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RHIZOME TO REMEDY: TURMERIC NUTRITIONAL COMPOSITION, VALUE ADDITION, PROCESSING AND HEALTH BENEFITS

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ABSTRACT

Turmeric (*Curcuma longa* L.) has gained global attention as a functional food and immune-modulatory agent, particularly during the COVID-19 pandemic. This review comprehensively summarizes the nutritional composition, phytochemical profile, processing effects, value-added applications, storage stability, and preclinical therapeutic evidence of turmeric. Proximate analyses reveal considerable variability in moisture, protein, fiber, ash, carbohydrate and mineral contents depending on genotype, geographical origin, and processing methods. Curcumin, the principal bioactive compound, along with other curcuminoids and essential oils, contributes significantly to turmeric's antioxidant, anti-inflammatory, antimicrobial, and anticancer properties. Advanced analytical techniques such as HPLC have enabled precise quantification of curcuminoids, while studies demonstrate that drying methods, blanching, microwave treatment, and fermentation markedly influence curcumin retention and antioxidant capacity. Freeze drying has been identified as the most effective technique for preserving bioactive compounds. Turmeric has been successfully incorporated into soups, beverages, dairy products, candies, lozenges, and nutraceutical formulations with favorable sensory acceptance. Storage studies indicate improved shelf stability under refrigerated and appropriate packaging conditions. Preclinical studies in rats and mice confirm hepatoprotective, neuroprotective, anti-arthritic, and anticancer effects, including mitigation of lead-induced toxicity. Collectively, the evidence supports turmeric's substantial potential as a functional ingredient and therapeutic adjunct in health promotion and disease prevention.
Keywords **:** Curcumin, anti-inflammatory, antimicrobial, antioxidant and anticancer properties.

Introduction

India dominates the global turmeric sector as the largest producer, consumer, and exporter, accounting for nearly 75% of total world production. In 2022–23, turmeric cultivation covered approximately 3.24 lakh hectares, yielding about 11.61 lakh tonnes. The country grows over 30 turmeric varieties across more than 20 states, with Maharashtra, Telangana, Karnataka, and Tamil Nadu being the producing regions.

India also holds over 62% of the global turmeric trade. During 2022–23, more than 380 exporters shipped around 1.534 lakh tonnes of turmeric and its products, valued at 207.45 million USD. Key export destinations include Bangladesh, the UAE, the USA, and Malaysia. With continued strategic initiatives, turmeric exports from India are projected to reach USD 1 billion by 2030.

Turmeric (*Curcuma longa* L.), belonging to the family Zingiberaceae, originated in Southeast Asia and is cultivated for its aromatic rhizomes, which are rich in curcumin, the principal bioactive compound responsible for its characteristic yellow colour. The crop thrives in tropical climates with temperatures ranging from 20–30°C, annual rainfall above 1500 mm, and well-drained loamy soils with a pH of 4.5–7.5. Nutritionally, 100 g of turmeric powder provides about 390 kcal of energy, 69.9 g carbohydrates, 21 g dietary fibre, 8 g protein, 10 g fat, and substantial minerals including potassium and iron. Fresh rhizomes contain high moisture (about 84.25%) and appreciable micronutrients. Composition varies among genotypes, necessitating nutrient profiling to identify elite varieties with superior antioxidant potential.

Turmeric contains curcuminoids, sesquiterpenoids, and volatile oils, contributing to antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, and anticancer properties. Traditionally used in Ayurveda, turmeric aids in digestion, wound healing, bile secretion, and immune enhancement. Curcumin has shown efficacy against arthritis, UV-induced damage, and several skin disorders. However its oral bioavailability is limited, though it improves significantly when consumed with spices such as black pepper and cumin.

Following the COVID-19 pandemic, demand for immunity-enhancing products has increased significantly. While turmeric powder is widely used in culinary preparations, fresh turmeric remains underutilized despite its higher antioxidant potential. Thus, the development and promotion of convenient, value-added raw turmeric products can provide both nutritional and therapeutic advantages, especially for consumers leading fast-paced, modern lifestyles.

