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Pharmacological Insights into Curcumin: From Traditional Remeadyto Modern Therapeutic Agents

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A B S T R A C T

Curcumin is the main active compound found in turmeric, which comes from the plant Curcuma longa.It has been used in Indian medicine and cooking for a long time because of its many health benefits. Modern research shows that curcumin has strong antioxidant, anti-inflammatory, antimicrobial, neuroprotective, and anticancer properties. These effects happen because curcumin affects various molecules and pathways in the body, such as NF-ÎºB, TLR4, and inflammatory chemicals like IL-6, TNF-Î±, and IL-1Î². Even though curcumin is promising for treatment, its use is limited by poor absorption in the body due to low solubility, quick metabolism, and fast removal. Recent developments in drug delivery systems, like nanoemulsions and nanoparticles, have improved its stability and uptake. Curcumin is considered safe in humans and animals, and it's being used in both traditional medicine and modern medical treatments. This summary covers curcumin's structure, how it works in the body, its health effects, ways to improve its use, its safety, and its medical applications.

Keywords: Curcumin; Turmeric; Pharmacological activities; Antioxidant; Anti-inflammatory; Bioavailability; Nanoformulations; NF-ÎºB; Therapeutic applications; Traditional medicine.

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INTRODUCTION

An Indian spice is turmeric. The herb Curcuma longa is rhizomatous.The Zingiberaceae family of ginger is well-known. Benefits for health: (1 2).Turmeric's potential medical advantages include Due to the presence of active principles known as Curcuminoids. Among the most fascinating One oingredients in curcuminoiddnoid is curcumin. A polyphenolic compound with a low molecular weight and insoluble in water due to lipophilic in nature.Soluble in ethanol but also in ether. Other organic solvents and dimethyl sulfoxide (3). Numerous studies have been conducted on curcumin's bioactivity and health benefits, including antioxidant, anti-inflammatory, immune regulatory, anticancer, antidiabetic, neuroprotective, cardiovascular protective, and hepatoprotective properties (4, 5).

The active ingredient Curcumin, or turmeric, is extracted from curcuma.Turmeric gains color from longa.There are several forms of curcumin available, including tablets, ointments, and capsules:(15). Turmeric is boiled, then dried, cleaned, and polished Turmeric longa rhizomes. After the harvest,Whole rhizomes are collected. The rhizomes are transported intact. They are usually Fingers are 2 to 8 cm long and 1 to 2 cm wide.With bulbs and splits. Drhizomesizomes are further processed and reprocessed to obtain.Turmeric Powder (2). Curcumin (1, 7-bis (4-hydroxy-3) Methoxyphenyl)-1, 6-heptadiene-3, 5- dione) is also called diferuloylmethane (6).Turmeric has been used for nearly 4,000 years. The Vedic culture of India, where it was used as a culinary spice had some religious significance (7).

It is known by various names in different cultures.Countries turmeric is widely used in northern India.called "haldi," and in the south, it's called "manjal."In French, it is referred to as terremerite."Yellow root" is a term used in many languages. In Arabic it is called Kurkum, Uqdah Safra. In Sturmeric turmeric contains at least 53 names, Rent names (7).

Curcumin has traditional use as a medicinal herb owing to its numerous benefits, including antioxidant, anti- Inflammatory, antimutagenic, antimicrobial. There are many therapeutic properties (8)(9)(10)(11)(12). Curcumin exhibits poor absorption and rapid metabolism, elimination. Several agents were introduced. Increase the bioavailability of curcumin. Interestingly, piperine enhances curcumin. Increasing bioavailability through metabolic inhibition pathway of Curcumin (13).

Chemical structure and Sources

The efficacy of curcumin combined with chemotherapeutic agents was lately reviewed (14). Curcumin is a polyphenolic emulsion with the IUPAC names 1E and 6E. -1,7-bis(4-hydroxy-3-methoxyphenyl) has the chemical formula $C_{21}H_{20}O_6$. Curcumin consists of three structural fractions a 7- carbon linker, an α, β- unsaturated β- diketone, and two sweet ring systems with o- methoxy phenolic groups. Curcumin (diferuloylmethane) has been linked as the most bioactive element (2 – 8) of the turmeric condiment excerpt along with the other two curcuminoids. Curcumin is used as a food preservative and as a yellowish Color.

