AUIQ Complementary Biological System
ISSN: 3007-973X
Journal homepage:
https://acbs.alayen.edu.iq

Volume 3 | Issue 2 Article 6

Bioactive Constituents and Pharmacological Activities of *Curcuma zedoaria*: A Mini-Review

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Recommended Citation
Allaq, Abdulmutalib; Alsayadi, Muneer M. Saleh Mohammed Saleh; Salihu, Mustapha; Agha, Hasan M.; Gheeth, Amena Hassan Hassan; Salim, Fatimah; and Sidik, Norrizah Jaafar Jaafar (2026), Bioactive Constituents and Pharmacological Activities of *Curcuma zedoaria*: A Mini-Review, *AUIQ Complementary Biological System*: Vol. 3: Iss. 2, 61-72.
DOI: https://doi.org/10.70176/3007-973X.1057
Available at: https://acbs.alayen.edu.iq/journal/vol3/iss2/6

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Cover Page Footnote

AUIQ COMPLEMENTARY BIOLOGICAL SYSTEM 3 (2026) 61–72

REVIEW

Bioactive Constituents and Pharmacological Activities of *Curcuma zedoaria*: A Mini-Review

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ABSTRACT

Curcuma zedoaria Rosc. (white turmeric) is a rhizomatous medicinal plant in the Zingiberaceae family, widely used in traditional Asian medicine. In recent years, increasing scientific attention has focused on its diverse pharmacological properties and bioactive constituents. This mini review summarises current knowledge of the phytochemical composition and biological activities of *C. zedoaria*, with particular emphasis on its antimicrobial, antioxidant, anti-inflammatory, and anticancer effects. Phytochemical investigations using analytical techniques such as GC–MS and HPLC have revealed the presence of numerous bioactive compounds, including sesquiterpenes (example, germacrone, curzerenone, and curdione) and curcuminoids, which contribute to its therapeutic potential. Experimental studies demonstrate that extracts and essential oils of *C. zedoaria* exhibit inhibitory effects against various bacterial pathogens, strong radical-scavenging capacity in multiple antioxidant assays, and notable anti-inflammatory activity in animal models. Furthermore, several studies report antiproliferative and apoptosis-inducing effects against different cancer cell lines. Despite these promising findings, limitations remain due to variations in extraction methods, insufficient mechanistic investigations, and the low bioavailability of certain phytochemicals. Therefore, further research focusing on standardised phytochemical characterisation, detailed mechanistic studies, and improved formulation strategies is required to support the development of *C. zedoaria*-derived therapeutic agents.

Keywords: *Curcuma zedoaria*, Phytochemistry, Antimicrobial activity, Antioxidant activity, Anticancer activity

1. Introduction

Curcuma zedoaria Rosc., known as white turmeric or zedoary, represents a therapeutically significant species within the Zingiberaceae family [1]. The genus *Curcuma* comprises nearly 120 species distributed throughout tropical and subtropical regions, including India, Southern China, Malaysia, Thailand, New Guinea, and northern Australia [2–4]. Among these taxa, *C. zedoaria* has been extensively studied for its established use in traditional medicine and its wide-ranging biological activities Fig. 1 [5, 6].

Indigenous to the Indian subcontinent, it maintains an important role in Asian medical traditions and is recognised by numerous vernacular names, underscoring its ethnobotanical value [7, 8]. Historical records indicate its introduction into Europe by Arab traders in the sixth century, facilitating its

Received 4 March 2026; accepted 10 April 2026.
Available online 29 April 2026

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https://doi.org/10.70176/3007-973X.1057

Fig. 1. *Curcuma zedoaria.*

dissemination across Asia and the Middle East [9, 10]. Its incorporation into Ayurveda, Traditional Chinese Medicine, and the Indonesian Jamu system further highlights its longstanding medicinal relevance [5, 11].

Plant-derived natural products remain central to pharmaceutical innovation due to their chemical diversity and broad biological activities [12]. These compounds contribute substantially to global drug revenues, emphasising their clinical and economic importance. Sustainable utilisation is therefore essential to prevent overexploitation and preserve ecological balance [13]. In addition to their therapeutic uses, Curcuma species are increasingly incorporated into functional foods due to their health-promoting properties [14]. Turmeric has been widely investigated for nutraceutical development and as a source of bioactive constituents with antioxidant, anti-inflammatory, antimicrobial, antiviral, antiulcer, and anticancer effects [15]. However, curcumin, the principal active compound, presents limitations including unfavorable pharmacokinetics, instability, and low bioavailability, which reduce its effectiveness in conventional delivery systems [16]. Collectively, these findings support the need for continued phytochemical and pharmacological investigations to advance the translational potential of *C. zedoaria*.