Nutritional composition

Ikpeama *et al*. (2014) reported that turmeric contained 8.92% moisture, 2.85% ash, 9.42% protein, 4.60% fiber, and 6.85% fat, and its extracts exhibited antimicrobial activity with inhibition zones ranging from 7 to 20 mm, comparable to those of standard antibiotics. Similarly, Imoru *et al*. (2018) found that turmeric rhizome powder contained 10.07% protein, 66.76% carbohydrates, 4.87% fiber, and minerals such as Ca (1.67 mg/g), Mg (0.92 mg/g), K (1.29 mg/g), P (1.07 mg/g), and S (0.73 mg/g), along with trace amounts of Cu, Se, and Fe. Supporting these findings, Fattepurkar *et al*. (2009) reported that *Curcuma aromatica* and *C. longa* rhizomes showed moisture, ash, protein, fat, fiber, and carbohydrate ranges of 7.01–7.91%, 4.34–5.07%, 4.05–7.09%, 2.66–4.46%, 2.09–3.67%, and 73.47–78.31%, respectively, noting that genotype CA 62/1 exhibited the highest acid value (4.72%), whereas genotype Salem recorded the highest curcumin content (3.43%). Further, Majeed *et al*. (2015) observed that turmeric powder contained 2.49% curcumin, 36% carbohydrates, 7.74% protein, 23.28% fiber, 8.69% ash, and 1.24% nitrogen, along with significant mineral levels including potassium (5532.5 μg/g), magnesium (715 μg/g), sodium (194.5 μg/g), iron (185 μg/g), calcium (104.25 μg/g), manganese (30 μg/g), zinc (6.25 μg/g), lead (10 μg/g), and cadmium (2.75 μg/g). In addition, Ahaotu and Lawal (2019) reported that turmeric rhizome powder contained 76.02% moisture, 16.37% carbohydrates, 3.04% ash, 1.95% fiber, 1.83% protein, and 0.80% fat, with minerals present in the order iron (0.57%) > potassium (0.42%) > magnesium (0.05%) > phosphorus (0.03%) > calcium (0.02%) > sodium (0.01%). Consistent with this, Mane *et al*. (2018) found that fresh turmeric rhizomes contained 84.25% moisture, 9.10% carbohydrates, 1.20% protein, 1.08% fat, 5.1% curcumin, 0.66% ash, 0.72% fiber, and 0.70% acidity at pH 5.7, with zinc (22.9 mg/100 g) as the most abundant mineral, followed by calcium (8.2 mg/100 g) and iron (2.3 mg/100 g). Similarly, Asagwara *et al*. (2018) reported that *Curcuma longa* leaves and rhizomes contained 76.02% moisture, 16.37% carbohydrates, 3.04% ash, 1.95% fiber, 1.83% protein, and 0.80% fat, with minerals ranked as potassium (0.42%) > magnesium (0.05%) > phosphorus (0.03%) > calcium (0.02%) > sodium (0.01%).

Wichitnithad *et al*. (2009) used HPLC to quantify turmeric curcuminoids, reporting detection and quantification limits of 0.90/2.73 mg/mL for curcumin, 0.84/2.53 mg/mL for desmethoxycurcumin, and 0.08/0.23 mg/mL for bisdemethoxycurcumin, with high recovery rates (≈99–102%) and low RSD values (≤1.74%). In support of turmeric's processing-related variations, Bambirra *et al*. (2002) found that removing the peel resulted in a 30% mass loss but produced more intensely colored powder, while cooking reduced dehydration time and yielded powder with lower moisture and higher curcuminoid content and color values (L*, a*, b*). Likewise, Tayyem *et al*. (2006) observed that pure turmeric powder contained the highest curcumin content (≈3.14% by weight), whereas curry powders had much lower levels. Singh *et al*. (2010) further demonstrated that drying turmeric significantly reduced major volatile compounds, with α-turmerone decreasing from 20.5% in fresh rhizomes to 6.5% in dried ones, and β-turmerone dropping to less than half, and also noted that essential oil and ethanol oleoresin from fresh rhizomes showed stronger antioxidant activity than those from dried samples. Expanding on chemical characterization, Li *et al*. (2011) identified over 235 compounds in turmeric, predominantly phenolics and terpenoids, with curcuminoids and essential oils recognized as the primary bioactive constituents in both *in-vitro* and *in-vivo* evaluations.

