

## Black Turmeric (*Curcuma caesia* Roxb.): A Review of its Ethnomedicinal Standing, Phytochemistry, Pharmacology & its Therapeutic Uses

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### Abstract:

*Curcuma caesia* Roxb. (Zingiberaceae), known throughout the Indian subcontinent as black turmeric or kali haldi, is a perennial rhizomatous herb separated from every other commonly encountered member of its genus by the deep bluish-black interior of its rhizome, a colouration now attributed to an anthocyanin content of roughly 1.3 to 7.1 per cent. The species is a mainstay of tribal and folk medicine across north-eastern and central India, where the rhizome is applied to leucoderma, leprosy, rheumatic complaints, bronchial disorders, gastrointestinal and menstrual problems, neurological conditions, cancer and diabetes. This review consolidates the published botanical, phytochemical and pharmacological literature on the species, with particular attention to its antifungal and antioxidant properties. Analyses of the volatile fraction across geographical accessions have identified camphor, 1,8-cineole, ar-turmerone, ar-curcumene, curzerenone, ocimene, linalool, zingiberol and tropolone as principal constituents, with furanodienone and curzerenone proposed as quality markers for the rhizome. Bioassay-guided fractionation has yielded eighteen secondary metabolites, predominantly germacrene, guaiane and elemene sesquiterpenoids, several of which were first reported from this species. Antifungal activity has been demonstrated against *Candida albicans*, *C. glabrata*, *Aspergillus fumigatus*, *A. niger*, *Saccharomyces cerevisiae* and a range of phytopathogenic fungi, while antioxidant capacity has been established across DPPH, ABTS, FRAP, nitric oxide, hydroxyl and superoxide radical systems and correlates with total phenolic and flavonoid content. Further reported activities include anticancer, anti-inflammatory, antidiabetic, anti-ulcer, neuropharmacological, thrombolytic, antimutagenic and anthelmintic effects. Notwithstanding this breadth of evidence, the species remains under-studied relative to *Curcuma longa*, and its endangered status in several Indian states lends urgency to both conservation and continued pharmacological investigation.

**Keywords:** *Curcuma caesia*; black turmeric; Zingiberaceae; sesquiterpenoids; curzerene; germacrene; antifungal activity; antioxidant activity; ethnopharmacology; phytochemistry

## 1. Introduction

### 1.1 Background

Plants have supplied the raw material of therapeutics for as long as medicine has existed as an organised discipline, and they continue to do so. The secondary metabolites responsible for this contribution are not required for the growth or reproduction of the producing organism in any direct sense; they mediate its dealings with the world around it, deterring herbivores, inhibiting competing microorganisms, attracting pollinators and moderating the effects of ultraviolet light, drought and nutrient stress. Because these molecules have been refined over very long evolutionary

timescales to bind biological macromolecules, they occupy regions of chemical space that rational synthetic design rarely reaches, and they remain a productive source of leads for the pharmaceutical industry.

The family *Zingiberaceae* has proved unusually rewarding in this respect. Comprising some fifty genera and in excess of thirteen hundred species distributed through the moist tropics, the family is centred on South and South-East Asia, and its members are perennial aromatic herbs in which the rhizome acts as the principal store of secondary metabolites. Two biosynthetically distinct groups dominate their chemistry: the volatile mono- and sesquiterpenoids of the essential oil, and the diarylheptanoids typified by curcumin. Within the family, the genus *Curcuma*, with approximately one hundred and twenty accepted species, supplies spices, dyes, condiments and traditional medicines used daily by a very large proportion of the world's population.

Research effort across the genus has been distributed very unevenly. *Curcuma longa* L. has generated an enormous literature and a substantial body of clinical work, while most of its congeners remain sparsely characterised. *Curcuma caesia* Roxb. illustrates this imbalance particularly clearly. Its rhizome, bluish-black rather than golden on the cut surface and possessing a penetrating camphoraceous odour quite unlike that of common turmeric, is credited by traditional healers across a wide swathe of India with efficacy in conditions ranging from leucoderma and rheumatic swelling to bronchial asthma, epilepsy, cancer and diabetes. Yet much of the published work on the species is confined to compositional analysis of the essential oil or to preliminary qualitative screening, and the species is simultaneously under pressure in the wild, being listed as endangered or vulnerable in several Indian states as a consequence of unsustainable collection and habitat loss.

The present review draws together the botanical, ethnomedicinal, phytochemical and pharmacological literature on *C. caesia*. Particular attention is given to the antifungal and antioxidant properties of the species, these being the two activities for which the evidence base is most consistent and for which the mechanistic rationale is clearest, and to the secondary metabolites that have been isolated and structurally characterised from the rhizome. The intention is to indicate both what is presently established and where the more profitable lines of further enquiry appear to lie.

## 2. Plant Introduction

*Curcuma caesia* Roxb. is an erect rhizomatous perennial herb of the family *Zingiberaceae*, first formally described by William Roxburgh in the early nineteenth century. The specific epithet derives from the Latin caesius, meaning bluish-grey, and refers to the colouration of the rhizome interior, which is the single most reliable character for separating the species in the field from its congeners. The species is native to north-eastern and central India and has additionally been recorded from Java and Myanmar. Within the family it belongs to the subfamily *Zingiberoideae* and is most closely allied to *C. zedoaria*, with which it has been repeatedly confused in the older literature — a source of persistent ambiguity when comparing published phytochemical analyses.

### 2.1 Botanical Classification

**Botanical name:** *Curcuma caesia* Roxb.

**Common names and synonyms:** Black turmeric, black zedoary (common names); *Curcuma caesia* Roxb. ex Sm.; *Curcuma bicolor* Mood & K. Larsen. The name *Curcuma zedoaria* has frequently been misapplied to black-rhizomed material.

