2021). It revealed approx 6-8 monomeric compound and other 12 unique compounds were found (Nair et al., 2019). Thirteen curcuminoids have been isolated from turmeric rhizomes, including some new compounds including 1, 5-dihydroxy-1,7-bis-4,6-heptadiene and 3-hydroxy-1,7-bis-6-heptene, which were identified by the use of modern spectroscopic techniques (Li et al. 2009). This overall molecular characterization provides the basis for its numerous therapeutic uses for *Curcuma longa*, supporting its traditional uses and guiding contemporary pharmacological research (Rahim-Mahdy and Seifert, 2025)

## BIOLOGICAL ACTIVITIES

### 5.1-Anti-inflammatory effect

The chief anti-inflammatory component of *Curcuma longa* is curcumin which has a number of molecular actions against inflammation. Curcumin was reported to exhibit a strong anti-swelling performance by inhibiting the working of key enzymes, COX-2, lipoxygenase and inducible nitric oxide synthase (iNOS) and consequently, their synthesis of the pro-inflammatory mediator's prostaglandin, leukotrienes and nitric oxide. Furthermore, curcumin restrict the induction of cytokines tumor necrosis factor- $\alpha$  and interleukins IL-1 $\beta$ , IL-6 and nuclear factor-kappa B activation, a transcription factor that start the inflammatory response (Zhu et al., 2023). Our studies indicated that curcumin is a promising herbal agent for treating the chronic inflammatory diseases due to its multimodal modulation of inflammatory signaling pathways (Shanmugam et al., 2015).

*Curcuma longa* contains other components such as essential oils, which have anti-inflammatory activity in addition to curcumin. These elements are functional with curcuminoids and have their own mode of actions (Gogoi et al., 2023). For instance, one of the important compounds in turmeric essential oil such as turmerones may inhibit inflammatory mediators and is capable of modulating immunological cell responses. Along with this is the general anti-inflammatory activity of the plant (Zhu et al. 2023). These additive effects are in agreement with the multi-phytochemical nature of *Curcuma longa* which has been reported to have a multi-dimensional approach to anti-inflammatory activity via multi-pathways simultaneously (Itokawa et al., 2008). All of this positive activity makes it extremely effective in treating the symptoms of a wide variety of inflammatory diseases (including osteoarthritis). In such cases, *Curcuma longa* extracts have been found to be highly effective in improving the patients' condition and also in reducing the inflammatory markers (Zhu et al., 2023) and according to clinical studies, oral curcumin supplementation is as effective as

conventional anti-inflammatory chemicals like cortisone or phenyl butazone, at reducing inflammation and swelling in acute cases (Labban, 2014). The effect is mainly attributed to curcumin's suppression of TNF $\alpha$ -dependent activation of the transcription factor NF- $\kappa$ B and to decreased synthesis of a pro-inflammatory enzyme (5-Lipoxygenase). This makes it an excellent anti-inflammatory agent (Rao et al., 2019). Additionally, *Curcuma longa* was reported to have anti-inflammatory properties because of its capability to lower the amount of interleukin-6, interleukin-8 and TNF- $\alpha$  in mice infected with *Mycoplasma pneumoniae* (Zhu et al., 2023). The various NASID activities of curcumin and other components of *Curcuma longa* suggest their potentiality in the treatment of various types of chronic disorders such as neurodestructive disorders, heart diseases and various cancers (Aggarwal and Harikumar, 2008; 2015).

Specifically, a low dose as 48 mg/kg, curcumin was effective at reducing swelling in mice (Nasri et al., 2014). What's more, this herb has a very strong anti-inflammatory quality which underpins its traditional role in osteoarthritis. In such cases, the extracts of *Curcuma longa* have reduced the pain and parameters of inflammation and oxidative damage (Zhu et al., 2024). Curcumin has been reported to reduce the progression of the disease and symptoms of osteoarthritis via a reduction in the overall action of matrix metalloproteinase and major some cytokines like IL-1 $\beta$  and TNF- $\alpha$  (Deng et al., 2023).

*Curcuma longa* has been shown to contain polysaccharides in addition to curcuminoids, the immunostimulative and anti-inflammatory potential of which, although less studied, is of great significance. Thus, they could have value as complementary treatment (Chandrasekaran et al., 2013). They may activate peripheral blood mononuclear cells to suggest a more generic contribution to inflammation-associated immune control (Yue et al., 2010). Whereas the inhibition of the both COX-1,2 with non-steroidal drugs occurs through a bimodal inhibition mechanism, the anti-inflammatory activity of curcuminoids is mainly mediated through the down-regulation of COX-2 expression. It might be a safer option than the treatment of inflammatory diseases (Feng et al., 2022). This selective inhibition not only minimizes the GI side effects generally experienced with the classical NSAIDs, and in this regard, curcumin is a promising anti-inflammatory agent with high efficacy and low toxicity (Bhowmik et al. 2009).

