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Curcuma caesia Roxb. - Update of phytochemicals and pharmacological properties

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Abstract

Curcuma caesia Roxb. commonly known as 'black turmeric' is an erect rhizomatous herb characterized by bluish-black rhizomes and leaves with a deep red-violet midrib. It is a native of northeast and central India and also found in Java and Myanmar. The plant is used in traditional medicine for the treatment of several metabolic disorders, leukoderma, leprosy, rheumatic complaints, bronchial disorders, menstrual disorders, gastrointestinal problems, neurological disorders, cancer and diabetes. The rhizomes contain 1.3-7.14% anthocyanins which determine its bluish black hue. 1,8-cineole, camphor, ar-turmerone, linalool, ocimene, ar-curcumene, zingiberol, curzerenone and tropolone were reported as the major components of rhizome oil from different geographical locations. The leaf oil is dominated by 1,8-cineole, camphor and borneol. Furanodienone and curzerenone were identified as the marker compounds for determining the quality of rhizomes. The present review is an update of its phytochemical constituents and pharmacological properties.

Keywords: *Curcuma caesia*, black turmeric, 1,8-cineole, camphor, ar-turmerone, curzerenone, furanodienone, pharmacological properties

Introduction

Curcuma caesia Roxb. popularly known as 'black turmeric' is an underutilised herb of the genus *Curcuma* of the family Zingiberaceae. It is a native of northeast and central India and also found in Java and Myanmar. It is cultivated as a medicinal plant in Southeast Asian countries. The rhizomes of this plant are used as stimulants, anti-diarrheal, diuretic, anti-emetic and for wound healing in India, Indonesia, Thailand and Malaysia (National Medicinal Plants Board, 2008). *Curcuma caesia* is an erect, perennial rhizomatous herb that grows to a height of 0.5–1.0 m. The rhizomes are deep bluish black in colour with pungent smell and hot bitter taste. It has vertical, oblong leaves with a deep red-violet patch, which runs throughout the whole lamina (Sharma *et al*. 2011).

Fig. 1. Morphological features of *C caesia*. A. field view; B. leaf; C. inflorescence and D. rhizome

Black turmeric is used for tantric sadhana and medication by tribal people. Northern tribes use rhizomes as a talisman to keep the evil spirits away. The name '*Kali haldi*' originated from the use of the rhizomes in *Kali puja* in West Bengal. It is also referred to as 'black zedoary' or 'black turmeric', due to its unique bluish-black inner part of rhizomes. In West Bengal it finds an important place in traditional system of medicine and is also used as a substitute for turmeric in fresh state (Wikipedia, 2017).

In traditional medicine, the rhizomes are used to treat leucoderma, leprosy, asthma, tumours, piles, menstrual disorders and bronchitis. The rhizomes and leaves of the plant are used in the treatment of ulcers, gastrointestinal disorders, liver inflammations, hepatic disorders, menstrual disorders, diabetes, bruises, boils, scabies and for wound healing (Rajkumari & Sanatombi 2017). In tribal medicine the rhizome is made into a paste and applied externally to treat rheumatic complaints,

sprains, bruises, bronchitis, skin diseases, psoriasis and inflammations (Angel *et al.* 2012). In Manipur, the rhizome paste is applied on bruises and contusions to relieve pain (Sarangthem & Haokip 2010, Sharma *et al.*2011). Adi tribes of Arunachal Pradesh use a decoction of fresh rhizomes to treat diarrhoea. The paste of fresh rhizome is applied in case of snake and scorpion bite by Khamti tribe of Lohit district (Kagyung *et al.* 2010; Tag *et al.* 2007). Fresh tubers are aromatic with an intense camphoraceous odour and used in cosmetics. This species is exploited by the pharmaceutical industries as it gives protection against some least curable and chronic diseases such as Alzheimer's disease and other inflammatory bowel diseases (Benya *et al.* 2023). *Curcuma caesia* leaves are used by farmers to stimulate rice seed germination and dried leaves are used for fuel purpose (Lalitha *et al. 1995*). Ethnobotanical uses of the plant are indicated in Table1.

Table 1. Ethno-botanical uses of *Cucuma caesia*

Diseases	Reference
Tonsillitis, Sprains, Bruises, Asthma, Piles	Devi *et al.* 2014
Leukoderma, Epilepsy, Jaundice, Dysentery	Sarangthem *et al.* 2010
Diarrhoea, Cough, Well Urination	Devi *et al.* 2015

Although several reviews are available on the medicinal and pharmacological properties of *C. caesia* (Ibrahim *et al.* 2023a, Kataki & Bhattacharjee 2020, Borah *et al.* 2020, Borah *et al.* 2019, Rajkumari & Sanatombi 2017, Jose & Thomas 2014, Das *et al.* 2013) the information on the phytochemical constituents of the species is scanty. Present review is an attempt to update the available information on its chemical constituents and pharmacological properties.

Phytochemistry

Starch, a dominant component of the *Curcuma* rhizomes, has been traditionally used as a food coloring and functional food. The starch content varied between 39.61-56.5% among 7 genotypes of *C. caesia* (Sajitha & Sasikumar 2015). Van Hung and Vo (2017) reported 20% resistant starch in the rhizomes. Resistant starch is a type of carbohydrate that doesn't get digested in our small intestine; but it ferments in large intestine and feeds beneficial gut bacteria. Its starch contains nutrients such as proteins, fibre, minerals and vitamins and has applications as a functional food in food and pharmaceutical industries. Due to its low solubility, *C. caesia* starch can be used in metabolic products and textiles as well. Angel *et al.* (2013) isolated about 1% non-starch polysaccharides from the rhizomes with antioxidant and anti-inflammatory activity. The polysaccharide was constituted by the monosaccharide units arabinose, galactose, glucose, rhamnose and glucuronic acid.

The rhizomes also contain 4.43% crude fibre, 5.93% protein, 3.79% fat and 5.64% carbohydrate (Bhardwaj *et al.* 2023). Table 2 shows the proximate composition of rhizomes. Freshly harvested rhizomes yield 0.37-1.5% essential oil (Mukunthan *et al.* 2014, Pandey & Chowdhury 2003, Angel *et al*. 2014, Singh *et al.* 2021). More than 130 constituents, majority being terpenes, have been reported from *C. caesia*. Tables 3 & 4 reveal various chemical constituents reported from this plant. In addition to these secondary metabolites glucose, sucrose, gallic acid, formic acid, threonine, valine and choline have been characterized from rhizomes (Ibrahim *et al*. 2023).

Table 2. Proximate composition of *C. caesia* rhizome

Sl. No.	Parameter	Values (g/100 g)
1	Ash content	15.7
2	Moisture content	9.7
3	Crude fiber	4.43
4	Nitrogen content	4.89
5	Crude protein	5.93
6	Crude fat	3.79
7	Carbohydrate content	5.64
8	Total energy (Kcal)	76
9	Water content	59

Source : Bhardwaj *et al.* (2023).

Rhizome oil

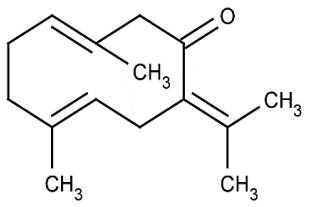
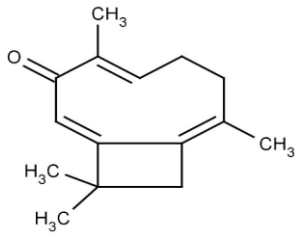
Wide variation in composition of rhizome oil has been reported in *C. caesia* grown at different geographical conditions. Benya *et al*. (2023) evaluated 50 genotypes from 10 different agroclimatic zones of Odisha for oil yield and anthocyanin content. Oil content in rhizomes ranged between 0.6-2.55% and the highest was recorded from Koraput (Eastern Ghat High Land Region) and the lowest from Mid Central Table Land region.