### 2.2 Vernacular Names

**Table 2.1 Vernacular names of *Curcuma caesia*.**

| Language | Name(s)                       | Language | Name(s)      |
|----------|-------------------------------|----------|--------------|
| English  | Black turmeric, Black zedoary | Assamese | Kola haladhi |

| Language | Name(s)                   | Language  | Name(s)        |
|----------|---------------------------|-----------|----------------|
| Sanskrit | Kalanirvisha, Nilakachura | Oriya     | Kali haladi    |
| Hindi    | Kali haldi, Nar kachur    | Manipuri  | Yaingang amuba |
| Bengali  | Krishna keli, Kala haldi  | Telugu    | Nalla pasupu   |
| Marathi  | Kala haldi                | Tamil     | Kattu manjal   |
| Gujarati | Kalo haledar              | Malayalam | Kari-manjal    |
| Kannada  | Kari arishina             | Mizo      | Aidu-hang      |

### 2.3 Taxonomical Classification

Table 2.2 Taxonomic hierarchy of *Curcuma caesia* Roxb.

| Rank          | Taxon                                 |
|---------------|---------------------------------------|
| Kingdom       | Plantae                               |
| Subkingdom    | Tracheobionta (vascular plants)       |
| Superdivision | Spermatophyta (seed-producing plants) |
| Division      | Magnoliophyta (angiosperms)           |
| Class         | Liliopsida (monocotyledons)           |
| Order         | <i>Zingiberales</i>                   |
| Family        | <i>Zingiberaceae</i>                  |
| Subfamily     | <i>Zingiberoideae</i>                 |
| Genus         | <i>Curcuma</i> L.                     |
| Species       | <i>Curcuma caesia</i> Roxb.           |

### 2.4 Habitat and Geographical Distribution

The natural range of *C. caesia* is centred on the Indian subcontinent, with the densest populations occurring in the moist deciduous and semi-evergreen forest belts of the north-eastern states — Assam, Meghalaya, Manipur, Mizoram,

Nagaland, Tripura and Arunachal Pradesh — where the species has long been embedded in the ethnobotanical practice of several tribal communities. Populations of diminishing size extend through West Bengal, Odisha, Bihar, Jharkhand, Madhya Pradesh and Chhattisgarh and into the eastern Deccan and the Eastern Ghats. Occurrences have also been reported from Java, Myanmar and parts of Bangladesh and northern Thailand, though in these areas the plant is more often cultivated than genuinely wild. Ecologically it favours partially shaded sites on rich, well-drained loam with an annual rainfall of roughly fifteen hundred to three thousand millimetres, and is encountered most frequently in the forest understorey, although it adapts readily to cultivation in homestead gardens. Sustained wild collection combined with habitat fragmentation has led to its listing as endangered or vulnerable in several Indian states, and programmes of ex-situ conservation and micropropagation are now in progress at a number of institutions.

## 2.5 Morphological Characteristics

The plant attains a height of approximately one to one and a half metres at maturity. The aerial pseudostem is short, formed by the overlapping sheathing leaf bases, and does not persist beyond the growing season. The leaves are simple, oblong-lanceolate, some thirty to sixty centimetres long and seven to fifteen centimetres broad, glabrous and glossy above and finely pubescent beneath along the principal nerves; a prominent longitudinal band of deep red-violet to maroon pigment runs along the midrib of the upper surface and is visible from a considerable distance, giving stands of the plant a distinctive appearance during active growth.

The inflorescence arises directly from the rhizome on a separate fleshy peduncle some fifteen to twenty centimetres long and takes the form of a dense erect spike, bearing greenish floral bracts in its lower portion and pink to crimson sterile coma bracts above. The individual flowers are pale yellow, tubular and strongly zygomorphic, with the three-lobed labellum characteristic of the *Zingiberaceae* formed by the fusion of two staminodes opposite the single fertile stamen. Viable seed set is rarely observed, a circumstance attributed in part to the reported triploid chromosome number, and propagation is effected almost exclusively through rhizome or daughter-tuber cuttings.

The rhizome is the organ of medicinal and commercial interest. Pale brown to dirty grey externally and marked with the scars of fallen scale leaves, it reveals on section a deep bluish-black to violet-black interior, frequently with radial bands of darker pigment. It is fleshy and sympodially branched and bears numerous slender secondary roots together with small ovoid daughter tubers. The freshly cut surface emits a strong, pungent, camphoraceous odour. The dried drug of commerce is irregular in outline and horny in texture, bluish-black on fresh section though fading towards dark brown on prolonged storage, and of bitter, slightly acrid and astringent taste.

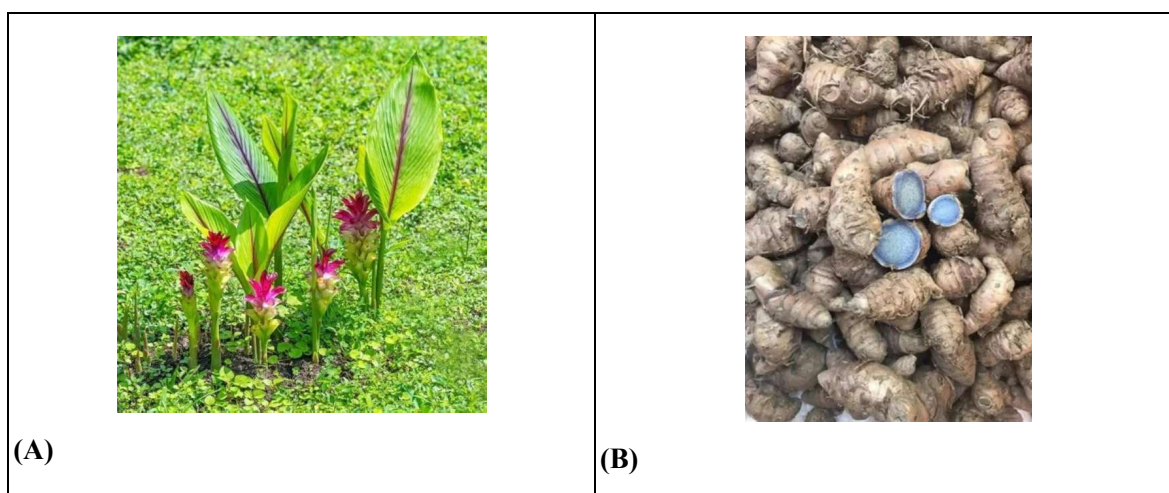


Figure 2.1 Morphological characteristics of *Curcuma caesia* Roxb. (A) Habit, showing the erect leafy shoots with the diagnostic deep red-violet band along the midrib of the upper leaf surface, together with the separately borne

inflorescences bearing pink to crimson sterile coma bracts. (B) Harvested rhizomes; the sectioned specimens reveal the bluish-black interior from which the plant takes its common name of black turmeric.

## 2.6 Phenology

Vegetative growth commences with the onset of the pre-monsoon rains. Flowering occurs chiefly between April and June, generally preceding or coinciding with the emergence of the leafy shoot. The aerial parts senesce during the post-monsoon period, and rhizomes are conventionally harvested between October and January, when the aerial portion has died back and the concentration of secondary metabolites in the underground organ is at its seasonal maximum. Reports indicate that rhizome age materially affects composition; calebin-A, for example, has been detected in rhizomes of twelve to fourteen months but not in younger material.