### 5.2- Antioxidant effect

Taking into consideration the active substance (curcumin and its derivatives), *Curcuma longa* is the most active antioxidant that effectively removes the reactive oxygen species and enhances the endogenous antioxidant system of the organism (Feng et al., 2022; Radomska-Lesniewska et al., 2019). Due to their capacity to directly scavenge the most significant free radicals such as superoxide, hydroxyl and to up-regulate the activity of some of the most special antioxidant enzymes such as superoxide dismutase, catalase and glutathione peroxidase, they were discovered to possess antioxidant properties (Zhu et al., 2023). Thus, it is the direct scavenging of free radicals, and also the indirect enhancement of the enzymatic protection, that explains the protective effect of turmeric against damage from oxidation, which is one of the primary symptoms of long-lasting diseases (Zhu et al., 2023).

For instance, turmeric and its curcumin component have powerful antioxidant actions like vitamins C and E. This results in better resistance of cells to oxidative damage and less production of proinflammatory cytokines (Labban, 2014). It also has potent antioxidant properties that add to its heart-protecting and anti-diabetic properties. These effects are derived from the reduction in lipid peroxidation and reduction in oxidative damage in different tissues (Nasri et al., 2014) (Ahmad et al., 2020).

Several studies found that curcumin was able to effectively inhibit the generation of ROS including H<sub>2</sub>O<sub>2</sub>, superoxide anion and nitrite radical produced by activated macrophages. This reflects its wide-ranging free radical scavenging potential (Nasri et al., 2014). Curcumin's potent antioxidant activity is also explained by its ability to chelate metal ions that would otherwise be involved in Fenton-type reactions to form highly reactive oxygen species (Jagetia & Aggarwal, 2007). In addition, its impact on oxidative stress pathway important enzymes, such as the heme oxygenase-1, is also part of its antioxidant profile (Labban, 2014).

In addition to direct antioxidant radical scavenging and modulation of enzymes, curcumin raises levels of glutathione. This helps the liver eliminate toxic substances and thereby enhances cellular protection against the oxidative insults (Labban, 2014). Furthermore, aqueous extracts of turmeric inhibited g-radiation-induced DNA damage of microbial DNA (Tilak et al., 2004), which supports its multiple antioxidant activities.

### 5.3 Antimicrobial effect

The antimicrobial properties of *Curcuma longa* are well documented. Curcumin shows broad activity against various bacteria, fungi, and viruses. It disrupts microbial cell membranes and prevents biofilm formation (Rahim-Mahdy & Seifert, 2025). This effectiveness includes its antiviral potential, as curcumin interferes with viral replication cycles and stops viruses from entering host cells (Labban, 2014). Its antifungal properties are also significant. Curcumin works against several fungal strains by disrupting ergosterol synthesis and stopping spore germination (Nasri et al., 2014).

Using essential oil from turmeric leaves has been found to significantly inhibit fungal growth. It also reduces the production of aflatoxins B1 and G1 (Ahmad et al., 2020). In animal studies, turmeric supplementation has reduced intestinal lesions and improved weight gain in chicks infected with *Eimeria maxima*. Additionally, applying turmeric oil on the skin has inhibited dermatophytes and harmful fungi in guinea pigs (Nasri et al., 2014).

Curcumin shows moderate activity against *Plasmodium falciparum* and *Leishmania major*, highlighting its potential against protozoa (Labban, 2014). These diverse antimicrobial effects point to *Curcuma longa* and its derivatives as natural alternatives to traditional antimicrobial agents, particularly for dealing with drug-resistant strains (Tilak et al., 2004).

The antimicrobial activity of turmeric volatiles has been reported to be more effective than established antimicrobial drugs like

Norfloxacin and ciprofloxacin. It has strong effects on *Bacillus subtilis*, *Bacillus cereus*, and various fungi. The most potent inhibition is against fungal pathogens (Zhu et al., 2023). Beyond stopping microbes directly, curcumin also reduces the growth of pathogens like *Streptococcus mutans* and interferes with their glycolytic abilities when made into a chitosan/curcumin nanocomplex (Zhu et al., 2023).

This broad antimicrobial action makes *Curcuma longa* a promising option for various uses, including protecting crops from fungal and insect pests. It can also serve as an aid in oral care to lower microbial load and gingivitis (Pandey et al., 2021; Ahmad et al., 2020). Its role in dentistry is backed by its effectiveness against oral pathogens and its anti-inflammatory benefits for gum tissues (Sood & Nagpal, 2013).