2. Vernacular names of *Curcuma zedoaria*

Curcuma zedoaria is known by a wide range of vernacular names, reflecting its broad geographical distribution and enduring cultural significance across diverse linguistic communities. Before discussing its ethnobotanical nomenclature, it is essential to consider its taxonomic synonyms, which have resulted from successive systematic revisions, regional floristic documentation, and evolving classification frameworks. The principal synonymous names, along with their respective taxonomic authorities and supporting references, are presented in Table 1.

Table 1. Vernacular Names of *Curcuma zedoaria* across Different Regions.

Language/Region	Vernacular Name	References
English	White turmeric, Zedoary	[17]
Hindi (India)	Kachur, Kachora	[18]
Malay/Indonesian	Kunyit putih, Temu putih	[19]
Vietnam	Nga truật	[20]
Chinese	莪术 (E Zhu)	[21]
Thai	Khamin oi	[22]
Philippines	Luya-luyahan	[23]
Bengali	Shothi, Kachura	[18]

3. Geographical distribution of *Curcuma zedoaria*

Curcuma zedoaria Rosc., widely known as white turmeric, is a perennial rhizomatous herb of the Zingiberaceae family [14]. The species originates from the Indian subcontinent, particularly India, Sri Lanka, and Bangladesh, and is further distributed throughout Southeast Asia, including Indonesia [24]. It is primarily associated with tropical climatic zones and has been reported from the Eastern Himalayan region and from the moist deciduous forests of Karnataka and Kerala, indicating adaptation to high rainfall and consistently warm conditions [25]. Historical documentation suggests that the species reached Europe during the sixth century via Arab trade routes, paralleling the transmission of Ayurvedic and Unani medical knowledge into Mediterranean and Middle Eastern traditions [26–28]. Since its introduction, the plant has been cultivated and naturalised in regions with favourable environmental conditions [29]. The species exhibits optimal growth under tropical and subtropical climates characterised by sustained warmth and humidity [30].

Sensitivity to low temperatures restricts its performance in temperate zones [31]. At present, its geographical range includes Bangladesh, Malaysia, China, India, Indonesia, Vietnam, and Japan, where climatic factors support vegetative growth and rhizome development [32]. Edaphic conditions significantly influence productivity, with a preference for well-drained, friable loamy or alluvial soils that promote healthy rhizome formation [33, 34]. In Bangladesh, the species is distributed from coastal areas to the northeastern uplands and occurs in the Gangetic floodplains and on elevated Pleistocene terraces, demonstrating adaptability to varied ecological settings [35]. Detailed information regarding its

Table 2. Geographical Distribution and Ecological Range of *Curcuma zedoaria*.

Region	Countries	Regional Status and Traditional Context	References
South Asia	India, Sri Lanka, Bangladesh, Nepal	Part of its native range; widely cultivated and integral to Ayurvedic and Siddha medical systems.	[11, 36]
Southeast Asia	Indonesia, Malaysia, Thailand, Vietnam	Prominent in Jamu and Thai traditional medicine; present in cultivated and semi-natural environments.	[37, 38]
East Asia	Southern China, Taiwan	Incorporated into Traditional Chinese Medicine as É zhú (莪术); primarily imported or grown under controlled cultivation.	[39, 40]
Oceania	Papua New Guinea, Northern Australia	Cultivated on a limited scale; occasionally used in indigenous healing practices.	[41, 42]
Middle East and Europe	Turkey, Mediterranean islands	Introduced through early trade networks, limited evidence of sustained medicinal integration.	[43]
Africa	Madagascar, Kenya, Tanzania	Spread via historical trade routes; maintained in botanical collections and small-scale cultivation systems.	[44, 45]
Americas	Brazil, Suriname, Caribbean islands	Preserved mainly in botanical gardens and research institutions; minimal commercial cultivation.	[46, 47]

Table 3. Taxonomic Classification of *Curcuma zedoaria*.