Over 130 constituents of rhizomes have been characterized. A preliminary study on the essential oil components of rhizome showed the occurrence of camphene, bornylene, d-camphor and sesquiterpenes (Sastri, 1962). Banerjee *et al.* (1984) reported linalool (20.42%), d-camphor (18.88%), ocimene (15.66%), ar-curcumene (14.84%), zingiberol (12.60%) , 1, 8-cineole (9.06%) and α-borneol (7%) in the oil. The rhizome oil from Thailand was dominated by 1,8-cineole (30.4%) and appreciable amounts of camphor, curzerene and curzerenone (Bjddhasukh *et al.* 1995). Camphor (28.3%), ar-turmerone (12.3%), (Z)-β-ocimene (8.2%), ar-curcumene (6.9%) and 1,8-cineole (5.3%) represented the prominent constituents of rhizome oil from Central India (Pandey & Chowdhury 2003). The essential oil of *C. caesia* rhizome from northeast India was dominated by eucalyptol

(28.55%), camphor (21.73%) and epicurzerenone (19.62%) (Paw *et al.* 2020). Mukunthan *et al.* (2014) recorded tropolone (15.86 %) as the major component of rhizome oil. Vairappan *et al.* (2013) isolated nine compounds belonging to four chemical skeletons - guainane type (aerugidiol and curcumenol), germacrane type (zederone, furanodiene, germacrone, germacrane 4,5-epoxide and isofuranodienone), elemane type (curzerenone) and carabrane type (curcumenone) from the ethanol extract. Chemotaxonomic analysis indicated *Curcuma caesia*, *C. aeruginosa, C. wenyujin* and *C. malabarica* formed an unique class of *Curcuma* species producing a mixture of the above four types of sesquiterpenes (Vairappan *et al*. 2013).

HPLC analysis and NMR spectral studies by Liu *et al*. (2013) revealed 11 compounds namely, curcumenone, furanodiene, furanodienone, 13-hydroxygermacrone, curdionolide A, curcumenol, alismoxide, zedoarondiol, dihydrocurcumene, eudesma-3, 5-diene and 4,7,7- trimethylbicyclo [2.2.1] heptan-1-ol from the hexane and methanol extracts of rhizomes. Al-Amin *et al.* (2019) characterized eighteen components of rhizomes of which germacrone, zerumbone, furanodienone, curzerenone, and curcuzederone exhibited potential anticancer property. The chemical structure of major bioactive compounds from *C. caesia* is depicted in Fig. 2.

The yield and composition of *C. caesia* rhizome oil was drastically affected by post-harvest drying and storage conditions (Mahanta *et al.* 2019). Freshly harvested rhizomes or the rhizomes stored under cold conditions (4^0C) yielded maximum oil with consistent composition. Storage and drying at high temperature resulted in significant reduction of oil yield and rearrangement of thermolabile compounds, leading to the formation of rearranged metabolites. The study indicated that high-temperature drying led to the conversion of the sesquiterpene furanodienone to curzerenone. Furanodiene, furanodienone, curzerenone, and germacrone were identified as chemical markers for determining the quality of rhizome oil. Chaturvedi *et al.* (2020) studied the antimycobacterial activity of SFE extract of rhizomes. The extract obtained at 50°C and 15 MPa showed the highest zone of inhibition and was represented by β-elemene, curzerenone, boldenone, and 2-cyclohexen-1-one and 4-ethynyl-4-hydroxy-3, 5, 5-trimethyl.

	
Germacrone	Zerumbone

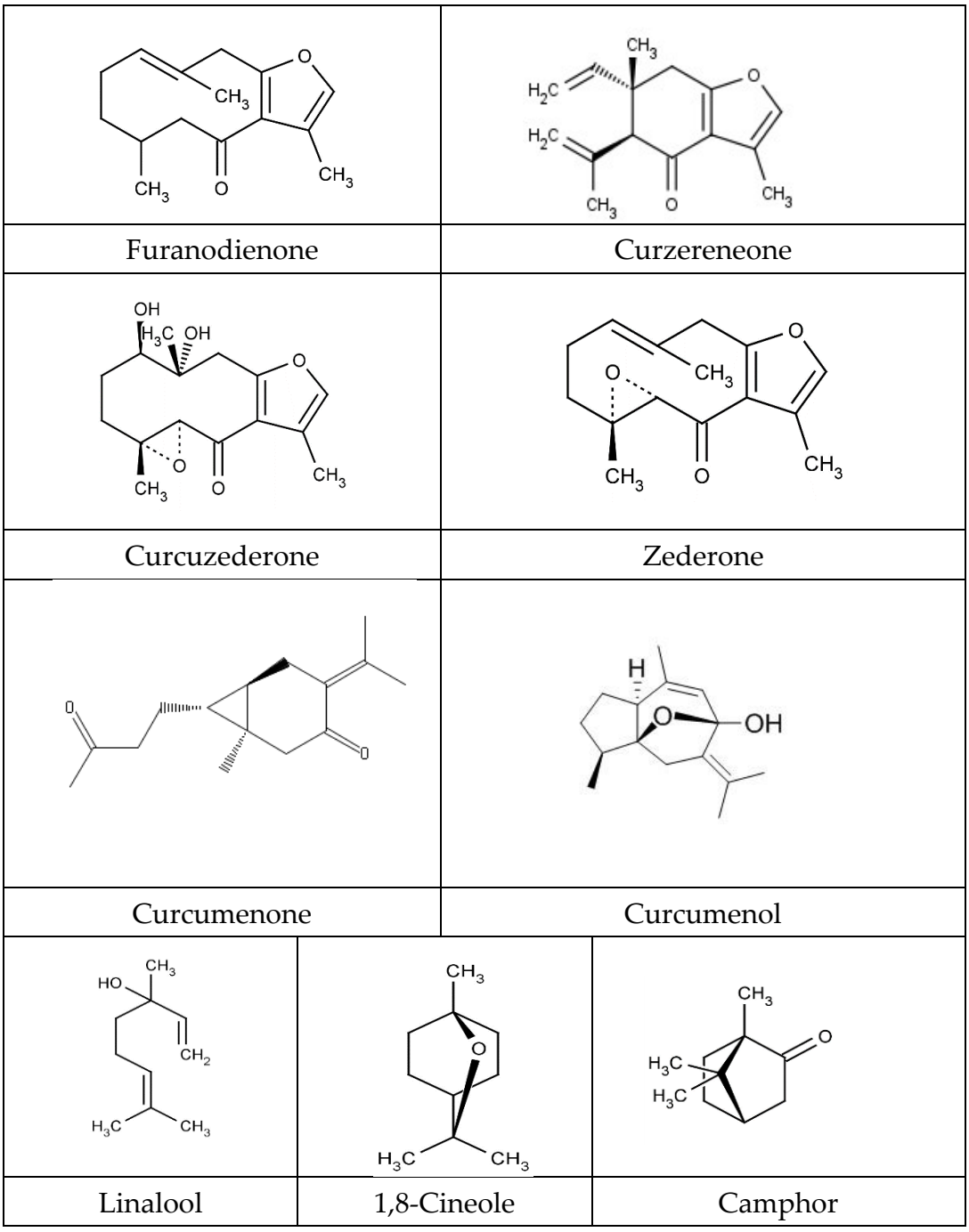


Fig. 2 Major bioactive compounds of *Curcuma caesia*

Jaiswal & Agrawal (2021) observed that essential oil yield and 1,8-cineole content increased in rhizomes grown under elevated UV-B radiation. Fatt *et al.* (2021) observed that the composition of hydrosol produced by hydrodistillation of *C. caesia* was temperature dependant. The hydrosol produced at 60°C, contained mainly oleic acid (12.66%) and n-hexadecanoic acid (8.45%) and loss of these components was noticed at higher temperatures.