Turmeric has also been used in traditional drug as a ménage remedy for colorful conditions. Currently, the health parcels (neuroprotection, chemoprevention, and cancer forestallment) of curcumin and curcuminoids are gaining ever- growing attention also in medicinal and clinical diligence (15). Curcuminoids have been approved by the United States Food and Drug Administration (FDA) generally honored as safe (GRAS) (16). Numerous reported natural and pharmacological conditioning can be attributed to curcumin's chemical derivations, similar as demethoxycurcumin, bisdemethoxycurcumin, and cyclocurcumin. Hydrazinocurcumin, a lately developed synthetic analog of curcumin, has demonstrated superior delivery capabilities and has been considerably studied for Pharmacological efficacity(17)(18). Curcumin has a wide range of natural conditioning, including antibacterial,anti-inflammatory, antioxidant, and anticancer parcels(19, 20, 21, 22, 23).

Mechanism of Action & Pharmacological Activities

Antioxidant activity of curcumin

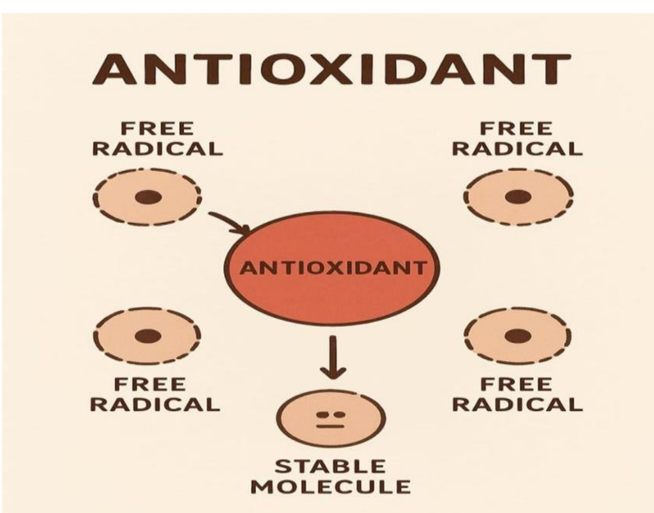

Figure: 1 Antioxidant Activity

Antioxidants help by stopping free radicals, which are harmful molecules that can damage the body. When there is too much reactive oxygen species (ROS), it causes oxidative stress and harms important substances in the body. Antioxidants, like certain enzymes and compounds, can stop free radicals and ROS from doing damage, which may slow down the development of many long-term health problems (24). Both lab tests and studies in living organisms show that curcumin's ability to fight free radicals helps explain its many health benefits. Research on curcumin's structure shows that parts of its molecule, especially the phenolic hydroxyl group, are mainly responsible for its antioxidant power (25).Curcumin mostly helps reduce oxidative stress by removing free radicals (26). Studies show that curcumin can directly eliminate extra free radicals and stop ROS from forming (27). Using curcumin on A549 cells that have been affected by influenza A virus reduces ROS and activates toll-like receptors, which may help stop the virus from spreading (28).Quinocetone can cause damage to DNA and increase oxidative stress in liver cells, but curcumin treatment before exposure can help lower ROS levels by boosting the activity of antioxidant enzymes, like superoxide dismutase (SOD), and the levels of antioxidants such as glutathione (GSH) (29). Also, curcumin treatment in mice with diabetes lowers ROS and reduces oxidative stress caused by high blood sugar by restoring the function of DNMT (30). Some diseases, like heart disease, are often linked to poor eating habits; as Wood and Brooks say, "We are what we eat" (33). This suggests that diets high in antioxidants, such as Mediterranean, Indian, or Nepalese diets, are good at preventing diseases related to oxidative stress, like heart disease (34-35) and cancer (36). In contrast, curcumin has been found to boost the activity of antioxidant enzymes. Treating with curcumin increases paraoxonase 1 arylesterase (PON1) activity, lowers the risk of low-density lipoprotein (LDL) oxidation, and fixes abnormal biochemical changes caused by mercury chloride (31, 32). A lab study found that curcumin's antioxidant properties can block the activation of NF-Î°B (37). However, antioxidant activity in a lab setting does not always mean it is effective in the body, and in some cases, it can even act as a pro-oxidant, offering no health benefits (38).