## 3. Traditional Uses

The folk-medical record for *C. caesia* rhizome is unusually broad. Ethnobotanical surveys conducted over several decades have documented its use among the Karbi, Bodo, Garo, Khasi, Mizo and Naga communities of the north-east; the Munda, Santhal, Oraon and Ho of the Chota Nagpur plateau; and the Gond, Baiga, Korku and Bhil of the central Indian forest belt, as well as among rural populations of coastal Odisha and the Eastern Ghats. The rhizome is used fresh or dried and powdered, and is administered as a paste, decoction, infusion or simple powder taken with honey, milk, ghee or warm water according to the indication.

Documented indications include wounds, fever, vomiting, toothache, sprains and bruises, bronchitis, dysentery, diarrhoea, tumours, piles, leprosy, leucoderma, asthma, epilepsy, haemorrhoids, cancer, menstrual disorders, anthelmintic use, aphrodisiac use, inflammation and gonorrhoeal discharge. Among the most consistently reported applications are the following. A paste of the fresh rhizome ground with mustard oil or warm water is applied to swollen joints, sprains, contusions and rheumatic pain. The dried powdered rhizome, taken with honey or fresh ginger juice, is given for cough, bronchitis, hoarseness and asthma, and in some communities the smoke of the burning rhizome is inhaled during acute asthmatic episodes. The rhizome paste is applied topically to wounds, abscesses, eczema, scabies and other dermatoses, and notably in the management of leucoderma, where it is used alone or compounded with the seed oil of *Psoralea corylifolia*. Gastrointestinal complaints including dyspepsia, anorexia, colic, helminthiasis and dysentery are treated with the powdered rhizome, and the drug is regarded in several traditions as hepatoprotective. The rhizome also features in the folk management of epilepsy and conditions described as nervous disorders, and is given to children as a reputed tonic for memory and concentration.

Beyond strictly medicinal application, the rhizome serves as a spice, a food preservative and a colouring agent in parts of the Indian subcontinent, and dried pieces are hung in dwellings or carried in amulets in several communities, the strong aromatic principle being held to repel both insects and malign influence. As with most ethnomedicinal records, a substantial proportion of these applications await systematic pharmacological and clinical validation.

## 4. Phytochemistry

The phytochemistry of *C. caesia* has been approached principally through analysis of the hydrodistilled essential oil, supplemented by a smaller body of work on the curcuminoid and non-volatile phenolic fractions and, more recently, by bioassay-guided isolation of individual secondary metabolites. The rhizome is reported to contain curcuminoids, essential oils, flavonoids, phenolics, alkaloids, saponins, tannins, phytosterols, fatty acids and abundant starch.

### 4.1 Pigments

The characteristic bluish-black colouration of the rhizome interior, long the subject of speculation, has been attributed to an anthocyanin content in the region of 1.3 to 7.1 per cent. This distinguishes the pigmentation chemistry of *C. caesia* sharply from that of *C. longa*, in which the golden colour of the rhizome derives from the curcuminoids, and indicates that the two species differ not merely in the quantity of their shared constituents but in the identity of the compounds responsible for their most conspicuous visual character.

## 4.2 Volatile constituents of the rhizome and leaf

Compositional analyses of the rhizome oil vary considerably between geographical accessions, and the constituents most frequently reported as major components across studies are 1,8-cineole, camphor, ar-turmerone, linalool, ocimene, ar-curcumen, zingiberol, curzerenone and tropolone. In an early and widely cited analysis of material from central India, camphor was found to predominate at approximately 28 per cent of the total oil, followed by ar-turmerone at around 12 per cent and (Z)-ocimene at roughly 8 per cent. A more recent investigation employing comprehensive two-dimensional gas chromatography coupled to time-of-flight mass spectrometry reported a markedly different profile, with curzerenone the leading constituent at 11.45 per cent, followed by eucalyptol (7.56 per cent), curzerene (4.56 per cent), epicurzerenone (4.23 per cent), camphor (3.59 per cent) and ar-turmerone (2.59 per cent); the same study resolved several co-eluting components not previously distinguished by conventional one-dimensional analysis [11]. The leaf oil is dominated by 1,8-cineole, camphor and borneol [5], and in the two-dimensional analysis camphor (6.59 per cent), heptacosane (4.26 per cent), curzerenone (3.85 per cent), epicurzerenone (3.70 per cent), curzerene (3.46 per cent), eucalyptol (2.69 per cent) and  $\alpha$ -farnesene (2.67 per cent) were the principal leaf constituents.

The degree of compositional variability documented across these studies is substantial and has so far prevented the emergence of an agreed chemotypic classification for the species. Geographical origin, season of collection, rhizome age, drying regime and distillation conditions have all been implicated. In an attempt to provide a practical basis for quality control, furanodienone and curzerenone have been proposed as marker compounds for assessing rhizome quality.

## 4.3 Secondary metabolites isolated from the rhizome

The most substantial isolation study reported for this species employed bioassay-guided fractionation directed by cytotoxicity against the breast carcinoma lines MCF-7 and MDA-MB-231. Chromatographic separation of the hexane fraction afforded germacrone, zerumbone, furanodienone, curzerenone, curcumenol, zederone, curcumenone and dehydrocurdione, while the chloroform fraction yielded curcuminol G, curcuzederone, a germacrone-1(10),4-diepoxide, wenyujinin B, alismoxide, aerugidiol, zedoarolide B, zedoalactone B, zedoarondiol and isozedoarondiol. Ten of these eighteen compounds were reported from *C. caesia* for the first time. Germacrone, zerumbone, furanodienone, curzerenone and curcuzederone were identified as the bioactive constituents of the fractions, and curcuzederone in particular produced significant inhibition of MDA-MB-231 migration in both scratch and Transwell assays.

The compounds recovered belong predominantly to the germacrane, guaiane, elemene and humulane sesquiterpenoid skeletons, and the overlap with the constituent profile of *C. zedoaria* is considerable — a chemotaxonomic observation consistent with the close morphological affinity of the two species and with the historical difficulty of distinguishing them. Separately, the diarylheptanoid calebin-A has been isolated and characterised from *C. caesia* rhizome, its presence being confined to material of twelve to fourteen months of age; an endophytic fungus recovered from the same plant and identified as *Ovatospora brasiliensis* was shown to biotransform curcumin into calebin-A, suggesting a possible route to production of this compound independent of the plant itself.