Comparative studies revealed turmeric's relative antioxidant potential among spices; for instance, Maizura *et al*. (2011) found that kesum exhibited the highest phenolic content (165.34 mg GAE/100 g) and antioxidant activity (82.6% DPPH), followed by ginger (101.56 mg GAE/100 g; 79%) and turmeric (67.89 mg GAE/100 g; 64.6%). Similarly, Ajayi *et al*. (2013) reported notable compositional differences between white and yellow ginger varieties, including crude fibre (21.90 vs. 8.30%), fat (17.11 vs. 9.89%), carbohydrate (39.70 vs. 58.21%), protein (12.05 vs. 11.65%), ash (4.95 vs. 7.45%), and moisture (3.95 vs. 4.63%), with potassium being the most abundant mineral (0.98–1.38 ppm) and copper the least (0.01 ppm). Consistent with the influence of processing on curcumin extraction, Panigoro and Dhianawaty (2013) found that homemade jamu prepared from 20 g fresh turmeric contained 30.35 mg curcumin, whereas a decoction from 3.98 g dried rhizome contained 25.5 mg. Moreover, Sharma *et al*. (2013) reported that *Curcuma longa* grown in Agra, Mathura, and Aligarh demonstrated favorable nutritional, vitamin, and amino acid profiles, supporting its potential use in combating malnutrition.

Location-dependent variability in curcumin content was confirmed by Pawar *et al*. (2014), who found turmeric from Bhandara had the highest curcumin level (4.32%) and that from Dhule the lowest (2.85%), while Geethanjali *et al*. (2016) reported the highest curcumin content (2.35%) in samples from Odisha and Andhra Pradesh, and the lowest in Kerala (0.12%). Kumar *et al*. (2016) additionally reported that *Curcuma longa* flowers contained 3.87 µg/g curcumin, exhibited strong antioxidant activity (IC50 3.2 µg/mL), and had high phenolic content (210.45 mg GAE/100 g). Regional differences were further confirmed by Paul *et al*. (2016), who showed that hydroalcoholic extracts from Arunachal Pradesh had the highest curcumin concentration (34.78 µg/mL), while methanolic extracts from Shillong reached 333.45 µg/mL, and Priyanka *et al*. (2017) noted that among eight turmeric cultivars, Prathibha showed the highest antioxidant activity (59.58), whereas Sudharshana exhibited the lowest (49.63). Shibru *et al*. (2017) also demonstrated that boiling temperature, duration, and rhizome type significantly influenced turmeric's dry matter, protein, fiber, and color characteristics, with notable treatment interactions.

Furthermore, Tanvir *et al*. (2017) reported that turmeric from Chittagong's mura possessed the highest polyphenol (16.07%), flavonoid (9.66%), and ascorbic acid (0.09 mg/100 g) contents, while Khulna's mura showed the strongest DPPH activity (IC50 1.08 µg/mL) and Khulna's chora the highest FRAP value (4204.46 µM Fe[II]/100 g). Similarly, Vishwavidyalaya *et al*. (2017) recorded the highest antioxidant potential for *Curcuma* rhizomes from Sarguja district. Madushanka *et al*. (2018) found that Sri Lankan and Indian turmeric rhizomes contained curcumin levels ranging from 3.76% (Local III) to 5.05% (Local II), with higher curcumin associated with bright yellow coloration. Mittal *et al*. (2018) observed that fresh rhizomes possessed greater phenolics (0.742 mg TAE/g), flavonoids (5.58 mg AAE/g), and antioxidant activity than dried or powdered forms, and Shashidhar *et al*. (2018) reported curcumin levels were highest in genotype Prathibha (4.73%) in northern Karnataka, with Suroma at 4.58% and CLI-327 the lowest at 2.08%.