Anti-inflammatory activity of curcumin

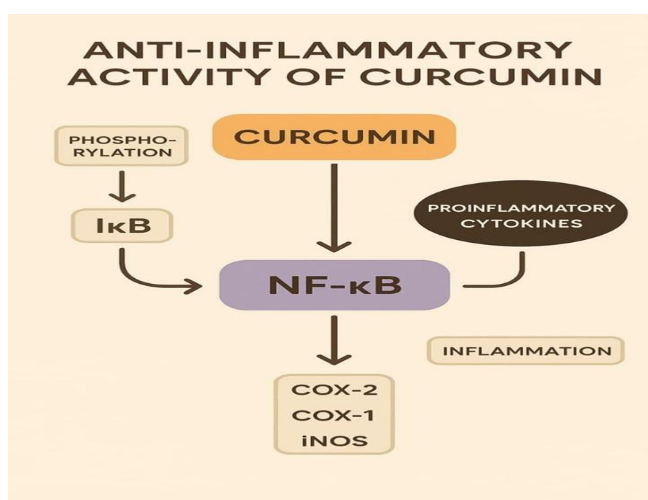

Figure 2: Antiinflammatory Activity

Ananti-inflammatory is a substance, similar as a medicine or a natural emulsion, that reduces or prevents inflammation, which is the body's response to injury or infection, characterized by greenishness, swelling, warmth, and pain. Habitual inflammation, which is caused by a variety of external and natural factors, is allowedtobe a crucial complaint middleman. Curcumin can reduce oxidative stress and inflammation by regulatingpro- seditious cytokines and signaling pathways, similar as NF- κB, PPAR- γ, and TLR4-MD2(39, 40, 41, 42). Pro-inflammatory cytokines similar as IL- 6, TNF- α, and IL- 1β are frequently overproduced during an seditious response. As a result, down regulating pro inflammatory cytokines may effectively reduce the prevalence of inflammation (43). Curcumin pre treatment on mortal genital epithelial cells inhibits glycoprotein 120-intermediated up regulation of pro-inflammatory cytokines TNF- α and IL- 6, as well as chemokines IL- 8, RANTES (regulated on activation, normal T cell expressed and buried), and interferon γ- convinced protein- 10(IP-10) (44). Likewise, the liposomal curcumin complex effectively reducespro-inflammatory cytokine and chemokine expression in synovial fibroblasts and macrophages while maintaining cell viability, indicating lower toxin than free curcumin (45). Curcumin- loaded solid lipid nanoparticles can lower serum situations ofpro-inflammatory cytokines, including IL- 6, TNF- α, and IL- 1β (39). Curcumin may inhibit the recap factor nuclear factor kappa B (NF- κB), which controls cyclooxygenase- 2 and inducible nitric oxide synthase and regulates cell proliferation (46). Theanti-inflammatory property of curcumin is also involved in other signaling pathways. Curcumin is also set up to Induce degranulation in mortal neutrophils by adding the cell face expression of cluster of isolation 35(CD35) (secretory vesicle), CD63 (azurophilic grains), and CD66b (gelatinase grains) (40).

Neuroprotective activity of curcumin

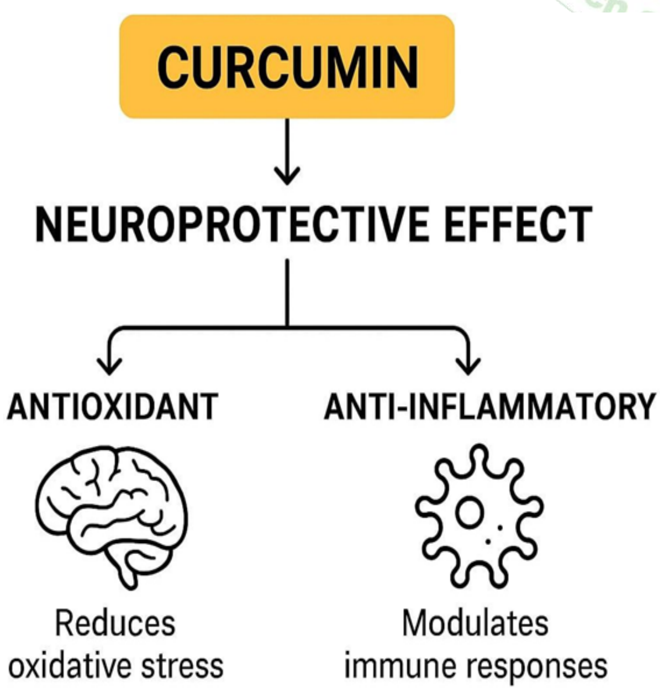

Figure 3: Neuroprotective Activity

Wound healing (47).chemopreventive, and anticancer properties (48, 49, 50). This review focuses on recent developments and the mechanisms that explain how curcumin has various effects on neurodegenerative diseases, especially Parkinson's disease. Curcumin's ability to impact multiple signal pathways has been linked to slower disease progression. Curcumin interacts with transcription factors like STAT proteins (51), growth factors and their receptors like epidermal growth factor receptors and HER2 (52, 53). cytokines like interleukin 1b (IL-1b) and interleukin 6 (IL-6), enzymes like hemeoxygenase (HO-1) (55). and genes that control cell growth and death (56).