In addition to inhibiting microbes directly, curcumin helps the body's immune responses, boosting natural defences against infections by increasing phagocytic activity and cytokine production. This complete antimicrobial profile, along with its effects on immunity, positions *Curcuma longa* as a valuable natural resource for tackling various microbial challenges, including those resistant to standard treatments (Zhu et al., 2023).

Specifically, curcumin has shown strong anticoccidial activity by causing sporozoite disconfiguration, lowering infectivity, and blocking cell growth (Ahmad et al., 2020). Additional research suggests that curcumin derivatives have different levels of anti-parasitic activity against various *Leishmania* species, with some being more effective than curcumin itself (Sahebi et al., 2024).

#### 5.4 Anticancer Effect

Curcumin, a key compound in *Curcuma longa*, has gained significant attention for its diverse anticancer properties. These properties impact various molecular pathways that are vital for tumor initiation (Zia et al., 2020). Its effectiveness comes from its ability to trigger apoptosis process in cancer cells, limit the growth of new blood vessels, slow down cell proliferation, and stop cancer from spreading by downregulating several oncogenic pathways and inflammatory substances (Nasri et al., 2014). For example, curcumin can inhibit NF- $\kappa$ B, a transcription factor important in inflammation and cancer development, which helps reduce tumor growth and improve sensitivity to chemotherapy in different types of cancer (Manju & Sreenivasan, 2011).

Additionally, curcumin has a remarkable ability to influence the expression of microRNAs and block histone deacetylase activity. These actions are essential for controlling gene expression in cancer cells (Ahmad et al., 2020). This wide-ranging effect highlights curcumin's promise as a broad-spectrum anti-cancer agent that can target multiple cancer traits at once (Ameer et al., 2024). From a safety standpoint, curcumin is considered safe and shows selective toxicity, meaning it targets tumor causing cells more effectively in action than some normal cells, which contributes to its positive safety profile (Üçışık et al., 2013) (Ahmad et al., 2020).

Curcumin, one of the important bioactive constituents of *Curcuma longa*, has shown its therapeutic effectiveness by various mechanisms like biological activity (Rahim-Mahdy and Seifert, 2025; Ahmad et al., 2020). In models, curcumin has been shown to inhibit cancer development in all stages -- initiation, promotion, and progression -- through the regulation of transcription factors that increase detoxification processes and reduced expression of cytokines (Labban, 2014; Nasri et al., 2014).

*Curcuma longa*, a major source of curcumin, has demonstrated a potent anticancer activity by band of cell cycle and apoptosis process through caspase-3-dependent pathways manner. It suppresses the nuclear translocation of p65 and regulates surviving and hexokinase II, which are important regulators of cancer cell survival (Ahmad et al., 2020). In addition, curcumin is able to potentiate the effectiveness of chemotherapeutic agents such as capecitabine and taxol by reversing drug resistance in colorectal cancer, mainly via the inhibition of the signalling process pathways of NF- $\kappa$ B and STAT3 (Ahmad et al., 2020).

The chief component of *Curcuma longa*, known as curcumin, has demonstrated remarkable anticancer properties through the inhibition of cytochrome enzymes that are key to the metabolism of carcinogens and therefore inhibit tumor formation (Mansouri et al., 2020). Its multifactorial activities make it an important preventive as well as therapeutic agent against cancer (Teiten et al., 2010). Curcumin influences the proliferation by several cellular signal pathways contains Wnt/b-catenin and phosphoinositide 3-kinase/protein kinase B, apoptosis, invasion with metastasis of cancer cells (Wang et al., 2019).

In cancers such as esophageal, cervical, and prostate cancers, one of the key bioactive compounds, curcumin in *Curcuma longa*, is found to be instrumental in reversing the maximum methylation of DNA of CDK inhibitor 2A and O-6-methylguanine-DNA methyltransferase (Farheen et al., 2024). Moreover, curcumin triggers the apoptosis of human kidney and colon adenocarcinoma cells via the regulation of Bax/Bcl-2 signaling pathway and targeting the spindle assembly checkpoint, specifically in cells with high levels of phosphorylated CDC27 (Ahmad et al., 2020).

Curcumin (a major bioactive constituent of *Curcuma longa*) is the anticancer agent that inhibits the phosphorylation of downstream molecules such as p70 and eukaryotic initiation factor with joining protein by targeting important signaling molecules such as mTORC1 complex, which is a critical pathway in a wide types of cancer (Beever et al., 2009). Additionally, curcumin exerts effects by regulating a variety of signaling molecules, such as cytokines as a transcription factors and enzymes involved in cancer prootions, (He et al., 2025). For example, it regulates the activation of NF- $\kappa$ B thereby helping apoptosis and inhibits protein kinase C, epidermal growth factor receptor tyrosine kinase and HER-2 (Manju & Sreenivasan, 2011). In addition, curcumin modulates the PI3K/Akt, JAK/STAT, and MAPK pathways, which control cell survival, proliferation and angiogenesis, coordinating a comprehensive anticancer effect (Wang et al., 2019).