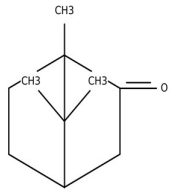
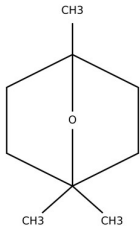
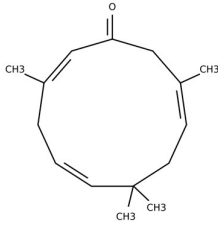
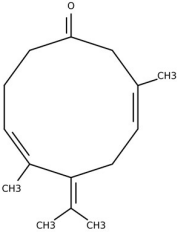
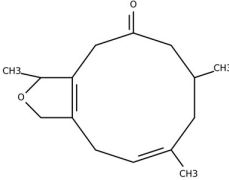
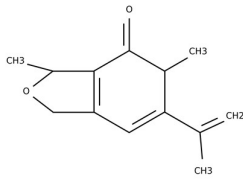
**Table 4.1 Phytochemical constituents reported from *Curcuma caesia* by various authors.**

| S. No. | Plant part / extract                      | Constituents reported                                                                                                                                                                                                                  | Nature of study                                                | Author(s)           | Year |
|--------|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|---------------------|------|
| 1      | Rhizome essential oil                     | ar-Turmerone, $\beta$ -elemene, $\beta$ -eudesmol, germacrone, curzerenone, curcumenol                                                                                                                                                 | Composition and antifungal evaluation                          | Banerjee & Nigam    | 1976 |
| 2      | Rhizome essential oil                     | Camphor (~28%), ar-turmerone (~12%), (Z)-ocimene (~8.5%), ar-curcumene, 1,8-cineole, borneol, bornyl acetate                                                                                                                           | GC-MS compositional analysis                                   | Pandey & Chowdhury  | 2003 |
| 3      | Leaf and rhizome oils                     | Camphor, $\beta$ -pinene, 1,8-cineole, $\alpha$ -phellandrene, ar-curcumene, $\beta$ -caryophyllene                                                                                                                                    | GC-MS and antimicrobial screening                              | Behura & Srivastava | 2004 |
| 4      | Rhizome — methanol and petroleum ether    | Curcuminoids, $\beta$ -sitosterol, alkaloids, flavonoids, tannins, saponins                                                                                                                                                            | Pharmacognostic standardisation                                | Paliwal et al.      | 2011 |
| 5      | Rhizome — petroleum ether and chloroform  | Curcumin, demethoxycurcumin, bisdemethoxycurcumin                                                                                                                                                                                      | HPLC quantification of curcuminoids                            | Angel et al.        | 2012 |
| 6      | Rhizome — methanolic extract              | $\beta$ -Sitosterol, stigmasterol, fatty acids, curcuminoids                                                                                                                                                                           | Isolation and characterisation                                 | Lal                 | 2012 |
| 7      | Rhizome (hexane and chloroform fractions) | Germacrone, zerumbone, furanodienone, curzerenone, curcumenol, zederone, curcumenone, dehydrocurdione, curcuminol G, curcuzederone, wenyujinin B, alismoxide, aerugidiol, zedoarolide B, zedoalactone B, zedoarondiol, isozedoarondiol | Bioassay-guided isolation; 18 compounds, 10 new to the species | Liu et al.          | 2013 |

| S. No. | Plant part / extract           | Constituents reported                                                                                                                                    | Nature of study                               | Author(s)     | Year |
|--------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|---------------|------|
| 8      | Rhizome (aged 12–14 months)    | Calebin-A                                                                                                                                                | HP-TLC, HPLC and MS; fungal biotransformation | Majeed et al. | 2019 |
| 9      | Rhizome (review of accessions) | Anthocyanins (1.3–7.14%); 1,8-cineole, camphor, ar-turmerone, linalool, ocimene, ar-curcumenone, zingiberol, curzerenone, tropolone                      | Compositional review; marker identification   | Paw et al.    | 2024 |
| 10     | Rhizome and leaf volatiles     | Curzerenone (11.45%), eucalyptol (7.56%), curzerene, epicurzerenone, camphor, ar-turmerone; leaf: camphor, heptacosane, curzerenone, $\alpha$ -farnesene | GC $\times$ GC–TOFMS terpenoid profiling      | Sci. Rep.     | 2025 |

## 5. Chemical Structures of Major Constituents

Figure 5.1 presents the structures of representative constituents reported from *Curcuma caesia*. The volatile monoterpene fraction is represented by camphor and 1,8-cineole; the bisabolane sesquiterpenoids by ar-turmerone and ar-curcumenone; the germacrane, elemene, humulene and guaiane sesquiterpenoids by germacrone, furanodienone, curzerenone, zerumbone and curcumenol; and the diarylheptanoid class by curcumin.

|                                                                                                       |                                                                                                          |                                                                                                          |
|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
|  <p>Camphor</p>    |  <p>1,8-Cineole</p>   |  <p>Zerumbone</p>   |
|  <p>Germacrone</p> |  <p>Furanodienone</p> |  <p>Curzerenone</p> |

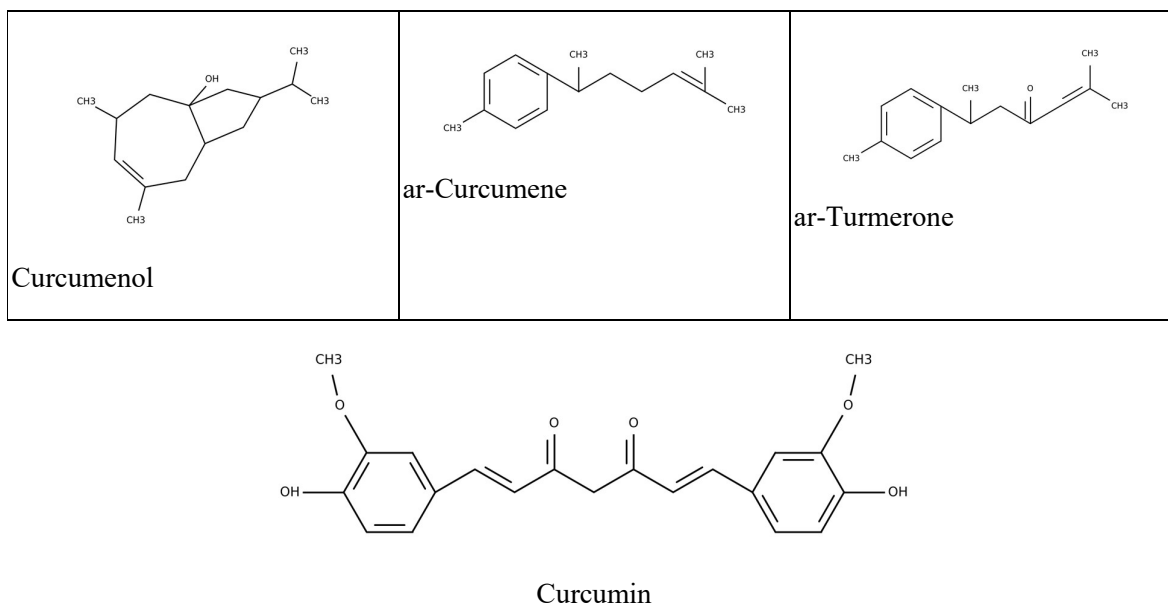


Figure 5.1 Structures of representative phytoconstituents reported from *Curcuma caesia* Roxb.