Classification	Taxonomic Name
Kingdom	Plantae
Phylum	Streptophyta
Class	Equisetopsida
Subclass	Magnoliidae
Order	Zingiberales
Family	Zingiberaceae
Genus	Curcuma

distribution and habitat characteristics is summarised in Table 2.

4. Taxonomic overview of *Curcuma zedoaria*

The classification of *C. zedoaria* has been established through integrated morphological assessments and molecular phylogenetic research. The resulting hierarchical framework, derived from previous botanical and phylogenetic studies, is systematically presented in Table 3.

5. Traditional uses of *Curcuma zedoaria*

Curcuma zedoaria is widely acknowledged as a prominent medicinal species within major Asian therapeutic traditions, including Ayurveda, Traditional Chinese Medicine (TCM), and the Indonesian Jamu system [48, 49]. Its sustained incorporation into these medical frameworks underscores its strong cultural relevance, grounded in accumulated empirical knowledge and long-standing traditional practice [50]. Experimental and clinical investigations have documented diverse biological activities, notably anti-inflammatory, gastroprotective, antimicrobial, and antineoplastic properties [51]. Historically, the species has been utilised in the management of gynaecological disorders, gastrointestinal dysfunctions, and dermatological conditions [52]. Rhizome-derived essential oil has traditionally functioned as a stomachic and emmenagogue, while leaf-based preparations, including poultices and expressed extracts, have been applied for leprosy, cutaneous infections, and lymphatic disorders [53]. In Southeast Asian medical systems, particularly in Indonesia and Thailand, *C. zedoaria* is valued for its anthelmintic efficacy and circulatory-enhancing effects [48, 54]. Beyond therapeutic applications, the species also contributes to culinary practices as a spice, flavouring component, and natural colourant [49]. Its relevance in women's health remains especially notable, with traditional indications including hematometra and leukorrhea [52]. Recent ethnopharmacological assessments further corroborate these traditional claims, demonstrating hepatoprotective capacity, cardiovascular modulation, and restorative benefits during the postpartum period [53, 55, 56]. A consolidated summary of these conventional applications is presented in Table 4.

6. Phytochemical composition and bioactive constituents of *Curcuma zedoaria*

Curcuma zedoaria (white turmeric) is recognised as a chemically complex species within the Zingiberaceae, characterised by a diverse assemblage of primary and secondary metabolites. Reported constituents include essential oils, starch, curcuminoids, polysaccharides such as arabin, gums, and multiple terpenoid derivatives that contribute to its biological activity as summarised in Table 5 [65, 66]. The volatile oil fraction has been the principal focus of phytochemical investigations due to its documented therapeutic relevance and increasing incorporation into modern phytopharmaceutical formulations [67–69].

Table 4. Traditional Medicinal Uses of *Curcuma zedoaria*.

Plant Material or Context	Traditional Application	References
Whole plant in classical medical systems	Incorporated into Ayurveda, Traditional Chinese Medicine, and Indonesian Jamu for multiple therapeutic indications	[48, 57, 58]
Rhizome	Management of menstrual disorders, digestive complaints, and wound healing	[52, 59, 60]
Rhizome essential oil	Administered as a gastric stimulant and menstruation-regulating agent	[53]
Leaf preparations	Applied externally for leprosy, skin infections, and lymphatic inflammation	[53]
Whole plant in Indonesian and Thai practice	Used for intestinal parasite expulsion and circulatory support	[48, 61]
Culinary context	Employed as a spice, seasoning, and natural food colorant	[60, 62]
Women's health	Indicated for hematometra and leukorrhea	[63]
Ethnopharmacological context	Reported for liver protection, cardiovascular regulation, and postpartum recovery support	[53, 56, 64]