#### 5.5 - Other effect

Some major bioactive compound derived from *Curcuma longa* and has a wide range of therapeutic properties in addition to its well-known working against cancer, inflammation and neuron, (Wang et al., 2019; Ahmad et al., 2020). Its antioxidant potential is due to a combination of increasing endogenous antioxidant enzymes as well as direct free radical scavenging activity, which reduces the amount of oxidative stress in chronic diseases. In addition to the anti-inflammatory activity, turmeric has been proven to block chemical cytokines and pathways including nuclear factor- $\kappa$ B (Shuvalov et al., 2023). Considering the significant role of PBFZT-1 in the inhibition of tumor growth and metastasis, PBFZT-1 has anti-antigenic properties as it inhibited the antigenic cytokines like IL-6, IL-23, and IL-1b (Mansouri et al., 2020). In addition, curcumin acts on the animal target of kanamycin (mTOR) signaling pathway, which is significant in regulating cell growth, proliferation, survival, and migration, which are frequently deregulated in cancer (Beevers et al., 2013). This modulation reflects the pleiotropic nature of curcumin in the regulation of cellular metabolism and proliferation. Besides, curcumin exhibits neuroprotective activity; curcumin can cross the blood-brain barrier, and its anti-oxidative activity can regulate synaptic plasticity and energy homeostasis to inhibit cerebral edema and inflammation. Because of these properties, it has been promising for treatment of neurodegenerative disorders and other neurological disorders (Rahban et al., 2020; Ahmad et al., 2020).

## CONCLUSION AND FUTURE DEVELOPMENT-

Recent investigations from 2010 to 2025 into *Curcuma longa* show a complex chemical profile mainly consisting of curcuminoids at 3 to 6%. Curcumin serves as the main active compound at 2 to 5%, along with demethoxycurcumin and bisdemethoxycurcumin. Volatile oils make up 2 to 7% of the composition, including turmerone, zingiberene, cineole, and borneol, which contribute to its aroma and biological activity. Other components, like polysaccharides (ukonan A to D), phenolic compounds, proteins, and trace elements such as potassium and iron, differ based on cultivation, variety, and processing methods. Curcumin has strong anti-inflammatory with antioxidant properties by banding pathways like NF- $\kappa$ B and combating reactive oxygen species. Its anticancer effects stand out in preclinical studies, as it encourages apoptosis and inhibits tumor growth. Antimicrobial properties affect various pathogens, and benefits for the nerves and heart show promise for treating neurodegenerative and cardiovascular diseases. Polysaccharides improve immune responses, and volatile oils assist in anti-inflammatory and antimicrobial actions. Despite these advantages, curcumin's low bioavailability limits its use in therapy. However, recent improvements in Nano formulations such as liposomes and polymeric nanoparticles enhance its delivery and effectiveness. Safety assessments suggest that turmeric is generally safe at doses up to 1.5 g/day, with little reported toxicity. Future research on *Curcuma longa* should focus on solving the challenges of curcumin's bioavailability through innovative delivery systems like micro emulsions, cyclodextrin complexes, and targeted nanoparticles to boost clinical effectiveness. We need large-scale, well-structured clinical trials to determine optimal dosing, long-term safety, and therapeutic results for conditions like cancer, diabetes, and neurodegenerative disorders. Studying the combined effects of turmeric's minor constituents, such as volatile oils and polysaccharides, might reveal new pharmacological uses. Additionally, sustainable farming and consistent extraction methods are vital for maintaining reliable chemical profiles for pharmaceutical applications. Incorporating turmeric into nutraceuticals and functional foods can help in preventive healthcare. Moreover, exploring its role in personalized medicine and combination therapies could broaden its therapeutic potential. Working together, academia and industry will be essential for turning these discoveries into practical uses.

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## Ethical Statement

The review paper, "A Comprehensive Review on Biochemical Makeup and Bioactive Components of Turmeric," was crafted with a steadfast commitment to ethical scholarship and academic integrity. All content was meticulously synthesized from peer-reviewed scientific sources, ensuring accurate representation and proper attribution to original authors to uphold a strict anti-plagiarism policy. The authors have no financial or personal conflicts of interest that could influence the objectivity of this work. The review utilizes only publicly accessible data, with no involvement of human or animal subjects or sensitive information, and assumes compliance with ethical standards in cited studies. This paper seeks to advance scientific understanding of turmeric's biochemical and bioactive properties through a transparent, original, and responsible contribution to the field.

## Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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