Bioavailability and Formulation Strategies

Curcumin has low bioavailability in the human body at a daily dose of 12 g because of poor absorption in the small intestine, fast metabolism in the liver, and quick removal from the body (60). Even though microemulsions have smaller droplet sizes than nanoemulsions, both terms are still used (54).Nanoemulsions (NEs) have shown great promise in improving the way drugs are absorbed and their effectiveness in the body (57).Using medium-chain triglycerides as a carrier in emulsions has been shown to greatly improve curcumin's absorption (58).NE curcumin has been studied for its bioaccessibility, wound healing, antiarthritic, anti-inflammatory, antifungal, antiparasitic, quorum sensing, antineoplastic, and cardioprotective properties (58).Recent research has shown that the stability and bioaccessibility of curcumin in NEs are affected by the type, category, and amount of emulsifier used (67). Also, the interaction between the emulsifier and curcumin plays a big role in how well curcumin is delivered by NEs (68).High-pressure homogenization, Solutol-HS 15, soybean oil, and antiarthritic activity have been studied.Curcumin NEs reduced NF-κB expression and inhibited the release of inflammatory factors like TNF-α and IL-1β. Nanoformulations given via intravenous or oral routes produced similar therapeutic effects in rheumatoid arthritis (59).

Toxicity of Curcumin

Both human and animal models have been used to study curcumin'stoxicity.Oral administration of curcumin has been found to be safe. In toxicity tests on rats, mice, guinea pigs, and monkeys, curcumin was safe even at high doses (61). Because turmeric is widely used in India as a spice and home remedy, consuming curcumin is considered safe. On average, a 60 kg Indian person consumes about 2-2.5 g of turmeric daily, which is about 60-100 mg of curcumin(62). In a study, healthy volunteers were given up to 12 g of curcumin daily, and no toxicity was seen (63, 64). However, some minor side effects, like headaches, diarrhea, and rashes, were reported but weren't related to the dose (63). Most colorectal cancer patients were able to tolerate a dose of 3.6 g daily, though some reported gastrointestinal side effects like diarrhea, which might be due to curcumin's effects. In phase II clinical trials, oral doses of 4 g and 8 g were well tolerated by patients with colorectal neoplasia and pancreatic cancer, respectively (66). Previous research found that curcumin has poor absorption and distribution, along with limited metabolism and bioavailability (69).

Medicinal Applications of Curcumin

Antibacterial activity

Improved antibacterial activity has been confirmed.Compared to PCH film, which is important for food packaging, natural curcumin-chitosan films may be useful for antimicrobial packaging in food and agricultural products (70). New fibrous materials made from cellulose acetate (CA) and curcumin can also be combined with polyvinylpyrrolidone (PVP). Using PVP increased the hydrophilicity of the fibers, leading to faster curcumin release (71). Made curcumin nanoparticles showed the best antimicrobial activity against Listeria monocytogenes (72).

Anticancer activity:

Curcumin's anticancer effects are mainly due to its ability to stop cancer cell growth, promote cell death, and stop cancer spreading (73).A study on head and neck squamous cell carcinoma (HNSCC) cells found that short exposure to low concentrations of curcumin inhibits colony formation and cell growth (73). Also, in vivo treatment with curcumin at doses of 1000 and 1500 mg/kg reduced tumor growth by 21.03% and 35.57%, respectively, when compared with a group of nude mice implanted with cervical carcinoma (74).

Antimicrobial activity:

Curcumin is effective against both gram-positive and gram-negative bacteria, but its minimal inhibitory concentration (MIC) of 100-500 µg/mL may limit its use in the body (75). Its antimicrobial effects could be useful for topical applications, like treating skin infections, and for oral and intestinal conditions where higher levels can be achieved with fewer side effects. Tetrahydrocurcumin (THC), a curcumin metabolite that doesn't change color, might be better for topical use (76, 77).

CONCLUSION

Curcumin, the principal bioactive compound of Curcuma longa, has emerged as a multifunctional therapeutic molecule with remarkable antioxidant, anti-inflammatory, antimicrobial, neuroprotective, and anticancer properties. Its pharmacological actions are mediated through the modulation of diverse molecular targets and signaling pathways, highlighting its potential in the prevention and management of chronic and degenerative diseases. Despite its limited bioavailability, recent advances in formulation strategies—such as nanoemulsions, liposomes, and polymeric nanoparticles—have significantly enhanced its solubility, stability, and therapeutic efficacy. Extensive preclinical and clinical data support curcumin's safety profile, underscoring its potential as a bridge between traditional herbal remedies and modern pharmacotherapy. Continued research focusing on novel delivery systems and clinical validation could establish curcumin as a cornerstone compound in evidence-based complementary medicine.

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