Choudhury (2019) noted that a local Assam variety contained 3.00% curcumin and a favorable proximate composition, while Kotra *et al*. (2019) emphasized that spectrophotometry was inadequate for resolving individual curcuminoids, confirming HPLC as the preferred analytical method. Lepcha (2019) showed that microwave-treated rhizomes with 0.1% $NaHCO_3$ for 6 min (T5) produced turmeric powder with the highest color parameters (L 58.94, a 26.74, b 57.68), curcumin content (5.20%), and essential oil (4.38%), whereas uncured samples (T1) produced the lowest. Complementing this, Luiram *et al*. (2019) reported that among 32 northeast Indian genotypes, TAS-9 had the highest curcumin level (6.51%), while TAS-3 showed the lowest (1.72%), and Mushtaq *et al*. (2019) found that combined turmeric-ginger powder exhibited higher antioxidant activity (DPPH 80.16%), free radical scavenging capacity (47.67 mg/100 g), total phenolics (103.39 mg GAE/g), and flavonoids (4.27 mg CE/100 g) than either spice alone. Sun *et al*. (2019) demonstrated that cooking reduced curcuminoid antioxidant activity, with boiled curcuminoids retaining more potency than roasted, and fried showing the least.

More recently, Praneetha and Sivakumar (2020) reported that among 148 turmeric accessions, CL 206 exhibited the highest curcumin (5.12%) and BS 122 the lowest (4.02%), while Shi (2020) identified and recommended specific varieties for optimal rhizome yield, curcumin concentration, and curcumin yield efficiency. Tamuno (2020) concluded that blanching followed by oven drying best preserved turmeric nutrients, whereas cooking followed by oven drying most enhanced its functional properties, and Vidal-Casanella *et al*. (2020) demonstrated that polyphenolic and curcuminoid fingerprints can differentiate turmeric types and spice adulteration. In addition, Gaur *et al*. (2021) reported that among ten genotypes in Jammu, Rajendra Sonia contained the highest curcumin (6.63%) and Sugandham the lowest (3.43%), and Kela *et al*. (2021) found that ginger ethanolic extract contained higher levels of bioactive compounds than aqueous extract. Magar *et al*. (2021) identified Lachin as having the highest curcumin (8.9%) and Yaimu the lowest (0.26%) among northeast Indian accessions, and Permatananda *et al*. (2021) characterized traditionally processed Balinese turmeric extract as rich in starch (67.38%), protein (3.42%), flavonoids (2709.39 mg/100 g), tannins (291.64 mg/100 g), phenols (1584.04 mg/100 g), and vitamin C (0.06 mg/100 g). Finally, Dudekula *et al*. (2022) reported wide variability in Indian turmeric germplasm, with total curcuminoids ranging from 1.2% to 4.55%, and Korese *et al*. (2022) determined that pre-treating rhizomes with ascorbic acid prior to hot-air drying at 60°C preserved the best color, vitamin C, and β-carotene content.