Anthocyanins

The rhizomes are rich source of anthocyanin pigments and massively exploited by the food, cosmetics, dye producing and pharmaceutical industries. Benya *et al.* (2023) evaluated anthocyanin content in 50 genotypes grown in ten agroclimatic conditions of Odisha and noticed wide variation ranging from 1.3% to 7.14%; fifteen genotypes had above 7% anthocyanin content. The highest anthocyanin content was observed in rhizomes of North Eastern Ghat region (Koraput) and Eastern Ghat High Land region. The genotype collected from Koraput recorded maximum anthocyanin followed by that from Pottangi (7.13%). The studies by Benya *et al.* (2023) indicated that the rhizomes from high altitude regions contain higher proportion of anthocyanin. The anthocyanin content increased with the deep inner core colour of the rhizomes. According to Mohan Kumar *et al.* (2020) the biochemical constituents and quality of the rhizome were determined by the inner blackish-blue colour of the rhizome. An optimum level of anthocyanin content (>6%) was observed in the Eastern Ghat region.

Curcuminoids

Although diarylheptanoids (curcuminoids) were the major secondary metabolites of the genus *Curcuma, C caesia* is an exception. The rhizomes yielded very low level of curcuminoids. Sarangthem and Haokip (2010) recorded the occurrence of curcuminoids, phenolics, flavonoids and alkaloids in *Curcuma caesia*. Studies by Dutta (2015) indicated that curcumin content was lowest in *Curcuma caesia* (8 mg/100 g) among the six *Curcuma* species evaluated. Sajitha (2017) analysed 7 accessions of *C. caesia* for curcuminoids and it was in the range of 0.024-0.039% by spectrophotometric method. HPLC analysis indicated that the contribution of curcumin (C), demethoxy curcumin (DMC) and bis-demethoxy curcumin (BDMC) to total curcuminoids was 0.095-0.163 x 10^{-2} %, 0.033-0.07x 10^{-2} % and 0.005-0.009x10^{-2} % respectively.

Leaf oil

Very few reports are available on the leaf oil constituents of *Curcuma caesia.* The leaf yielded 0.3-1.25% dark yellow volatile oil, with strong aroma (Behura & Srivastava 2004, Borah *et al.* 2019, Benya *et al*. 2023). The genotype collected from Koraput (Eastern Ghat High Land Region) recorded highest leaf oil yield (Benya *et al*. 2023). The major component of the oil, camphor varied from 26.3% to 38% among the genotypes (Benya *et al*. 2023). A total of 37 compounds have been identified based on GC-MS analysis. Behura & Srivastava (2004) characterized 13 components of leaf oil from Orissa, which contained 1,8-cineole (27%) , camphor (16.8%), β- pinene (6.3%), β-caryophyllene (8.7%) and borneol (5.2%) as the chief components. Borah *et al.* (2019) identified 32 constituents of leaf oil which was dominated by 1,8-cineole (16.43%), camphor (11.56%), β-pinene (6.54%) and borneol (4.7%). Table 4 depicts the components identified from the leaf oil.

Table 3. Chemical constituents of *Curcuma caesia* rhizome

S No	Compound	Reference	S No	Compound	Reference	S No	Compound	Reference
1	Aerugidiol	[1,2]	46	Curcuzederone	[1,15]	91	Ledol	[7]
2	α-Acorenol	[3]	47	Curdionolide A	[4]	92	Linalool	[6,8]
3	Alismoxide	[1,4]	48	Curzerene	[3,5,11,15]	93	1,2- Longidione	[5]
4	d- Amorphene	[5]	49	Curzerenone	[1,2, 11,13]	94	Luteolin	[15]
5	Amadannulen	[15]	50	p-Cymene	[6]	95	Megastigmatrienone	[7]
6	Arglabin	[3]	51	Cyclohexanol, 1,3,3-trimethyl-2- (3-methyl-2-methylene-3-butenylidene)-(2Z)	[7]	96	Menthone	[6]
7	Borneol	[6,7,8]	52	Dehydrocurdione	[1]	97	Methyl steorolate	[3,5]
8	Bornylene	[9]	53	Demethoxycurcumin	[15]	98	Myrcene	[5]
9	Bornyl acetate	[6]	54	Dihydrocurcumene	[4]	99	τ-Muuralol	[3]
10	Bicyclo- (10,10)- tridec-1-ene	[5]	55	β- Elemene	[3,5,6,7]	100	Neointermedol	[5]
11	Bicyclo[3.1.0]hexane-3-one	[7]	56	γ-Elemene	[3,5,6]	101	5-Nonanone	[6]
12	α-Bulnesene	[3,7]	57	δ-Elemene	[3,6]	102	2- Nonanol	[3,5]
13	1,1,4,4-Tetramethyl-2,3-tetralindione	[7]	58	β-Elemenone	[3,7]	103	Occidentalol	[7]
14	(1S,10S),(4S,5S)-Germacrone-1, 4-diepoxide	[1]	59	Elemol	[6]	104	δ-1(9)-2-Octalone	[7]
15	(Z)-β-Ocimene	[6,8]	60	Endo-fenchol	[6]	105	β-Pinene	[5]
16	(Z,E)-α-Farnesene	[6]	61	Endo- borneol	[3]	106	Rosifoliol	[7]

17	1,8-Cineole	[3,5,6,7,8,10,11]	62	Endo-fenchyl acetate	[6]	107	Rotundene	[3]
18	2,7-Dimethyl oxepine	[7]	63	Epicurzerenone	[5,10]	108	α-Selinene	[3,7]
19	4-(Dimethylamino)-,3,5-dimethyl-phenol	[7]	64	Epiglobulol	[5,6]	109	β-Selinene	[6, 7]
20	4,7,7- Trimethylbicyclo [2.2.1] -heptan-1-ol	[4]	65	Estragole	[6]	110	3, 7(11) – Selinadiene	[3]
21	4-Dimethyamino-benzoic acid	[7]	66	α-Eudesmol	[3]	111	Selina-4(15),7(11)-dien-8-one	[15]
22	13- Hydroxygermacrone	[4]	67	Eudesma-3, 5-diene	[4]	112	Spathulenol	[3,7]
23	6-Isopropenyl-4,8a-dimethyl- 1,2,3,5,6,7,8,8a-octahydro-napthalen-2-ol	[7]	68	Furanodiene	[2,4]	113	β- Sitosterol	[3]
24	6-Isopropylidene-bicyclo[3.1.0]hexane	[7]	69	Furanodienone	[1,4,13]	114	α-Terpineol	[3,5,7]
25	6-Methyl-2(1H)-pteridinone	[7]	70	Germacran-4,5-epoxide	[2]	115	α-Terpinolene	[6]
26	γ-Cadinene	[7]	71	Germacrene A	[5]	116	ar-Turmerone	[6,7]
27	δ-Cadinene	[3,7,]	72	Germacrene B	[5,6]	117	β- Turmerone	[15]
28	τ-Cadinol	[3]	73	Germacrene D	[3,5]	118	Terpinen-4-ol	[3,5,6]
29	Camphanyl acetate	[5]	74	Germacrone	[1,2,3,15]	119	Thujene	[5]
30	Camphene	[5,6,9]	75	13-hydroxygermacrone	[4,15]	120	4,7,7-trimethylbicyclo [2.2.1] heptan-1-ol	[4]
31	Camphor	[3,5,6,7, 8,9,10,11,12]	76	Globulol	[7]	121	Tropolone	[7]
32	Carveol	[5]	77	β-Guaiene	[7]	122	Velleral	[3,5]
33	β-Caryophyllene	[3,5,6,7]	78	Hydroxyl valerenic acid	[5]	123	Viridiflorol	[6]