Chromatographic and spectrometric analyses, including GC, HPLC, and GC–MS, have enabled detailed characterisation of its volatile constituents [2]. These studies consistently demonstrate the predominance of sesquiterpenes, monoterpenes, and oxygenated analogues, reflecting structural diversity across chemotypes and plant parts [70]. Chemical profiling of Malaysian rhizome oil identified camphor, zerumbone, curzerenone, isovelleral, α-turmerone, and β-eudesmol among the major constituents [71]. Variation between samples was evident, with differences in relative abundance of camphor, zerumbone, α-cuparenol, 1,8-cineole, and related terpenoids. Additional investigations reported epicurzerenone, arcurcumene, zingiberene, and β-sesquiphellandrene as dominant metabolites in rhizome extracts [72]. Broader volatile screening detected curzerenone, 1,8-cineole, germacrone, and camphor as principal components [73, 74], while integrated analytical approaches confirmed the presence of 1,8-cineole, o- and p-cymene, α-phellandrene, and terpinolene in substantial proportions [75]. Leaf-derived oil exhibits a distinct chemical profile, with eucalyptol, α-caryophyllene, 1-octen-3-ol, and β-elemene identified as the predominant constituents, along with minor aromatic and aliphatic compounds [76]. Complementary analyses revealed additional terpenoid derivatives, including α-terpinyl acetate, isoborneol, and dehydrocurdione [77].

Subsequent GC–MS assessments indicate pronounced chemotypic variability within the species. Certain rhizome samples showed elevated levels of curzerenone, germacrone, and camphor [2]. Examination of dried rhizome oil further identified epicurzerenone and curdione as the major constituents, along with azulenone derivatives [76]. Collectively, these findings emphasise substantial compositional heterogeneity, which may influence biological activity and therapeutic performance [78].

7. Biological activities of *Curcuma zedoaria*

Curcuma zedoaria Roxb. (white turmeric) is a medicinal species of the *Curcuma* genus widely used in traditional medicine and increasingly investigated for its pharmacological potential. Rhizome extracts contain diverse bioactive compounds, including polyphenols, flavonoids, terpenoids, sesquiterpenoids, and curcuminoids, which contribute to reported antibacterial, antioxidant, anti-inflammatory, and anticancer activities. Evidence supporting these effects arises from antibacterial assays, antioxidant tests such as DPPH, cytokine-related anti-inflammatory studies, and cytotoxicity evaluations in cancer cell lines and animal models. These findings are synthesized and critically discussed in this review, as illustrated in Fig. 2.

8. Antibacterial activities of *Curcuma zedoaria*

Several studies have consistently highlighted the remarkable antibacterial properties of *C. zedoaria*, demonstrating its effectiveness against a wide range of bacterial pathogens. Researchers have utilised various solvents to extract bioactive compounds from the rhizome and evaluated these extracts using different *in vitro* laboratory methods. The findings indicate potent antibacterial activity against both Gram-positive and Gram-negative bacteria. [65] assessed the antibacterial effects of rhizome extracts using agar diffusion and broth dilution techniques. Extracts prepared with chloroform, hexane, acetone, petroleum ether, and ethanol effectively inhibited six bacterial strains, underscoring the plant's broad-spectrum antibacterial potential [101–103]. Further supported these findings through agar diffusion assays, which demonstrated notable inhibitory effects

Table 5. List of reported activities for phytochemical constituents from *Curcuma zedoaria*.

S. No.	Compound Name	Chemical Formula	Reported Biological Activities	References
1	Germacrone	$C_{15}H_{20}O$	Antioxidant; antibacterial	[79]
2	Curzerene	$C_{15}H_{14}O_2$	Analgesic	[80]
3	1,8-Cineole	$C_{10}H_{18}O$	Antioxidant; antimicrobial	[81]
4	B-Caryophyllene	$C_{15}H_{24}$	Anticancer; cytotoxic	[82]
5	α-Curcumene	$C_{15}H_{24}$	Antioxidant	[83]
6	Germacrene D	$C_{15}H_{24}$	Cytotoxic	[84]
7	Xanthorrhizol	$C_{15}H_{22}O$	Anticancer	[85]
8	Camphor	$C_{10}H_{16}O$	Antimicrobial; analgesic	[86]
9	Curzerene	$C_{15}H_{24}O$	Antioxidant	[80]
10	Spathulenol	$C_{15}H_{24}O$	Antibacterial	[87]
11	Zerumbone	$C_{15}H_{22}O$	Anti-inflammatory	[88]
12	Curcumone	$C_{15}H_{22}O_2$	Hepatoprotective	[89]
13	Phytol	$C_{20}H_{40}O$	Antinociceptive	[90]
14	Eucalyptol	$C_{10}H_{18}O$	Anticancer	[91]
15	Bornyl acetate	$C_{12}H_{20}O_2$	Antioxidant	[92]
16	Carvacrol	$C_{10}H_{14}O$	Hepatoprotective	[93]
17	Thymol	$C_{10}H_{14}O$	Anti-inflammatory	[94]
18	Zingiberene	$C_{15}H_{24}$	Cytotoxic	[95]
19	ar-Turmerone	$C_{15}H_{20}O$	Larvicidal; anti-inflammatory	[96]
20	p-Cymene	$C_{10}H_{14}$	Antifungal	[97]
21	Furazadiene	$C_{15}H_{16}O_2$	Insecticidal; analgesic	[98]
22	Methyl eugenol	$C_{11}H_{14}O_2$	Antioxidant; antibacterial	[99]
23	α-Pinene	$C_{10}H_{16}$	Fungicidal	[100]