## 6. Pharmacological Properties

### 6.1 Antifungal activity

Antifungal activity is among the best-documented properties of *C. caesia* and among the most consistent with its traditional application to dermatological conditions. The earliest systematic report examined the rhizome essential oil and established activity against dermatophytes and *Aspergillus* species. Subsequent work has extended the tested spectrum considerably.

An in-vitro study directed specifically at *Candida* evaluated an alcoholic rhizome extract against *Candida albicans* and *Candida glabrata*, determining both minimum inhibitory concentration and zone of inhibition, and framed the work explicitly in terms of the need for alternatives where resistance to conventional antifungal agents has emerged. A comparative assessment of *C. caesia* and *C. amada* tested dichloromethane and ethanolic extracts against *Aspergillus fumigatus* and *Candida albicans* by the cup-plate method with clotrimazole as reference standard, alongside antibacterial testing against *Staphylococcus aureus*, *Streptococcus pyogenes*, *Escherichia coli* and *Pseudomonas aeruginosa*. Work on the leaf essential oil — the first such report for this species — demonstrated antifungal activity against *Aspergillus fumigatus*, *Aspergillus niger*, *Saccharomyces cerevisiae* and *Candida albicans*, together with antibacterial activity against *Bacillus subtilis*, *Bacillus cereus*, *Staphylococcus aureus* and *Salmonella typhimurium*.

Activity has also been established against phytopathogenic fungi of agricultural significance. Rhizome extracts have been reported effective against *Fusarium oxysporum*, *Aspergillus niger*, *Aspergillus nidulans* and *Alternaria solani*, and screening by the agar cup method has demonstrated inhibition of *Fusarium oxysporum*, *Botrytis cinerea* and *Rhizopus oryzae*. A herbal bioformulation combining crude *C. caesia* rhizome extract with *Ixora coccinea* leaf extract produced greater inhibition of *Botrytis cinerea* than either extract used alone, indicating a degree of synergy and suggesting possible application in crop protection.

The constituents responsible have not been definitively assigned, but the lipophilic terpenoid fraction is the most probable source. Camphor, 1,8-cineole, ar-turmerone,  $\beta$ -caryophyllene and  $\beta$ -eudesmol all possess intrinsic antifungal activity, and comparative work within the genus has shown curdione, isocurcumenol, curcumenol, curzerene,  $\beta$ -elemene, germacrone and curcumol — constituents that *C. caesia* shares — to be individually inhibitory towards filamentous fungi. The generally accepted mechanistic basis involves disruption of fungal membrane integrity,

interference with ergosterol biosynthesis and inhibition of hyphal and biofilm development, though studies addressing these mechanisms specifically in *C. caesia* remain scarce.

## 6.2 Antioxidant activity

The antioxidant capacity of *C. caesia* has been examined more frequently than any other of its activities, across a range of assay systems and extract types. The reported values vary widely, which reflects genuine differences in extraction solvent, plant material and assay protocol as much as it does variation between accessions, and comparisons across studies should accordingly be made with caution.

In a study of rhizome extracts and their fractions, the ethanolic fraction gave the highest DPPH radical scavenging activity at 86.91 per cent, approaching the 94.77 per cent recorded for ascorbic acid, with half-maximal inhibitory concentrations of 418, 442, 561 and 591  $\mu\text{g/mL}$  for the ethanolic, methanolic, ethyl acetate and aqueous fractions respectively; free-radical scavenging was attributed to high phenolic and flavonoid content together with a substantial reducing capacity. A separate evaluation of a methanolic rhizome extract against butylated hydroxytoluene reported a DPPH  $\text{IC}_{50}$  of 862.35  $\mu\text{g}$  compared with 46.25  $\mu\text{g}$  for the standard, and characterised the extract activity as moderate. A study examining several radical systems reported considerably lower  $\text{IC}_{50}$  values —  $1.08 \pm 0.06 \mu\text{g/mL}$  for DPPH,  $10.08 \pm 2.01 \mu\text{g/mL}$  for hydroxyl radical,  $29.63 \pm 2.07 \mu\text{g/mL}$  for superoxide anion and  $37.50 \pm 1.54 \mu\text{g/mL}$  for nitric oxide [22]. More recent work on a methanolic rhizome extract obtained  $\text{IC}_{50}$  values of  $66.5 \pm 8.81 \mu\text{g/mL}$  for DPPH,  $42.69 \pm 5.78 \mu\text{g/mL}$  for ABTS and  $132.35 \pm 8.08 \mu\text{g/mL}$  for metal chelating activity.

Comparative work on enzymatic and non-enzymatic extracts found the non-enzymatic preparation the more active, giving  $55.32 \pm 0.2$  per cent DPPH scavenging at 200  $\mu\text{g/mL}$  against  $31.2 \pm 0.8$  per cent for the enzymatic extract, with hydroxyl radical scavenging of 40.26 per cent. Evaluation of sequential extracts of fresh and dried rhizomes across hexane, petroleum ether, benzene, chloroform, ethyl acetate, methanol and water, assessed by DPPH, total antioxidant capacity, ferric reducing activity and thiobarbituric acid reactive species assays, has further characterised the polarity dependence of the activity [5]. Notably, in a study directed at cancer apoptosis, the hexane rhizome extract displayed the most striking total antioxidant capacity at 1200 mg ascorbic acid equivalents per 100 g, indicating that non-polar constituents contribute materially and that activity is not confined to the phenolic fraction. Metabolomic work employing  $^1\text{H}$  NMR has correlated extract composition with both antioxidant and  $\alpha$ -glucosidase inhibitory activity, with a freeze-dried rhizome extracted in absolute ethanol giving a total phenolic content of  $45.4 \pm 2.1$  mg gallic acid equivalents per gram and a ferric reducing antioxidant power of  $147.7 \pm 8.3$  mg Trolox equivalents per gram.

Antimutagenic activity has been demonstrated as a corollary of this antioxidant capacity: rhizome extracts selected on the basis of their radical-scavenging performance were shown to protect against the indirect-acting mutagen cyclophosphamide in *Salmonella typhimurium* strains TA98 and TA100.