34	Caryophyllene oxide	[7]	79	1-hydroxy-1,7-bis(4-hydroxy-3-methoxyphenyl)-(6*E*)-6-heptene-3,4-dione	[15]	124	Wenyujinin B	[1]
35	β- Copaene	[3]	80	1-(4-Hydroxy-3,5-dimethoxyphenyl)-7-(4-hydroxy-3-methoxyphenyl)-(l*E*,6*E*)-1,6-heptadiene-3,4-dione	[15]	125	Xanthinin	[3]
36	z-α-Copaene-8-ol	[7]	81	Isoborneol	[3,5,7]	126	Xanthorrizol	[15]
37	Coniferol	[3]	82	Isobornyl acetate	[7]	127	Zederone	[1,2]
38	ar-Curcumene	[6,8]	83	Isocurcumenol	[5]	128	Zedoalactone A	[15]
39	γ-Curcumene	[6]	84	Isofuranodienone	[2]	129	Zedoalactone B	[1,15]
40	β-Cubebene	[6]	85	Isomenthone	[6]	130	Zedoarolide B	[1]
41	Curcumenol	[1,2,4,5]	86	Isozedoarondiol	[1]	131	Zedoarondiol	[1,4,15]
42	Curcumenone	[1,2,4,5]	87	Isoaromadendrene epoxide	[3]	132	Zerumbone	[1]
43	Curcumin	[15]	88	Isofuranogermacrene	[3]	133	Zerumin B	[15]
44	Curcuminol G	[1]	89	Khusimone	[5]			
45	(Z) -7-methoxy-1, 5-dihydrobenzo [c] oxepine	[14]	90	Zingiberol	[8]			

1. Al -Amin *et al.* 2019; 2. Vairappan *et al.* 2013; 3. Chaturvedi *et al.* 2021; 4. Liu *et al.* 2013; 5. Jaiswal & Agrawal 2021; 6. Pandey & Choudhury 2003; 7. Mukunthan *et al.* 2014; 8. Banerjee *et al.* 1984; 9. Sastry 1962; 10. Paw *et al.* 2020; 11. Bjddhasukh *et al.* 1995; 12. Fatt *et al.* 2021; 13. Mahanta *et al.* 2019; 14. Ghosh *et al.* 2013; 15. Ain Ibrahim *et al.* 2023

Table 4. Chemical constituents of *Curcuma caesia* leaf

S No	Compound	Reference	S No	Compound	Reference
1	Aromadendrene	[1]	20	Germacrone	[1]
2	Borneol	[1,2]	21	Germacrene – B	[1]
3	l-Borneol	[1]	22	Germacrene – D	[1]
4	Camphene	[1]	23	α – Humulene	[1]
5	Camphor	[1,2]	24	Junipene	[1]
6	t – Caryohyllene	[1,2]	25	Limonene	[2]
7	Caryophyllene oxide	[1]	26	l- Linalool	[1,2]
8	*t*-Carveol	[1]	27	Methyl eugenol	[2]
9	*Z*- Carveol	[1]	28	t-Methylisoeugenol	[2]
10	Coniferin	[1]	29	Muurolene	[1]
11	Curdione	[1]	30	Myrcene	[2]
12	Curzerene	[1]	31	Neocurdione	[1]
13	Eucalyptol	[1,2]	32	Nerolidol	[1]
14	β – Elemene	[1,2]	33	α – Pinene	[1,2]
15	δ – Elemene	[1]	34	β – Pinene	[1,2]
16	α-Eudesmol	[1]	35	Phytol	[1]
17	β – Farnesene	[1]	36	a- Terpineol	[2]
18	α – Fenchyl acetate	[1]	37	Verbenol	[1]
19	Xanthinin	[1]			

Source: [1]. Borah *et al.* (2019) and [2]. Behura & Srivastava (2004)

Pharmacological properties

C. caesia is reported to have diverse pharmacological properties which include antioxidant, anti-inflammatory, antimicrobial, anticancer, neuropharmacological and antiulcerogenic activities (Arulmozhi *et al.* 2006, Jose & Thomas 2014, Borah *et al.* 2020, Paw *et al.* 2020, Baghe *et al.* 2013, Ibrahim *et al.* 2023a).

Antioxidant activity

The essential oil of rhizome possessed potent antioxidant activity. Among the solvent extracts the ethanolic extract of rhizome showed maximum DPPH free radical

scavenging activity. The IC_{50} value of ethanolic extract was 418 µg/ml where as that of methanolic, ethyl acetate and aqueous extracts was 441.90 µg/ml, 561µg/ml and 591 µg/ml respectively (Devi *et al.* 2015). Potent antioxidant (IC_{50}= 48.08±0.003 µg/mL) activity of the rhizome oil was reported by Paw *et al.* (2020). Reenu *et al.* (2015) determined antioxidant potential of sequential extracts of fresh and dried rhizomes of *C. caesia* and recorded highest activity with chloroform extract. Chaturvedi *et al.* (2021) observed maximum activity with the methanol extract among the solvent extracts prepared by cold-percolation. The rhizome extracts inhibited lipid peroxidation (Liu *et al.* (2013). By ^{1}HNMR- based metabolomic approach Ibrahim *et al.* (2023b) correlated the constituents of rhizome with antioxidant activity. They observed that 1-hydroxy-1,7-bis(4-hydroxy-3-methoxyphenyl)-(6*E*)-6-heptene-3,4-dione, valine, luteolin, zedoardiol, β-turmerone, selina-4(15),7(11)-dien-8-one, zedoalactone B and germacrone, were positively correlated with the antioxidant activity.

Anti-inflammatory activity

The rhizome oil exhibited strong, anti-inflammatory activity with IC_{50} value of 121.7±0.0013 µg/mL (Paw *et al.* 2020). According to Borah *et al.* (2019) anti-inflammatory potential of leaf oil was higher than that of the standard anti-inflammatory drug, diclofenac sodium. The leaf oil exhibited negligible toxicity indicating the possibility of developing it as an anti-inflammatory drug. Liu *et al.* (2013) tested anti-inflammatory activity of hexane and methanolic extracts by COX-1 and COX-2 enzyme inhibition assays. The extracts inhibited COX-2 enzyme and was not active against COX-1 enzyme. Interestingly, curcumenone isolated from the extract showed inhibition of COX -1 enzyme activity.

Anticancer potential

Curcuma caesia is traditionally used for the treatment of cancer, bruises, and inflammation. Anticancer potential of its extracts on various types of cancer has been reported. Das *et al.* (2012) reported anti-ulcer activity of the ethanolic extract of the rhizome of *Curcuma caesia* on albino rats. Hexane extract of *C. caesia* rhizome exhibited inhibition of HepG2 cancer cell lines (Mukunthan *et al*. 2017). Methanol extract of rhizomes exhibited promising antitumor activity on Ehrlich's ascites carcinoma treated mice (Karmakar *et al*. 2013). Anticancer effect of methanol extract of the *C. caesia* against diethylnitrosamine-induced cancer in mouse liver was reported by Hadem *et al.* (2014). Methanolic extract of *C. caesia* showed protective effect against the cyclophosphamide induced toxicity in liver and kidney of mice (Devi & Mazumder 2016). Rhizome extracts showed inhibitory effect on the migration of triple-negative human breast cancer cell lines (MCF-7) and five bioactive constituents viz., germacrone, zerumbone, furanodienone, curzerenone, and curcuzederone were isolated. The compounds showed varying levels of inhibitory effect on the tested cell lines and maximum inhibitory activity was exhibited by zerumbone followed by curcuzederone (Al -Amin *et al.* 2021).