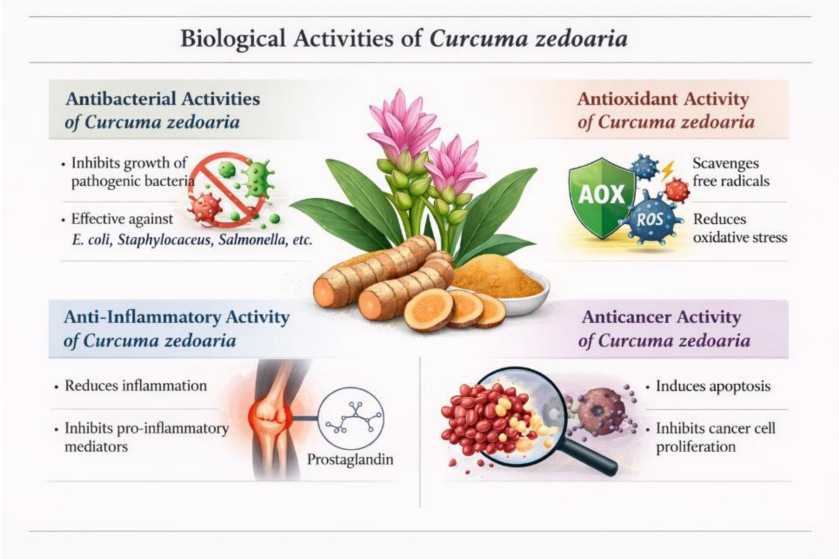

Fig. 2. Biological Activities of *Curcuma zedoaria*.

against Gram-positive bacteria, including Staphylococcus aureus and Bacillus subtilis, as well as Gram-negative species such as *Enterococcus faecalis*, *Escherichia coli*, and *Pseudomonas aeruginosa* [104].

Additional studies have reinforced the broad antibacterial activity of *C. zedoaria* extracts. Significant sensitivity was observed among Gram-positive bacteria, including *Bacillus subtilis*, *Bacillus cereus*, *Bacillus megaterium*, *Staphylococcus aureus*, and *Sarcina lutea* [76], [105]. Similarly, the extracts effectively inhibited Gram-negative organisms such as *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella paratyphi*, *Salmonella typhi*, *Vibrio parahaemolyticus*, *Vibrio mimicus*, and *Shigella* species [106–108].

Specifically, ethanolic extracts of *C. zedoaria* exhibited prominent antibacterial activity against *Bacillus cereus*, *Staphylococcus aureus*, *Sarcina lutea*, *Bacillus megaterium*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella typhi*, and *Shigella boydii* [109]. Corroborated these findings, demonstrating comparable effectiveness against both Gram-positive and Gram-negative bacteria using Mueller–Hinton agar.

Further research by [110] explored the antibacterial properties of chloroform, petroleum ether, and methanolic extracts through both laboratory and animal models. Agar well diffusion assays revealed consistent inhibition against *Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus cereus*, and *Staphylococcus aureus* [111]. Two active terpenoids, ketolactone and propanone, from the rhizomes of *C. zedoaria*, and confirmed their structures using nuclear magnetic resonance (NMR) spectroscopy. Disc diffusion assays demonstrated substantial antibacterial activity, with ketolactone showing significant inhibition against *Listeria monocytogenes* (24 mm) and *Staphylococcus pseudointermedius* (16 mm), while propanone exhibited notable inhibition against *Bacillus cereus* (18 mm at 100 μg/disc).