## 6.3 Anticancer and cytotoxic activity

Cytotoxic and antiproliferative activity has been reported across several models. Bioassay-guided fractionation directed by activity against MCF-7 and MDA-MB-231 breast carcinoma cells identified germacrone, zerumbone, furanodienone, curzerenone and curcuzederone as the bioactive constituents, with curcuzederone significantly inhibiting migration of the triple-negative MDA-MB-231 line. Methanolic extracts of *C. caesia*, examined alongside *Aristolochia tagala*, inhibited diethylnitrosamine-induced hepatocellular carcinoma in BALB/c mice [25]. Phytochemicals from South Indian black turmeric have been evaluated specifically for their capacity to target cancer apoptosis, with attention to drug-ability and toxicity parameters that the authors noted were poorly documented for this endangered species.

## 6.4 Anti-inflammatory activity

The leaf essential oil has been shown to possess in-vitro anti-inflammatory activity with an  $\text{IC}_{50}$  of 182.5  $\mu\text{g/mL}$ , while exhibiting only negligible genotoxicity relative to the diclofenac standard. In-vivo evaluation of rhizome extract has

demonstrated reduction of the inflammatory mediators tumour necrosis factor alpha, interleukin-6 and inducible nitric oxide synthase together with the hepatic transaminases alanine and aspartate aminotransferase, alongside elevation of the anti-inflammatory cytokine interleukin-10 and of superoxide dismutase. These findings are consistent with the traditional application of the rhizome to rheumatic and inflammatory complaints.

### 6.5 Antidiabetic activity

A methanolic rhizome extract has been reported to inhibit  $\alpha$ -amylase and  $\alpha$ -glucosidase with  $IC_{50}$  values of  $442.92 \pm 10.05$  and  $95.40 \pm 9.74$   $\mu\text{g/mL}$  respectively, against  $154.33 \pm 9.08$  and  $38.63 \pm 8.05$   $\mu\text{g/mL}$  for acarbose, and to enhance glucose uptake by yeast cells. In a diabetic animal model, treatment normalised body weight, oral glucose tolerance, glycosylated haemoglobin and fasting blood glucose, effects the authors attributed in part to strengthening of endogenous antioxidant defences.

### 6.6 Other reported activities

**Anti-ulcer.** An ethanolic rhizome extract has been evaluated in an experimental in-vivo model of gastric ulceration, the rationale advanced being the cost and adverse-effect burden of the corresponding synthetic agents.

**Neuropharmacological.** Rhizome extracts have been assessed in experimental animal models for central nervous system depressant, anxiolytic, anticonvulsant and locomotor effects, and smooth-muscle relaxant activity has been investigated mechanistically.

**Thrombolytic.** An ethanolic rhizome extract has been examined in an in-vitro clot-lysis model with streptokinase as positive and distilled water as negative control.

**Anthelmintic.** Ethanolic, chloroformic and aqueous rhizome extracts tested at 25, 50 and 100 mg/dL against earthworms, with albendazole at 20 mg/dL as standard, were assessed for time to paralysis and death; the ethanolic extract proved the most effective.

**Antibacterial.** Ethanolic extract has shown appreciable activity against *Staphylococcus aureus*, with clinical isolates proving more sensitive than the standard strain, alongside activity against *Bacillus subtilis* and *Escherichia coli* reported by several groups.

**Table 6.1 Pharmacological activities reported for *Curcuma caesia* and the experimental approaches employed.**

| S. No. | Activity    | Experimental approach and principal findings                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1      | Antifungal  | Rhizome essential oil active against dermatophytes and <i>Aspergillus</i> spp. Alcoholic extract evaluated against <i>Candida albicans</i> and <i>C. glabrata</i> with determination of MIC and zone of inhibition. Dichloromethane and ethanolic extracts tested by cup-plate method against <i>Aspergillus fumigatus</i> and <i>Candida albicans</i> with clotrimazole as standard. Leaf essential oil active against <i>A. fumigatus</i> , <i>A. niger</i> , <i>Saccharomyces cerevisiae</i> and <i>C. albicans</i> . Rhizome extracts inhibitory towards <i>Fusarium oxysporum</i> , <i>Botrytis cinerea</i> , <i>Rhizopus oryzae</i> , <i>Aspergillus nidulans</i> and <i>Alternaria solani</i> ; synergy observed in combination with <i>Ixora coccinea</i> extract. |
| 2      | Antioxidant | Ethanolic fraction gave 86.91% DPPH scavenging (ascorbic acid 94.77%), $IC_{50}$ 418 $\mu\text{g/mL}$ , followed by methanolic (442), ethyl                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

| S. No. | Activity               | Experimental approach and principal findings                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|        |                        | acetate (561) and aqueous (591) fractions. Methanolic extract IC <sub>50</sub> 66.5 (DPPH), 42.69 (ABTS) and 132.35 µg/mL (metal chelating). Separate reports of IC <sub>50</sub> 1.08 (DPPH), 10.08 (hydroxyl), 29.63 (superoxide) and 37.50 µg/mL (nitric oxide). Hexane rhizome extract total antioxidant capacity 1200 mg ascorbic acid equivalents per 100 g. FRAP 147.7 mg Trolox equivalents per gram; total phenolics 45.4 mg GAE/g. |
| 3      | Antimutagenic          | Rhizome extracts selected on antioxidant performance protected against the indirect-acting mutagen cyclophosphamide in <i>Salmonella typhimurium</i> TA98 and TA100.                                                                                                                                                                                                                                                                         |
| 4      | Anticancer / cytotoxic | Bioassay-guided fractionation against MCF-7 and MDA-MB-231 identified germacrone, zerumbone, furanodienone, curzerenone and curcuzederone as active; curcuzederone inhibited MDA-MB-231 migration in scratch and Transwell assays. Methanolic extract inhibited diethylnitrosamine-induced hepatocellular carcinoma in BALB/c mice.                                                                                                          |
| 5      | Anti-inflammatory      | Leaf essential oil IC <sub>50</sub> 182.5 µg/mL in vitro with negligible genotoxicity. In vivo reduction of TNF-α, IL-6, iNOS, ALT and AST with elevation of IL-10 and superoxide dismutase.                                                                                                                                                                                                                                                 |
| 6      | Antidiabetic           | Methanolic extract inhibited α-amylase (IC <sub>50</sub> 442.92 µg/mL; acarbose 154.33) and α-glucosidase (95.40 µg/mL; acarbose 38.63) and enhanced yeast-cell glucose uptake. Diabetic animal model showed normalisation of body weight, OGTT, HbA1c and fasting blood glucose.                                                                                                                                                            |
| 7      | Anti-ulcer             | Ethanolic rhizome extract evaluated in an experimental in-vivo model of gastric ulceration.                                                                                                                                                                                                                                                                                                                                                  |
| 8      | Neuropharmacological   | CNS depressant, anxiolytic, anticonvulsant and locomotor activity assessed in rodent models; smooth-muscle relaxant effect investigated mechanistically.                                                                                                                                                                                                                                                                                     |
| 9      | Thrombolytic           | Ethanolic rhizome extract assessed in an in-vitro clot-lysis model with streptokinase as positive control and distilled water as negative control.                                                                                                                                                                                                                                                                                           |

| S. No. | Activity      | Experimental approach and principal findings                                                                                                                                                                                                                                                                          |
|--------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10     | Anthelmintic  | Ethanollic, chloroformic and aqueous extracts at 25, 50 and 100 mg/dL against earthworms; albendazole 20 mg/dL standard. Time to paralysis and death recorded; ethanolic extract most effective.                                                                                                                      |
| 11     | Antibacterial | Activity against <i>Staphylococcus aureus</i> (clinical isolates more sensitive than standard strain), <i>Bacillus subtilis</i> , <i>Bacillus cereus</i> , <i>Streptococcus pyogenes</i> , <i>Escherichia coli</i> , <i>Pseudomonas aeruginosa</i> and <i>Salmonella typhimurium</i> reported across several studies. |