Table 5. Antimicrobial properties of *Curcuma caesia*

Activity	Extract	Organism	References
Antibacterial	Rhizome extracts (methanol, acetone and ethyl acetate)	*Enterococcus faecalis Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae, Proteus mirabilis, Pseudomonas aeruginosa,Salmonella typhi, Serratia marcescens, Shigella flexneri*	Chaturvedi *et al.* 2021
	Rhizome hexane extract	*Bacillus cereus, Salmonella typhi Vibrio cholerae*	Jose *et al.* 2014
	Rhizome chloroform Extract	*Bacillus cereus,* P*seudomonas aeruginosa S. aureus, Salmonella typhi, Serratia marcescense, Streptococcus haemolyticus, Vibrio cholera*	Jose *et al.* 2014
	Rhizome acetone extract	*Bacillus cereus, Staphylococcus aureus, Streptococcus haemolyticus,*	Jose *et al.* 2014
	Rhizome methanol extract	*Enterobacter aerogens, Pseudomonas aeruginosa, Salmonella typhi, Serratia marcescens, Vibrio cholerae*	Jose *et al.* 2014
	Leaf, stem and root extracts	*Bacillus cerus, Staphylococcus epidermidis, Staphylococcus aureus Bacillus subtilis*	Pandey & Gupta 2014
	Oleoresin	*Bacillus subtilis, Escherichia coli. Staphylococcus aureus,*	Rajamma *et al.* 2012
	Leaf essential oil	*Bacillus subtilis, Bacillus cereus, Staphylococcus aureus, Staphylococcus typhimurium*	Borah *et al*. 2019
Antifungal	Leaf essential oil	*Aspergillus fumigatus, Aspergillus niger Candida albicans, Saccharomyces cerevisiae*	Borah *et al*. 2019
	Leaf essential oil	*Curvularia oryzae, Aspergillus niger, Aspergillus flavus.*	Banerjee & Nigam 1976
	Leaf, stem and root extracts	*Bacillus cerus, Bacillus subtilis, Staphylococcus aureus, Staphylococcus epidermidis, Escherichia coli, Proteus vulgaris, Pseudomonas aeruginosa and Klebsiella pneumoneae.*	Pandey & Gupta 2014

Antibacterial activity

Essential oil of *C. caesia* leaf exhibited antimicrobial activity against *Bacillus subtilis, Bacillus cereus, Staphylococcus aureus* and *Salmonella typhimurium* (Borah *et al.* 2019). The extracts of *C. caesia* rhizomes showed differential anti-bacterial activity against Gram positive and Gram-negative bacteria in a dose-dependent manner. Among Gram positive bacteria, acetone extract showed

maximum inhibitory activity against *Staphylococcus aureus* which was comparable to that of standard antibiotic, streptomycin. The hexane extract of *C. caesia* showed inhibitory effect against *Bacillus cereus* (Borah *et al*. 2019). Chloroform extract of *rhizomes* exhibited maximum activity *against Serratia marcescense* and moderate activity against *Salmonella typhi* and *Vibro cholera*. Ethanolic extract of *C. caesia* showed antibacterial activity against *Staphylococcus aureus* (Ahmed *et al.* 2012). According to Jose and Thomas (2014) anti-bacterial activity of *C. caesia* was more prominent on Gram negative bacteria. The essential oil of rhizome possessed a strong antibacterial effect against the bacterial strains *B. subtilis* and *B. cereus* (MIC value =7.5 μg/mL), better than the standard drug ciprofloxacin for bacteria (Paw *et al*. 2020). The methanol extract of roots exhibited promising antibacterial activity against Gram positive bacteria and chloroform extracts against Gram negative bacterial species (Pandey & Gupta 2014).

Antifungal activity

Essential oil of *C. caesia* leaf exhibited antifungal effect against *Aspergillus fumigatus, A. niger, Saccharomyces cerevisiae* and *Candida albicans* (Borah *et al.* 2019). Fungitoxic activity of the rhizome oil against *Curvulari oryzae, Aspergillus niger* and *A. flavus* was reported by Banerjee and Nigam (1976*).* Its leaf essential oil showed growth inhibition against *Aspergillus fumigatus, A. niger,* and *Saccharomyces cerevisiae* and *Candida albicans* (Borah *et al*. 2019). The protein extract of rhizomes exhibited antifungal activity against *C. albicans* (Mannangatti & Narayanasamy 2008). Strong antifungal activity of rhizome oil against *Saccharomyces cereviaceae* with MIC value of 2.5 μg/mL was reported by Paw *et al. (*2020). They also observed that the rhizome oil was superior to the standard drug fluconazole for fungus.

Antidiabetic property

Methanolic extract of *C. caesia* rhizome inhibited α-amylase and α-glucosidase activities *in vitro.* The extract showed potential hypoglycemic activity in Streptozotocin-induced diabetic rats (Majumder *et al.* 2017). Jain and Parihar (2018) observed that ethyl acetate extract showed higher inhibitory activity of α-amylase compared to curcumin. By ^{1}HNMR-based metabolomic approach Ibrahim *et al.* (2023) reported that curdione and 1-(4-hydroxy-3,5-dimethoxyphenyl)-7-(4-hydroxy-3-methoxyphenyl)-(l*E*,6*E*)-1,6-heptadien-3,4-dione were positively correlated with α-glucosidase inhibitory activity (Ibrahim *et al.* 2023b.) Grover *et al*. (2019) reported the possibility of using *C. caesia* in the treatment of diabetic neuropathy due to its antioxidant, anti-inflammatory, CNS depressant and antimicrobial potential.

Neuroprotective activity

Curcuma caesia extracts exhibited neuro protective activity in clinical trials. Oral administration of methanol extract-based fractions of rhizomes to hypoxia induced and amnesia induced Wistar albino female rats showed significant memory-enhancing, anxiolytic and antidepressant effects (Borah *et al*., 2021). Zederone, a component of *C. caesia* rhizome improved cognition capacity

in the aluminium-induced demented rats (Borah *et al.* 2022).

Muscle relaxant activity

Hydroalcoholic extract of *C. caesia* rhizomes showed dose-dependent, non-specific muscle relaxation activity in guinea pig (Arulmozhi *et al.* 2006). Karmakar *et al.* (2011 a, b) reported analgesic, locomotor depressant, anticonvulsant and muscle relaxant effects of methanol extract of rhizome in experimental animal models. The studies by Borah *et al*. (2021) indicated that the rats administered with ethyl acetate fraction of rhizome extract acquired significant memory-enhancing, anxiolytic and antidepressant effects.

Thrombolytic activity

C. caesia rhizome extract showed thrombolytic activity (Fathima *et al.* 2015, Bharathi *et al.,* 2017). Bharathi *et al.* (2017) compared the clot lysis activity of the rhizome extract and its nano form. *C. caesia* rhizome extract showed removal of clot by 38.75%. Silver nanoform of ethanolic rhizome extract possessed higher clot dissolving activity (51%) compared to the parent extract indicating its use as thrombolytic drug (Bharathi *et al*. 2017).

Antimutagenic property

The antioxidant phytochemicals inhibit cancer initiation by modulating phase I and phase II enzymes involved in the mutation process and maintaining the DNA structure. The studies by Devi *et al*. (2015) showed strong activity of the rhizome extract against cyclophosphamide induced mutagenicity in *Salmonella typhimurium* strains.