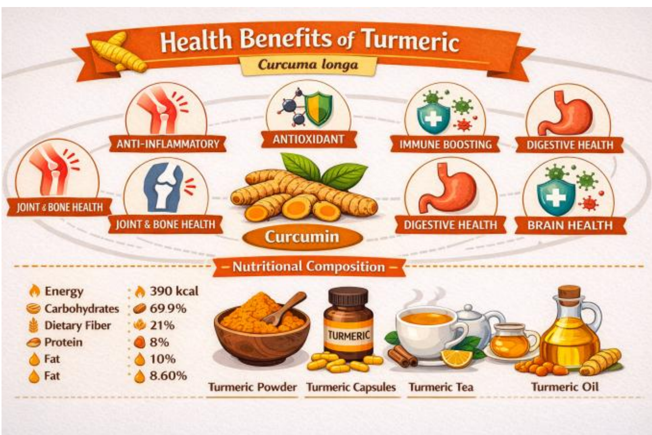

Fig. 1 : Health Benefits of Turmeric

Value added products and sensory evaluation

Owing to the numerous therapeutic and functional properties of turmeric, several value-added products have been developed that are rich in antioxidant activity and aid in the treatment of coughs, colds, and sore throats. Pawar *et al*. (2017) standardized turmeric soup preparation and found that the 20% turmeric pulp formulation (S2) was the most acceptable, containing 0.65% curcumin. Similarly, Chauhan *et al*. (2018) developed turmeric chutney using 5%, 10%, and 15% fresh turmeric and reported that the 5% variant was most preferred by consumers. Complementing these developments, Rudyatmi *et al*. (2018) observed that the first turmeric-tamarind drink exhibited higher microbial counts but demonstrated stronger inhibition against *B. subtilis* and *E. coli*, and was preferred by most sensory panelists over the second formulation. In addition, De *et al*. (2019) reported that turmeric black tea was safe up to 10 g/kg body weight with no mortality or hepato-renal toxicity, while showing potential in reducing hypertension and supporting neuroprotection in animal models.

Further advancements in functional food applications were noted by Yong *et al*. (2019), who found that fermenting turmeric with *Lactobacillus fermentum* increased curcumin levels by 9.76%, remained non-cytotoxic, and enhanced anti-inflammatory activity via JNK pathway suppression, in contrast to unfermented turmeric. Supporting the probiotic potential of turmeric-based products, Sharma *et al*. (2021) identified *Enterococcus durans* TP2 isolated from traditional turmeric pickle as a promising candidate due to its antioxidant activity, sodium nitrite depletion, cholesterol reduction ability, and antibiotic susceptibility. In dairy applications, Martina *et al*. (2020) reported that stirred yogurt containing 5% turmeric extract (YTBF1, 95:5) was the most preferred formulation, whereas higher levels (>10%) resulted in excessively intense color and spiciness, which were disliked by panelists.

Technological innovations have also been pursued; Hettiarachchi *et al*. (2021) successfully synthesized curcumin nanoparticles averaging 82 ± 0.4 nm and confirmed their functional groups through FTIR analysis. Likewise, Ogori *et al*. (2021) demonstrated that increasing turmeric and decreasing pineapple in ginger-pineapple-turmeric juice blends increased Ca, Mg, vitamin C, and β-carotene contents, although sensory acceptability remained dependent on appearance, taste, aroma, and mouthfeel. Moreover, Pawar and Chavan (2021) found that steam blanching best preserved curcumin content in turmeric candy, while alum-treated candy (TA) achieved the highest scores in overall sensory quality. Deepthi *et al*. (2022) also reported that turmeric-jaggery lozenges formulated with 3 g turmeric, 2 g pepper, 70° Brix jaggery, and 5 mL lemon juice received the highest consumer preference. Finally, Giri *et al*. (2022) developed golden A2 milk enriched with turmeric and soy, reporting a composition of 76.9% moisture, 2.57% protein, 5.5% fat, 9.57% carbohydrates, 0.74% ash, 3.7% crude fiber, and 1.83% curcumin, further highlighting turmeric's potential for functional food innovation.

Yee and Hamzah (2012) found that pumpkin Javanese noodle gravy powder exhibited low water absorption (WAI 2.0–3.0 g/g) and moderate solubility (WSI 33–50%), with carbohydrate levels increasing and fat content decreasing upon the addition of tapioca and corn flour. Building on research related to plant-based food products, Ahammed *et al*. (2014) reported that fresh ginger contained 87.4% moisture, 1.6% protein, 0.8% fat, 1.0% ash, and 4 mg/100 g vitamin C, and evaluated its storage stability over four months at 25°C. Similarly, Pingale and Dabhade (2015) developed pickles from bitter gourd and bottle gourd in different ratios, finding that sample C (bitter:gourd 60:40 g) was most acceptable, receiving an overall score of 9. In the confectionery segment, Akib *et al*. (2016) formulated herbal hard candies with red ginger extract, determining that 1% extract (formula A) provided the best color, aroma, flavor, and texture.