In addition, [112] investigated the clinical potential of *C. zedoaria* extracts as an alternative root canal irrigant. The antibacterial activity of various concentrations (100%, 50%, 25%, and 12.5%) was evaluated against *Streptococcus viridans*. The 100% concentration produced the largest inhibition zone; however, the 50% extract demonstrated antibacterial effectiveness comparable to 2% chlorhexidine, suggesting promising potential for clinical application in dentistry [113]. Germacrone and related sesquiterpenes are major bioactive constituents of *C. zedoaria* essential oil and exhibit various pharmacological activities, including potential antimicrobial effects [53]. Although most mechanistic studies focus on anticancer and antifungal properties, germacrone is consistently reported as a biologically active compound that may contribute to antibacterial activity, though direct mechanistic evidence remains limited [114]. Ethnopharmacological studies also identify curcuminoids and essential oils as key bioactive fractions exhibiting broad antimicrobial properties, supporting the therapeutic potential of *C. zedoaria* [115]. However, further studies are needed to clarify the specific antibacterial mechanisms of these phytochemicals [114].

9. Antioxidant activity of *Curcuma zedoaria*

The antioxidant potential of *C. zedoaria* (white turmeric) has been extensively explored through a wide range of *in vitro* redox-based and free radical scavenging assays, demonstrating substantial bioactivity across different plant parts and solvent extracts [116, 117] evaluated the essential oil derived from *C. zedoaria* rhizomes using DPPH, ABTS, and reducing power assays and observed significant radical scavenging activity. Similarly, [118] investigated leaf-derived essential oil and reported effective DPPH scavenging activity, further supporting the plant's antioxidant profile [119]. Significant antioxidant activity has been reported for rhizome extracts evaluated using DPPH and ferric-reducing antioxidant power (FRAP) assays [120]. Comparable antioxidant effects were observed in hydroethanolic extracts, with ascorbic acid employed as the reference standard [51]. A broader assessment incorporating multiple analytical systems, including DPPH, ABTS, hydrogen peroxide, nitric oxide, and superoxide radical scavenging assays, further confirmed the extensive antioxidant capacity of the extracts [121]. These observations were subsequently supported by [122], reinforcing the consistency and reproducibility of the reported antioxidant activity.

From a mechanistic perspective, [123] evaluated *C. zedoaria* extracts in lipopolysaccharide (LPS)-stimulated RAW 264.7 macrophage cells and observed significant inhibition of reactive species production. Additionally, the extracts downregulated key inflammatory mediators, including inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2), suggesting dual antioxidant and anti-inflammatory effects. Further supporting these findings, [124]employed the oxygen radical absorbance capacity (ORAC) assay and demonstrated strong antioxidant activity for most tested compounds derived from *C. zedoaria*, using quercetin as the reference compound. However, curcumin exhibited only moderate activity [125]. Moreove isolated specific phytochemicals from the rhizome and confirmed their antioxidant potential through DPPH scavenging and reducing power assays.

In a comparative study, [65]evaluated different solvent fractions ethyl acetate (EtOAc), methanol (MeOH), and n-hexane for antioxidant activity using the DPPH assay. The EtOAc and MeOH fractions exhibited strong activity, with IC_{50} values of 153.49 $\pm$ 2.66 ppm and 185.77 $\pm$ 3.91 ppm, respectively, whereas the n-hexane fraction showed significantly lower potency (IC_{50}: 837.92 $\pm$ 5.32 ppm) [126, 127]. The antioxidant mechanism was attributed to modulation of intracellular oxidative stress, potentially mimicking endogenous detoxification pathways involving superoxide dismutase (SOD) and glutathione-dependent redox systems [128, 129].

10. Anti-inflammatory activity of *Curcuma zedoaria*

The anti-inflammatory potential of *C. zedoaria* has been validated through multiple *in vivo* investigations involving crude extracts and isolated phytochemicals across diverse animal models. These findings

provide pharmacological support for its traditional use in the management of inflammatory disorders. The carrageenan-induced paw oedema model in rats, a standard method for assessing acute inflammation, has been widely applied to evaluate its efficacy. Ethanolic extracts significantly reduced paw swelling, demonstrating effects comparable to diclofenac sodium [128]. Petroleum ether and chloroform extracts also produced statistically significant reductions in inflammatory response ($P < 0.001$) [129]. Dose-dependent activity was observed at 200 mg/kg for petroleum ether extracts and 400 mg/kg for chloroform extracts, highlighting the influence of solvent polarity and dosage on pharmacological outcomes.