Anthelmintic activity

Gill *et al*. (2011) studied anthelmintic activity of solvent extracts of *Curcuma caesia* and *C. zedoaria*. The efficacy of the extracts on paralysis time and time of death of earthworms was studied. The extracts of both the plants exhibited dose dependant activity. The results indicated that the ethanol extract of *Curcuma caesia* was the most effective.

Toxicity studies

Curcuma caesia extracts showed toxicity against several cell lines *in vitro* and animal models (Mukunthan *et al*. 2017, Karmakar *et al*. 2013, Al -Amin *et al.* 2021). Meanwhile studies on the acute toxicity of the extracts in mice and rats indicated that oral administration the extract at a concentration of 2000 mg/kg body weight had no adverse effect or behavioural changes in the animals enabling its utility as safe therapeutics for industrial applications (Borah *et al*. 2021).

Bioactive constituents

Curcuma caesia contains several potential bioactive constituents. Eucalyptol (1,8-cineole) one of the major components of rhizome oil is widely used in the production of cough syrups and mouthwashes. It is a well-known bronchodilator (Fischer & Dethlefsen, 2013). Its antimicrobial activity in biofilm cultures has been reported (Hendry *et al*. 2009). Eucalyptol is extensively used in aromatherapy. Camphor, a chief constituent of rhizome oil is bestowed with anti-inflammatory, analgesic, anticancer and antimicrobial activities. It relieves pain and is also used to treat skin ailments (Singh *et*

al. 2023, Lee *et al*. 2022). Anti-inflammatory, analgesic, antimicrobial, antioxidant and anticancer properties of linalool have been reported. Several *in vivo* studies have confirmed various effects of linalool on the central nervous system (Kamatou & Vilijoen 2008). Furanodienone and curzerenone present in rhizome oil displayed anti-inflammatory, antimicrobial and anticancer activities (Joshi & Mathela 2012, Li *et al.* 2011, Al-Amin *et al.* 2019). Al -Amin *et al.* (2019) reported promising anticancer activity of the rhizome extracts and the active principles viz., germacrone, zerumbone, furanodienone, curzerenone and curcuzederone against human breast cancer cell lines. Riaz *et al.* (2020) documented wide spectrum of activities of germacrone which include anti-inflammatory, anticancer, antiviral, anti-androgenic, antimicrobial, antifungal, neuroprotective and insecticidal activities. Zerumbone also exhibited multiple biological activities viz., anticancer, antimicrobial, antioxidant, anti-inflammatory and antitumor activities (Girisa *et al.* 2019). Analgesic property of curcumenol and zederone have been reported. Zedoalactone B and isozedoarondiol possessed strong inhibitory activity against LPS-induced nitric oxide production and could be useful in preventing inflammatory diseases (Sun *et al*. 2017). Curcumenone inhibited cox-1 enzyme involved in inflammatory responses, contributing to its anti-inflammatory activity (Liu *et al.* 2013). The traditional use of the *C. caesia* in treatment of various aliments is validated by the observed pharmacological activities of its extracts and phytochemicals.

Conclusion

C. caesia is an underexploited herb which is gaining importance among researchers due to its numerous health benefits and low toxicity values. Most of its studies are centred on the rhizomes while other parts of the plant are equally beneficial. Hence there is scope for exploring leaf, stem and inflorescence of the plant for new phytochemicals which can be exploited for beneficial effects. Although a few pharmacological properties have been validated through clinical studies, in depth studies are warranted on this plant to develop natural drug formulations that can be used in complementary and alternative health therapy. Further, the rhizomes are rich source of anthocyanins which needs to be exploited for their beneficial health effects.

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References

Ahmed S, Mukundam B & Das S 2012 A comparative study of the antibacterial activity of the ethanolic extracts of *Phlogacanthus Thyrsiflorus, Hottuynia Cordata, Curcuma Caesia* and *Syzygium Jumbos.* International Res. J. Pharm. 3(9): 282–285.

Al-Amin M, Eltayeb N M, Khairuddean M & Salhimi S M 2019 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. 1–5. doi:10.1080/14786419.2019.1690489.

Angel G R, Vimala B & Bala Nambisan 2012 Phenolic content and antioxidant activity in five underutilized starchy *Curcuma* species. International Journal of Pharmacognosy and Phytochemical Research. 4(2): 69–73.

Angel G R, Vimala B & Bala Nambisan 2013 Isolation and Evaluation of Bioactive Non Starch Polysaccharides from Eight Starchy *Curcuma* Species. The Natural Products Journal 3: 204–211, DOI : 10.2174/2210315511303999000 09.

Arulmozhi D K, Sridhar N, Veeranjaneyulu A & Arora K S 2006 Preliminary Mechanistic Studies on the Smooth Muscle Relaxant Effect of Hydroalcoholic Extract of *Curcuma caesia*. J. Herb. Pharmacother 6: 3–4.

Baghe S O, Baghel R S, Sharma K & Sikarwar L 2013 Pharmacological activities of *Curcuma caesia*. International Journal of Green Pharmacy 7(1): 1–5.

Banerjee A & Nigam SS 1976. Antifungal activity of the essential oil of *Curcuma caesia* Roxb. Indian J. Medical Research 64: 1318–1321.

Banerjee A K, Kaul V K & Nigam S S 1984 Essenze Deriv. Agrum 54(2): 117–121.

Behura S & Srivastava V K 2004 Essential oils of leaves of *Curcuma* species. J. Essent. Oil Res. 16: 109–110.

Benya A, Mohanty S, Hota S, Das A P, Rath C C, Achary KG & Singh S 2023 Endangered *Curcuma caesia* Roxb.: Qualitative and quantitative analysis for identification of industrially important elite genotypes, Industrial Crops and Products 195: 116363 https://doi.org/10.1016/j.indcrop.2023.116363.

Bharathi S V, Anuradha V, Ahmad A & Tajo S M 2017 Thrombolytic activity of *Curcuma amada* and *Curcuma caesia.* Asian Journal of Pharmaceutical and Clinical Research 10: 317–318.

Bhardwaj A K, Kashyap N K, Bera S K, Hait M & Dewangan H 2023 Proximate composition and mineral content analysis of *Curcuma caesia* rhizome. Biochemical Systematics and Ecology 109: 104661.

Bjddhasukh D, Smith J & Ternai B 1995 J. Sci. Fac. Chiang Mai Univ., 21–22(1–2): 14–16.

Borah A, Paw M, Gogoi R, Loying R, Sarma N, Munda S & Lal M 2019 Chemical composition, antioxidant, anti-inflammatory, anti-microbial and in-vitro cytotoxic efficacy of essential oil of *Curcuma caesia* Roxb. leaves: An endangered medicinal plant of North East India. Ind. Crops and Prod. 129: 448–454.

Borah A, Kumar D, Paw M, Begum T & Lal M 2020 A review on ethnobotany and promising pharmacological aspects of an endangered medicinal plant, *Curcuma caesia* Roxb. Turk. J. Bot. 44:

205-213. https://doi.org/10.3906/ bot-1910–33.

Borah S, Sarkar P & Sharma H K 2021 Analysing *Curcuma caesia* fractions and essential oil for neuroprotective potential against anxiety, depression, and amnesia 3. Biotech. 11(5): 240. doi: 10.1007/s13205-021-02793-w. Epub 2021 Apr 26.

Borah S, Sarkar P & Sharma H K 2022 Zederone Improves the Faecal Microbial Profile in Dementia Induced Rat Model: A First Report. CNS Neurol. Disord. Drug Targets. 21(4): 335–342. doi: 10.2174/18715273.