Further exploring ginger-based products, Chorage *et al*. (2018) found that shrikhand prepared with 5% ginger juice was most acceptable, containing 59.18% total solids, 6.93% fat, 7.19% protein, 0.51% ash, and 1.27% titratable acidity, while Gabbi *et al*. (2018) reported that ice cream containing 6% ginger juice, 4% ginger paste, 10% ginger candy, and 1% ginger powder achieved the highest overall acceptability. In the convenience food category, Malik *et al*. (2018) developed a ready-to-cook curry using 8, 10, and 12 g Maggie bhuna masala, concluding that sample B (10 g) was most preferred, with 9% moisture, 0.09% fat, and 1.4% ash. Complementing this, Malik and Kajla (2018) developed another ready-to-cook curry from dried vegetables, demonstrating that blanched curry had superior nutritional quality, rehydration characteristics, nutrient retention, and color compared to boiled curry; the standardized formulation utilized 25 g dried vegetables, 10 g gravy mix, and 200 ml water, prepared within 5 minutes in a pressure cooker.

Continuing with dehydration-based products, Malik *et al*. (2018) formulated a ready-to-cook curry consisting of 50 g dried vegetables (carrot, cauliflower, and green beans 8.64 g each; potato and peas 12 g each), 32 g Maggie bhuna masala, and 320 ml water, ready in approximately 7 minutes in a pressure cooker. Subsequently, Malik *et al*. (2020) standardized another version using 25 g dried vegetables, 10 g gravy mix, and 200 ml water per serving, prepared within ~5 minutes. In addition, Prasoona *et al*. (2020) developed instant chutney powder and identified CVCP1, a combination of cabbage, basella, and spinach (1:1:1), as the most suitable vegetable formulation.

Drying methods

Chumroenphat *et al*. (2021) reported that curcumin loss was highest during sun drying (72%), followed by hot-air drying (61%) and freeze drying (55%), establishing freeze drying as the most suitable method for turmeric. In agreement with the benefits of advanced drying techniques, Inchuen *et al*. (2010) found that although different drying methods did not alter the chemical composition of Thai red curry powder, microwave drying produced a darker color and resulted in higher phenolic content and antioxidant activity compared to hot-air drying. Similarly, Chaloeichitratham *et al*. (2018) demonstrated that freeze-dried Thai green curry powder exhibited lower moisture, water activity, colour values, bulk density, and browning than hot-air dried samples, while hot-air drying at 70°C maintained total phenolic content comparable to freeze drying. Complementing these findings, Kamali *et al*. (2019) showed that hot-air oven drying was most effective in preserving the nutritional composition of coriander leaves, including protein, crude fiber, fat, and ash.

Storage and shelf life studies of value added products

Mane *et al*. (2019) reported that a turmeric–orange RTS beverage (90:10) could be safely stored under refrigeration for 90 days while maintaining desirable sensory attributes. In support of the importance of appropriate storage conditions, Rahman *et al*. (2019) found that home-made fortified turmeric gel (F2) remained safe for 21 days, whereas formulation F3 had a shelf life of only 2 days under normal conditions. Similarly, Siddiqui *et al*. (2012) identified ginger preserve (70% sugar) and candy (75% sugar) as optimal formulations, noting that ginger candy exhibited longer storage stability of 90 days compared to 60 days for the preserve. Extended storage potential was further demonstrated by Devi *et al*. (2016), who concluded that ginger paste could be safely stored in metalized polypropylene pouches at 5°C for up to 120 days without significant deterioration in colour, safety, or nutritional quality. In addition, Malik *et al*. (2020) observed that ready-to-cook gravy powder remained microbiologically acceptable for up to four months when packed in LDPE pouches under normal atmospheric storage. Complementing these findings, Paudel (2022) reported that beetroot–ginger RTS drinks retained quality more effectively under refrigeration than at room temperature, with glass bottles providing the highest protection against chemical degradation.