Quantitative assessments of oedema inhibition following 1% carrageenan administration consistently showed significant reductions compared with untreated controls [130]. Methanolic extracts produced effects comparable to those of the non-steroidal anti-inflammatory drug indomethacin in albino rats, further supporting their therapeutic relevance [129, 131].

However, efficacy appears to be model-dependent. While several studies reported significant activity [132, 133]. However, no significant reduction in inflammatory responses was detected in the adjuvant-induced arthritis model in mice [134]. These variations indicate that pharmacological responses may depend on administration route, extract composition, inflammatory stage, and model specificity [135, 136].

11. Anticancer activity of *Curcuma zedoaria*

The rhizome of *C. zedoaria* represents a rich reservoir of structurally diverse phytochemicals with recognised relevance in oncological research. Among its principal constituents are curcumin and related curcuminoids, together with sesquiterpenes such as curdione and curcumenone [136, 137]. These compounds have been associated with growth suppression and induction of apoptosis in experimental cancer models. Mechanistically, their activity is linked to modulation of cell death–regulating networks and stress-response signaling pathways, consistent with molecular patterns reported across the *Curcuma* genus [138].

Building on these biochemical insights, computational approaches have further clarified the molecular basis of anticancer potential. Molecular docking analyses combined with ADMET profiling demonstrate that curcumin, desmethoxycurcumin, and curcumadiol exhibit favourable pharmacokinetic properties and predicted binding affinity toward cancer-associated targets [139]. Experimental investigations provide complementary biological evidence. Although cytotoxicity data for crude extracts are variably reported, isolated constituents consistently demonstrate antiproliferative and apoptosis-inducing effects in preclinical models [138]. Documented mechanisms include regulation of Bcl-2 family proteins, involvement of p53-mediated signaling, and disruption of survival cascades [140]. Such mechanistic observations align with broader pharmacodynamic trends observed within related species.

Further insight is provided by solvent-partitioned extract studies, which reveal selective cytotoxic activity. Non-polar fractions, particularly hexane extracts, exhibit pronounced growth inhibition against MCF-7 and CaSki cell lines while sparing normal human umbilical vein endothelial cells (HUVEC), indicating selective targeting [141, 142]. Bioassay-guided fractionation has identified curcumenone and curcumenol as key contributors to apoptosis induction in breast cancer cells [143, 144]. Similarly, petroleum ether fractions have demonstrated inhibitory effects in triple-negative breast cancer (MDA-MB-231), suggesting that synergistic interactions among phytochemicals may enhance overall efficacy [142, 145]. Phytochemical profiling using GC–MS and HPLC techniques further substantiates these findings by confirming the presence of sesquiterpenes and related metabolites implicated in apoptosis-associated mechanisms [146]. The convergence of analytical characterisation, computational modelling, and experimental validation provides a coherent and biologically plausible framework for anticancer activity [144].

12. Conclusion and future perspectives

Curcuma zedoaria is a phytochemically rich medicinal plant that exhibits notable antibacterial, antioxidant, anti-inflammatory, and anticancer activities. These biological effects are largely attributed to its diverse bioactive constituents, particularly sesquiterpenes (example, germacrone, curzerenone, and curdione) and curcuminoids. This mini review provides a concise synthesis of recent research on the phytochemistry and pharmacological potential of *C. zedoaria*, emphasising its value as a promising natural source for therapeutic development. However, translating these findings into clinical applications remains limited due to chemotypic variability, inconsistent extraction and experimental methodologies, insufficient mechanistic evidence, and the low bioavailability of certain active compounds. Future studies should therefore prioritise standardised

phytochemical characterisation, comprehensive investigations of molecular mechanisms, and well-designed *in vivo* and clinical evaluations. Furthermore, the development of advanced delivery strategies, including nano-based formulations, may enhance stability, bioavailability, and therapeutic efficacy, thereby facilitating the development of *C. zedoaria-derived* compounds for pharmaceutical and functional food applications.

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

Not applicable.

Data availability

None.

Funding

None.

Author contributions

None.

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