Emran T B, Rahman M A, Uddin M M, Rahman M M, Uddin M., Dash R & Layzu C 2015 Effects of organic extracts and their different fractions of five Bangladeshi plants on in vitro thrombolysis. BMC complementary and alternative medicine 15: 128.

Bharathi S V, Ahmad & Tajo S M 2015 Silver Nanoparticle Synthesis Using *C. Caesia* and *C. amada* Rhizome Extract. International Journal of PharmTech Research 8(7): 142–145.

Chaturvedi M, Rani R, Sharma D & Yadav J P 2020 Effect of temperature and pressure on antimycobacterial activity of *Curcuma caesia* extract by supercritical fluid extraction method. Int. J. Mycobacteriol. 9(3): 296-302. doi: 10.4103/ijmy.ijmy_113_20. PMID: 32862164.

Chaturvedi M, Rani R, Sharma D & Yadava J P 2021 Comparison of *Curcuma caesia* extracts for Bioactive Metabolite Composition, Antioxidant and Antimicrobial Potential Nat. Prod. Res. 35(18): 3131–3135.

Das S, Mondal P & Zaman K 2013 *Curcuma caesia* Roxb. and it's medicinal uses: a review. Int. J. Research in Pharmacy and Chemistry 3: 370–375.

Das S, Bordoloi P, Phukan D & Sing S R 2012 Study of the Anti-Ulcerogenic Activity of the Ethanolic Extracts of Rhizome of *Curcuma caesia* against Gastric Ulcers in Experimental Animals. Asian J. Pharm. Clin. Res. 5: 200–203.

Devi H P, Mazumder P B & Devi LP 2015 Antioxidant and antimutagenic activity of *Curcuma caesia* Roxb. rhizome extracts. Toxicology Reports 2: 423–428.

Devi H P & Mazumder P B, 2016 Methanolic Extract of *Curcuma caesia* Roxb. Prevents the Toxicity Caused by Cyclophosphamide to Bone Marrow Cells, Liver and Kidney of Mice, Pharmacognosy Res. 8(1): 43–49.

Dutta B 2015 Study of secondary metabolite constituents and curcumin contents of six different species of genus *Curcuma*. Journal of Medicinal Plants Studies 3(5): 116–119.

Fathima S N, Ahmad S V & Kumar B NR 2015 Evaluation of in vitro thrombolytic activity of ethanolic extract of rhizomes. The International J. Pharmaceutical Sci ences and Health Care 11: 50–54.

Fatt L C, Rahman N W A, Aziz M A A, & Isa K M 2021 Identification of the Chemical

Constituents of *Curcuma caesia* (Black Turmeric) Hydrosol Extracted by Hydro-distillation Method. In IOP Conference Series: Earth and Environmental Science 765(1): 012025. IOP Publishing.

Fischer J & Dethlefsen U 2013. Efficacy of cineole in patients suffering from acute bronchitis: a placebo-controlled double-blind trial. Cough 9(1): 25. doi:10.1186/1745–9974–9–25.

Ghosh A, Parthadeb G & Chatterjee P 2013 Evaluation of antimicrobial and antifungal potential of (Z) -7-methoxy-1,5 dihydrobenzo[c]oxepine, isolated from *Curcuma caesia* Roxb. Jour nal of Scientific and Innovative Research 2(4): 745–750.

Girisa S, Shabnam B, Monisha J, Fan L, Halim C E, Arfuso F, Ahn K S, Sethi G & Kunnumakkara A B 2019 Potential of Zerumbone as an Anti-Cancer Agent. Molecules. 24(4):734. doi: 10.3390/molecules 24040734.PMID: 30781671; PMCID: PMC6413012.

Grover M, Shah K, Khullar G, Gupta J & Behld T 2019 Investigation of the utility of *Curcuma caesia* in the treatment of diabetic neuropathy. Journal of Pharmacy and Pharmacology 71: 725–732 doi: 10.1111/jphp.13075.

Hadem K L, Sharan R N & Kma L 2014 Inhibitory potential of methanolic extracts of *Aristolochia tagala* and *Curcuma caesia* on hepatocellular carcinoma induced by diethylnitrosamine in BALB/c mice. J. Carcinog. 13: 7-10. doi: 10.4103/1477–3163.133520.

Hendry E R, Worthington T, Conway B R & Lambert P A 2009 Antimicrobial efficacy of eucalyptus oil and 1,8-cineole alone and in combination with chlorhexidine digluconate against microorganisms grown in planktonic and biofilm cultures. Journal of Antimicrobial Chemotherapy 64: 1219–1225.

Ibrahim N N A, Wan Mustapha W A, Sofian-Seng N S, Lim S J, Mohd Razali N S, Teh A H, Rahman H A & Mediani A 2023a A Comprehensive Review with Future Prospects on the Medicinal Properties and Biological Activities of *Curcuma caesia* Roxb. Evid. Based Complement Alternat. Med. Jan 17 2023: 7006565.

Ibrahim N N A, Kamal N, Mediani A, Sajak A A B, Lee S Y, Shaari K & Rahman H A 2023b ^{1}H NMR-Based Metabolomics Approach Revealing Metabolite Variation of Black Turmeric (*Curcuma caesia*) Extracts and Correlation with Its Antioxidant and α-Glucosidase Inhibitory Activities. Food Technol. Biotechnol. 61(1): 107–117. doi: 10.17113/ftb.61.01.23.7711. (Abstracts).

Jain A & Parihar D K 2018 In-vitro antidiabetic potential of endangered *Curcuma caesia* rhizome extracts and its characterization by FTIR and GC/HR-MS analysis, International J. Advances in Science Engineering and Technology 6: 16–22.

Jaiswal D & Agrawal S B 2021 Ultraviolet-B induced changes in physiology, phenylpropanoid pathway, and essential oil composition in two *Curcuma* species (*C. caesia* Roxb. and *C. longa* L.). Ecotoxicology and Environmental Safety 208: 111739. doi:10.1016/j.ecoenv.2020.111739.

Jose S & Thomas T D 2014 Comparative phytochemical and anti-bacterial studies of two indigenous medicinal plants *Curcuma caesia* Roxb. and *Curcuma aeruginosa* Roxb. International Journal of Green Pharmacy 8(1): 67–69.

Joshi S C & Mathela C S 2012 Antioxidant and antibacterial activities of the leaf essential oil and its constituents furanodienone and curzerenone from *Lindera pulcherrima* (Nees.) Benth. Ex hook. f. Pharmacognosy Res. 4(2): 80-84. doi: 10.4103/0974-8490.94721. PMID: 22518079; PMCID: PMC3326761.

Kagyung R, Gajurel P R, Rethy P & Sing B 2010 Ethnomedicinal plant used for gastrointestinal diseases by Adi tribe of Dehang-Debang biosphere reserve in Arunachal Pradesh. J. Traditional Knowledge 9(3): 496–501.

Kamatou GP & Viljoen A 2008 Linalool – A review of a biologically active compound of commercial importance. Natural Product Communications 3: 1183–1192.

Karmakar I, Dolai N, Bala A & Haldar P K 2011a Anxiolytic and CNS Depressant Activities of Methanol Extract of *Curcuma caesia* Rhizome. Pharmacolology Online. 2: 738–747.

Karmakar I, Saha P, Sarkar N, Sb S & Haldar P K 2011b Neuropharmacological Assessment of *Curcuma caesia* Rhizome in Experimental Animal Models. Orient Pharm. Exp. Med. 11: 251–255.