Clinical trials in rats and mice

Huang *et al*. (1994) demonstrated that dietary curcumin significantly reduced tumor incidence, number, and size in the mouse fore-stomach, duodenum, and colon, with histopathological analysis confirming decreases in both benign and malignant lesions. Supporting its therapeutic potential, El-Ashmawy *et al*. (2006) reported that turmeric and myrrh effectively reduced lead-induced oxidative liver damage and genotoxicity in mice, noting that 5% powdered turmeric provided the strongest protective effect, despite reduced GSH levels across treated groups. Similarly, Salama *et al*. (2013) found that

Curcuma longa ethanolic extract protected rats against thioacetamide-induced liver cirrhosis, lowering histopathological, immuno-histochemical, and biochemical markers while promoting apoptosis, suppressing hepatocyte proliferation, and showing no effect on CYP2E1 levels. Further extending evidence for the therapeutic value of curcumin, Da Costa *et al*. (2019) reviewed 32 studies and concluded that curcumin supplementation reverses neurotoxic and behavioural impairments in both *in vivo* and *in vitro* Alzheimer's disease models. Additionally, Hemshekhar *et al*. (2021) demonstrated that curcumin reduced arthritis severity by approximately 60% in a collagen-induced arthritis (CIA) murine model, while combining curcumin with a diet enriched in vitamin D3 and omega-3 fatty acids decreased severity by more than 80% and delayed both disease onset and progression.

Alwaleedi (2016a) found that 12-week exposure to lead acetate in mice significantly reduced total erythrocyte count, packed cell volume, hemoglobin, mean corpuscular volume, mean corpuscular hemoglobin, and mean corpuscular hemoglobin concentrationwhile increasing total leukocyte count and platelet counts. In a related study, Alwaleedi (2016b) reported that 12-week exposure to sublethal doses of lead acetate (0.4–1.2 mg/kg) caused marked reductions in body weight, ranging from 80–71% in males and 82–70% in females compared to controls. Similarly, Mailafiya *et al*. (2020) observed that four weeks of oral lead exposure (50 mg/kg) in rats resulted in significant decreases in TEC, Hb, PCV, MCV, MCH, and MCHC, accompanied by increased platelet volume. Complementing these hematological findings, Zou *et al*. (2020) demonstrated that 12-week exposure to 300 mg/L lead in drinking water caused marked increases in Alanine aminotransferase (ALT) and aspartate aminotransferase (AST), indicating liver impairment. Supporting this, Amin *et al*. (2021) reported that intraperitoneal administration of lead acetate (25 mg/kg) elevated liver enzymes (GGT, AST, ALT, ALP) and reduced total protein and albumin levels in rats, confirming hepatotoxic effects. Further, turmeric offers numerous health benefits. Additional benefits of the powder/rhizome, apart from those mentioned above, are summarized in Table 1.