**Table 6.2 Biological activities of *Curcuma caesia* reported by various authors.**

| S. No. | Part / extract                                     | Biological activity                                | Author(s)        | Year |
|--------|----------------------------------------------------|----------------------------------------------------|------------------|------|
| 1      | Rhizome essential oil                              | Antifungal (dermatophytes, <i>Aspergillus</i> )    | Banerjee & Nigam | 1976 |
| 2      | Rhizome extracts                                   | Smooth muscle relaxant                             | Arulmozhi et al. | 2006 |
| 3      | Rhizome, ethanolic / chloroform / aqueous          | Anthelmintic                                       | Gill et al.      | 2011 |
| 4      | Rhizome, methanolic and aqueous                    | CNS depressant, anxiolytic, anticonvulsant         | Karmakar et al.  | 2011 |
| 5      | Rhizome, hexane and chloroform fractions           | Cytotoxic; isolation of 18 sesquiterpenoids        | Liu et al.       | 2013 |
| 6      | Rhizome, methanolic                                | Anticancer (hepatocellular carcinoma, BALB/c mice) | Hadem et al.     | 2014 |
| 7      | Rhizome, ethanolic                                 | Thrombolytic (in-vitro clot lysis)                 | Fathima et al.   | 2015 |
| 8      | Rhizome extract and fractions                      | Antioxidant and antimutagenic                      | Devi et al.      | 2015 |
| 9      | Rhizome, hexane / ethyl acetate / methanol / water | Antioxidant; cancer apoptosis targeting            | Mukunthan et al. | 2017 |

| S. No. | Part / extract                         | Biological activity                                                       | Author(s)                  | Year |
|--------|----------------------------------------|---------------------------------------------------------------------------|----------------------------|------|
| 10     | Rhizome, dichloromethane and ethanolic | Comparative antimicrobial and antifungal                                  | Asian J. Pharm. Clin. Res. | 2018 |
| 11     | Leaf essential oil                     | Anti-inflammatory, antimicrobial, antifungal                              | Borah et al.               | 2019 |
| 12     | Rhizome (12–14 months)                 | Isolation of calebin-A; fungal biotransformation                          | Majeed et al.              | 2019 |
| 13     | Rhizome, methanolic                    | DPPH antioxidant (IC <sub>50</sub> 862.35 µg)                             | Mangla et al.              | 2020 |
| 14     | Rhizome, alcoholic                     | Antifungal against <i>Candida albicans</i> and <i>C. glabrata</i>         | Savithri et al.            | 2021 |
| 15     | Rhizome extracts (freeze-dried)        | Antioxidant and α-glucosidase inhibition; <sup>1</sup> H NMR metabolomics | Nurcholis et al.           | 2023 |
| 16     | Rhizome and leaf volatiles             | Terpenoid profiling and DPPH scavenging                                   | Sci. Rep.                  | 2025 |

## 7. Conclusion

*Curcuma caesia* Roxb. presents an unusually wide gap between the breadth of its traditional therapeutic reputation and the depth of the scientific literature devoted to it. The published record nonetheless establishes a rhizome chemistry that is clearly distinct from that of the better-studied *Curcuma longa*: the bluish-black colouration derives from anthocyanins rather than from curcuminoids, camphor and the furanosesquiterpenoids curzerenone and furanodienone figure prominently among the volatile constituents, and bioassay-guided fractionation has furnished eighteen secondary metabolites of predominantly germacrone, guaiane and elemene type, ten of them reported from the species for the first time.

Of the pharmacological activities examined, the antifungal and antioxidant properties rest on the most substantial and internally consistent evidence. Antifungal activity has been demonstrated across both clinically relevant yeasts and agriculturally important filamentous fungi, and corresponds closely to the traditional application of the rhizome to dermatological conditions, in which fungal colonisation is a recognised complicating factor. Antioxidant capacity has been established in a wide range of radical systems and correlates with phenolic and flavonoid content, although the non-polar fraction contributes materially and the activity cannot be attributed to the phenolics alone.

Three limitations of the present evidence base deserve emphasis. First, the compositional variability documented across accessions is substantial, and in the absence of an agreed chemotypic classification results obtained on one accession cannot safely be generalised to material of different provenance; the proposal of furanodienone and

curzerenone as quality markers is a useful step towards addressing this. Second, the great majority of the pharmacological work has been performed on crude extracts rather than on isolated constituents, so that the compounds responsible for the observed activities remain largely unassigned, and mechanistic studies — particularly for the antifungal effect — are correspondingly scarce. Third, clinical evidence is effectively absent, all available data deriving from in-vitro systems or laboratory animal models.

These considerations define the more profitable directions for further work: determination of minimum inhibitory and fungicidal concentrations for isolated constituents against clinical fungal isolates, including azole-resistant strains; mechanistic characterisation of the antifungal effect with reference to ergosterol biosynthesis and membrane integrity; systematic chemotypic survey across the geographical range under standardised harvesting and processing conditions; and structure–activity investigation of the germacrone and guaiane sesquiterpenoid scaffolds. Given the endangered status of the species in several Indian states, such work should proceed alongside sustained investment in conservation, micropropagation and regulated cultivation, without which the pharmaceutical promise of black turmeric will remain difficult to realise.