Karmakar I, Dolai N, Kumar R B S, Kar B, Roy S N & Haldar P K 2013Antitumor Activity and Antioxidant Property of *Curcuma caesia* against Ehrlich's Ascites Carcinoma Bearing Mice, Pharm. Biol. 51(6): 753–759.

Kataki C & Bhattacharjee M 2020 An Overview on Medicinal Uses of Exiguous Plant *Curcuma caesia* Roxb. Int. J. Pharm. Sci. Rev. Res. 63(1): 4–7.

Lalitha C R, Raveendran K & Salim N 1995 Effect of *Curcuma caesia* leaves on rice seed germination and seedling establishment. *Ancient Science of Life* 15(2): 115–118.

Lee SH, Kim DS, Park SH & Park H 2022 Phytochemistry and Applications of *Cinnamomum camphora* Essential Oils. Molecules 27(9): 2695. doi: 10.3390/molecules27092695. PMID: 35566046; PMCID: PMC9102863.

Li YW, Zhu GY, Shen XL, Chu JH, Yu ZL & Fong WF. 2011Furanodienone inhibits cell proliferation and survival by suppressing ERα- signaling in human breast cancer MCF-7 cells. J. Cell Biochem. 112(1):217-224. doi: 10.1002/jcb.22922. PMID: 21069738.

Liu Y, Roy S S, Nebie R H C, Zhang Y, & Nair M G 2013 Functional Food Quality of *Curcuma caesia*, *Curcuma zedoaria* and *Curcuma aeruginosa* Endemic to Northeastern India. Plant Foods for Human Nutrition 68(1): 72–77. doi:10.1007/s11130-013-0333–5.

Mahanta B P, Sut Dristi, Kemprai P, Paw M, Lal M & Haldar S 2019 A 1H-NMR spectroscopic method for the analysis of thermolabile chemical markers from the essential oil of black turmeric (*Curcuma caesia*) rhizome: application in post-harvest analysis. Phytochemical Analysis:1-9. doi:10.1002/pca.2863.

Majumder P, Mazumder S, Chakraborty M, Chowdhury S G, Karmakar S & Haldar P K 2017 Preclinical evaluation of Kali Haldi (*Curcuma caesia*): a promising herb to treat type-2 diabetes, Oriental Pharmacy and Experimental Medicine, 17(2): 161–169.

Mannangatti K, & Narayanasamy M 2008 Antifungal protein from a medicinal plant, *Curcuma caesia* Roxb. Journal of Biotechnology 136:S90. doi:10.1016/j.jbiotec.2008.07.204.

Mohan Kumar A B, Vasundhara M, Shyamalamma S, Doreswamy C, Anil V S 2020 DUS descriptor characterization of black turmeric (*Curcuma caesia* Roxb.) genotypes IJCS, 8 (4) : 2656-2664, 10.22271/chemi.2020.v8.i4ae.10042.

Mukunthan K S, Anil Kumar N V, Balaji S & Trupti N P 2014 Analysis of Essential Oil Constituents in Rhizome of *Curcuma caesia* Roxb. from South India, Journal of Essential Oil Bearing Plants, 17:4, 647–651.

Mukunthan K S, Satyan R S & Patel TN 2017 Pharmacological evaluation of phytochemicals from South Indian Black Turmeric (*Curcuma caesia* Roxb.) to target cancer apoptosis. J Ethnopharmacol. 209:82–90.

National Medicinal Plants Board, 2008 Agro-Techniques of Selected Medicinal Plants, vol. 1. The Energy and Resources Institute Press. New Delhi.

Pandey A K & Chowdhury A R 2003 Volatile constituents of the rhizome oil of *Curcuma caesia* Roxb. from central India. Flavour and Fragrance Journal 18(5): 463–465.

Pandey D & Gupta AK 2014 Antibacterial efficacy of *Curcuma caesia* from Bastar district of Chhattisgarh, India. Int. J. Pharm. Sci. Res. 5(6): 2294–01.

Paw M, Gogoi R, Sarma N, Pandey SK, Borah A, Begum T& Lal M 2020 Study of Anti-oxidant, Anti-inflammatory, genotoxicity, and antimicrobial activities and analysis of different constituents found in rhizome essential oil of *Curcuma caesia* Roxb., collected from North East India. Curr. Pharm. Biotechnol. 21(5): 403–413 (Abstracts).

Rajkumari S & Sanatombi K 2017 Nutritional value, phytochemical composition, and biological activities of edible Curcuma species: A review. International journal of food properties, 20 (sup3): S2668–S2687.

Reenu J, Shamina A & Chempakam B 2015 In vitro Antioxidant Potential in Sequential Extracts of *Curcuma caesia* Roxb. Rhizomes. Indian J. Pharm. Sci. doi: 10.4103/0250-474x.151596.

Riaz A, Rasul A, Kanwal N, Hussain G, Shah M A, Sarfraz I, Ishfaq R, Batool R, Rukhsar F & Adem S 2020 Germacrone: A Potent Secondary Metabolite with Therapeutic Potential in Metabolic Diseases, Cancer and Viral Infections. Curr. Drug Metab. 21(14):1079-1090. doi: 10.2174/1389200221999200728144801. (Abstracts).

Sajitha P K & Sasikumar B 2015 Qualitative and Quantitative Variation in Starch from Four Species of *Curcuma*. Cytologia 80(1): 45–50.

Sajitha P K 2017 Diversity and characterization of few *Curcuma* genetic resources. PhD thesis University of Calicut, Kozhikode. p384.

Sarangthem K & Haokip MJ 2010 Bioactive components in *Curcuma caesia* Roxb. grown in Manipur, The Bioscan. 5 (1): 113–115.

Sastri BN 1962 The Wealth of India, Raw Materials. CSIR New Delhi.

Sharma G J, Chirangini P & Kishor R 2011 Gingers of Manipur: Diversity and Potentials as Bioresources. Genet. Resour. Crop Evol. 58:753–767.

Singh S, Sahoo BC, Ray A, Jena S, Dash M, Nayak S, Kar B & Sahoo S 2021 Intraspecific Chemical Variability of Essential Oil of *Curcuma caesia* (Black Turmeric). Arab. J. Sci. Eng. 46: 191–198 https://doi.org/10.1007/s13369-020-04940–6.

Singh H, Kumar R, Mazumder A, Salahuddin, Yadav RK, Chauhan B & Abdulah MM 2023 Camphor and Menthol as Anticancer Agents: Synthesis, Structure-Activity Relationship and Interaction with Cancer Cell Lines. Anticancer Agents Med. Chem. 23(6): 614–623.

Sun W, Wang S, Zhao W, Wu C, Guo S, Gao H, Tao H, Lu J, Wang Y& Chen X 2017 Chemical constituents and biological research on plants in the genus *Curcuma*. Crit. Rev. Food Sci. Nutr. 57(7):1451–1523.

Tag H, Das AK & Loyi H 2007 Antiinflammatory plant used by Khamti tribes of Lohit District in Arunachal Pradesh. Natural Product Radiation (6) 4:340–343.

Vairappan C S, Elias U M, Ramachandran T R & Kamada T 2013 Secondary Metabolites from Rhizome of *Curcuma caesia* Roxb. (Zingiberaceae). Biochem. Syst. Ecol. 48: 107–110.

Van Hung P & Vo T N D 2017 Structure, physicochemical characteristics, and functional properties of starches isolated from yellow (*Curcuma longa*) and black (*Curcuma caesia*) turmeric rhizomes. Starch-Stärke 69 (5–6): 1600285.

Wikipedia 2017 *Curcuma caesia* Roxb. https://en.wikipedia.org/w/index.php?title=Curcuma_caesia:01-04.