Table 1: Health benefits of turmeric powder/rhizome

S.No.	Particulars	Function	Subjects used	Reference
1	Tannins in turmeric	Antimicrobial activity	-	Scalbert (1991)
2	Turmeric	Anticancerous	Rats and mice	National Toxicology Program (1993)
3	Curcumin	Antioxidant activity	-	Bandyopadhyay *et al*. (1999)
4	Curcumin	Induce apoptosis among leukaemia B lymphoma cells and inhibits the multiplication of leukaemia cells	Humans	Hsieh (2001)
5	Turmeric	Cardio protection	Rats	Mohanty *et al*. (2006)
6	Steroids in turmeric	Sex hormone	-	Okwu and Josiah (2006)
7	Iron in turmeric	Haemoglobin formation	-	Okwu and Josiah (2006)
8	Potassium and calcium in turmeric	Improve bone mineralization and reduces bone resorption	Humans	Kubinarawa *et al*. (2007)
9	Curcumin	Increase absorption	Humans	Antony *et al*. (2008)
10	Curcumin	Increased antitumor activity in breast cancer patients	Humans	Bayet-Robert *et al*. (2010)
11	Curcumin	Decrease joint pain in Osteoarthritis patients	Humans	Belcaro *et al*. (2010)
12	Turmeric	Remedy for *Diabetes Mellitus*	Humans	Wickenberg *et al*. (2010)
13	Fibre in turmeric	Guard against metabolic conditions such as hypercholesterdemic and *Diabetes mellitus*	-	Bamishaiye *et al.* (2011)
14	Curcumin powder	Increased bioavailability	Humans	Sasaki *et al*. (2011)
15	Turmeric	Protective effects on human intestine and inhibits ulcer formation	Humans	Khajehdehi (2012)
16	Fermented turmeric powder	Hepatoprotective effects on live function in subjects with elevated alanine transaminase levels	Humans	Kim *et al*. (2013)
17	Curcumin	Hepatoprotective effects Hepatic detoxification	Rats	Salama *et al*. (2013)
18	Turmeric	Antimicrobial acitivity	Turmeric plant extract	Ikpeama (2014)
19	Curcumin	Anti-inflammatory, antioxidant, antimalarial, anticancerous and	Humans	Panahi *et al*. (2014)

		immunoenhancer against life threatening viral diseases		
20	Curcumin	Alleviate the symptoms of Joint Arthritis	Humans	Daily *et al*. (2016)
21	Curcumin	Decreased microbial biofilm, microbial viability in dental caries patients	Humans	Panhoca *et al*. (2016)
22	Nanocurcumin	Decreased frequency of headache attack in migraine patients	Humans	Abdolahi *et al*. (2017)
23	Curcumin	Decreased depressive and anxiolytic symptoms	Humans	Lopresti and Drummond (2017)
24	Curcumin	Therapeutic effects in inflammatory and immune-mediated diseases	-	Abdollahi *et al*. (2018)
25	Turmeric residue	Increased survival rate of Chinese soft-shelled turtles	Turtles	Chen *et al*. (2018)
26	Turmeric	Prevent the deleterious processes involved in neurogenerative diseases like Alzheimer's disease	Rats, mice and humans	Da Costa *et al*. (2019)
27	Bioavailable curcumin	Decrease endoscopic disease severity of Crohn's disease in patients	Humans	Sugimoto *et al*. (2020)
28	Curcumin	Treatment of skin diseases	Rats and humans	Vollono *et al*. (2019)
29	Combination of bioavailable Curcumin + Vit D_3 + O3FA	Delays the development and severity of collagen induced arthritis	Mice	Hemshekhar *et al*. (2021)
30	Nanocurcumin	Decreased symptoms, O_2 saturation, recovery in COVID-19 patients	Humans	Saber‐Moghaddam *et al*. (2021)
31	Curcumin + piperine	Decreased weakness, dry cough, sore throat in COVID-19 patients	Humans	Askari *et al*. (2022)
32	Nanocurcumin	Decreased inflammation in Rheumatic arthritis patients	Humans	Nivetha *et al*. (2022)
33	Turmeric and curcumin	Prevention and treatment of chronic diseases	Humans	Kunnumakkara *et al*. (2023)

Conclusion

Turmeric exhibits substantial variability in nutritional composition, curcuminoid content, and antioxidant activity based on genotype, processing, and geographical origin. Advanced processing methods such as freeze drying, fermentation, and nanoparticle synthesis enhance bioavailability and functional properties. Extensive preclinical evidence supports its antioxidant, hepatoprotective, anti-inflammatory, and anticancer potential, reinforcing turmeric's importance as a functional food ingredient and therapeutic agent.

Declaration of competing interest

The authors declare that no financial interests or personal relationships exist that may have impacted the work described in this article.

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