## References

- [1] Harvey AL, Edrada-Ebel R, Quinn RJ. The re-emergence of natural products for drug discovery in the genomics era. *Nat Rev Drug Discov.* 2015;14(2):111–129.
- [2] Newman DJ, Cragg GM. Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019. *J Nat Prod.* 2020;83(3):770–803.
- [3] Dewick PM. *Medicinal Natural Products: A Biosynthetic Approach*. 3rd ed. Chichester: Wiley; 2009.
- [4] Paudel A, Khanal N, Khanal A, Rai S, Adhikari R. Pharmacological insights into *Curcuma caesia* Roxb., the black turmeric: a review of bioactive compounds and medicinal applications. *Discover Plants.* 2024;1:76.
- [5] Paw M, et al. *Curcuma caesia* Roxb. — update of phytochemicals and pharmacological properties. *J Spices Aromat Crops.* 2024;33(1):1–22.
- [6] Isha, et al. Black turmeric (*Curcuma caesia* Roxb.) *Zingiberaceae*: unveiling mystical phytochemicals and their pharmacological wonders. *Discov Appl Sci.* 2025;7:1385.
- [7] Majeed M, et al. Bioconversion of curcumin into calebin-A by the endophytic fungus *Ovatospora brasiliensis* EPE-10 MTCC 25236 associated with *Curcuma caesia*. *AMB Express.* 2019;9:79.
- [8] Mukunthan KS, Satyan RS, Patel TN. Pharmacological evaluation of phytochemicals from South Indian black turmeric (*Curcuma caesia* Roxb.) to target cancer apoptosis. *J Ethnopharmacol.* 2017;209:82–90.
- [9] Pandey AK, Chowdhury AR. Volatile constituents of the rhizome oil of *Curcuma caesia* Roxb. from central India. *Flavour Fragr J.* 2003;18(5):463–465.
- [10] Angel GR, Vimala B, Nambisan B. Quantitative analysis of curcuminoids in *Curcuma caesia* by HPLC. *J Spices Aromat Crops.* 2012;21(1):30–33.
- [11] Unlocking terpenoid treasures of rhizome and leaf volatiles of *Curcuma caesia* Roxb. through 1D and 2D GC × GC TOFMS analysis. *Sci Rep.* 2025;15:93460.
- [12] Liu Y, et al. Bioactive chemical constituents from *Curcuma caesia* Roxb. rhizomes and inhibitory effect of curcuzederone on the migration of triple-negative breast cancer cell line MDA-MB-231. *Nat Prod Res.* 2013 / PubMed 31726856.
- [13] Banerjee A, Nigam SS. Essential oil composition of *Curcuma caesia* Roxb. and its antifungal activity. *Parfum Kosmet.* 1976;57(4):153–156.
- [14] Savithri S, et al. Evaluation of an antifungal property of *Curcuma caesia*, a traditional herb, against *Candida* species: an in-vitro study. *J Pharm Bioallied Sci.* 2021.

- [15] Comparative assessment of in-vitro antimicrobial activity of *Curcuma caesia* Roxb. and *Curcuma amada* Roxb. Asian J Pharm Clin Res. 2018;11(9).
- [16] Borah A, et al. Chemical composition and biological activities of the leaf essential oil of *Curcuma caesia* Roxb. Ind Crops Prod. 2019.
- [17] Bioformulation of antifungal herbal extract from *Curcuma caesia* Roxb. and *Ixora coccinea* L. against *Botrytis cinerea*. J Pharmacogn Phytochem. 2018;7(1).
- [18] Pandey N, et al. Antifungal screening of *Curcuma caesia* against plant pathogenic fungi. Int J Pharm Sci Rev Res. 2020;63(1):4–7.
- [19] Chen C, et al. Antifungal activity, main active components and mechanism of *Curcuma longa* extract against *Fusarium graminearum*. PLoS One. 2018;13(3):e0194284.
- [20] Devi HP, Mazumder PB, Devi LP. Antioxidant and antimutagenic activity of *Curcuma caesia* Roxb. rhizome extracts. Toxicol Rep. 2015;2:423–428.
- [21] Mangla B, et al. Evaluation of antioxidant activity of methanolic extract of rhizomes of *Curcuma caesia* by DPPH free radical scavenging assay. Int J Pharm Sci Rev Res. 2020;63(1):4–7.
- [22] Phytochemical screening and evaluation of antioxidant, antimicrobial and anti-inflammatory activity of *Curcuma caesia*. Int J Pharm Sci Res. 2020.
- [23] Dhal Y, Deo B, Sahu RK. Comparative antioxidant activity of non-enzymatic and enzymatic extracts of *Curcuma zedoaria*, *Curcuma angustifolia* and *Curcuma caesia*. Int J Plant Anim Environ Sci. 2012;2(4).
- [24] Nurcholis W, et al. <sup>1</sup>H NMR-based metabolomics approach revealing metabolite variation of black turmeric (*Curcuma caesia*) extracts and correlation with its antioxidant and  $\alpha$ -glucosidase inhibitory activities. Food Technol Biotechnol. 2023;61(1).
- [25] Hadem KL, Sharan RN, Kma L. Inhibitory potential of methanolic extracts of *Aristolochia tagala* and *Curcuma caesia* on hepatocellular carcinoma induced by diethylnitrosamine in BALB/c mice. J Carcinog. 2014;13:7.
- [26] Karmakar I, et al. Evaluation of anti-ulcer potential of *Curcuma caesia* rhizome ethanolic extract in experimental models. Indian J Pharm Sci. 2015.
- [27] Karmakar I, Saha P, Sarkar N, Bhattacharya S, Halder PK. Neuropharmacological assessment of *Curcuma caesia* rhizome in experimental animal models. Orient Pharm Exp Med. 2011;11(4):221–225.
- [28] Arulmozhi DK, Sridhar N, Veeranjanyulu A, Arora SK. Preliminary mechanistic studies on the smooth muscle relaxant effect of hydroalcoholic extract of *Curcuma caesia*. J Herb Pharmacother. 2006;6(3–4):117–124.
- [29] Fathima SN, Ahmad SV, Kumar BR. Evaluation of in-vitro thrombolytic activity of ethanolic extract of *Curcuma caesia* rhizomes. Int J Pharma Res Rev. 2015;4(11):50–54.
- [30] Gill R, Kalsi V, Singh A. Study on anthelmintic activity of *Curcuma caesia*. J Pharm Res. 2011;4(9).
- [31] Paliwal P, Pancholi SS, Patel RK. Pharmacognostic parameters for evaluation of the rhizomes of *Curcuma caesia*. J Adv Pharm Technol Res. 2011;2(1):56–61.
- [32] Behura S, Srivastava VK. Chemical composition and antimicrobial activity of essential oil of *Curcuma caesia*. Indian Perfum. 2004;48(1):83–87.
- [33] Lal J. Isolation and characterization of phytoconstituents from rhizomes of *Curcuma caesia*. Asian J Chem. 2012;24(9):4051–4054.
- [34] Baghel SS, Baghel RS, Sharma K, Sikarwar I. Pharmacological activities of *Curcuma caesia*. Int Res J Pharm. 2013;4(3):8–11.