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The Genus *Curcuma* under the Lens: A Multi-Tier Review of Bibliometric Performance Analysis, Ethnobotanical Insights, Species-Specific Evidence Mapping, and Clinical Trial Landscape

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Abstract: Background, the genus *Curcuma* (Family: Zingiberaceae), which comprises 180 accepted species, as per the Plants of the World Online (POWO) database, is well known for its extensive usage in traditional medicine. Several species of the genus offer a wide spectrum of biological/ pharmacological activities, yet a significant number remain unexplored. Objective, This review aims to assess the global research landscape of the genus *Curcuma* through a concise bibliometric (performance) analysis, to identify species-specific evidence for highlighting the underexplored species, to map the clinical trial landscape of the genus *Curcuma* and suggest future directions for the *Curcuma* research associated with biomedical fields. Methods, a concise bibliometric analysis was conducted utilising R software (Bibliometrix, an R package with a web-based interface, Biblioshiny) on Scopus-indexed publications from 2014 to 2024. The information regarding the accepted *Curcuma* species, their biogeographical insights and their synonyms was retrieved from the database 'Plants of the World Online' (POWO). Furthermore, an extensive literature review was carried out using databases such as ScienceDirect, PubMed, and Google Scholar to determine the taxonomic, nutritional, as well as pharmacological attributes of the genus *Curcuma*. At the same time, the evidence and data regarding the reported compounds and/or biological/pharmacological activities of each species were extracted from peer-reviewed literature sources. Apart from these, clinical trial data related to *Curcuma* were retrieved from the ClinicalTrials.gov database for subsequent analysis. Results, the bibliometric analysis revealed an increasing trend in *Curcuma*-based medicinal studies, high global research, and increased citations. Furthermore, species-wise literature search implied that ~62% of the genus is yet to be explored in terms of chemical characterisation and biological/pharmacological evaluation, which indicates a significant research gap. Also, the clinical trial landscape of the genus revealed a globally active yet predominantly early-to-mid-stage, academically driven research domain with significant gaps, which needs to be addressed for full-scale clinical translation as well as therapeutic integration. Conclusion, although the pharmacological importance of selected *Curcuma* species is well established, a large portion of the genus remains underexplored in terms of chemical characterisation (including phytochemical profiling) and biological/pharmacological evaluation. Integrating traditional ethnobotanical knowledge with modern technologies can reveal the complete therapeutic potential of the genus.

Keywords: *curcuma*; phytochemicals; pharmacological activities; clinical trials; ethnomedicine; bioactive compounds; bibliometric analysis

1. Introduction

The growing global interest in plant-based therapeutics has intensified the scientific exploration of traditional medicinal flora, especially those having a deep ethnobotanical legacy, extensive geographic distribution, as well as scientifically validated bioactivity [1]. Within this realm, the genus *Curcuma* (Family: Zingiberaceae) emerges as a cornerstone of ethnobotany and pharmacology as shown in Figure 1. *Curcuma* stands out as one of the most significant and pharmacologically versatile genera [2]. They are a taxonomically rich and phytochemically diverse group of annual or perennial, rhizomatous herbs that are native to tropical and subtropical regions, particularly South and Southeast Asia [3,4]. Since time immemorial, the use of *Curcuma* has been deeply rooted in traditional medicine systems such as Ayurveda, Siddha, Unani, and Traditional Chinese Medicine, where they have been constantly used for treating a broad spectrum of health conditions such as infections, inflammation, neurodegenerative disorders, metabolic dysfunctions, etc. [5–8].

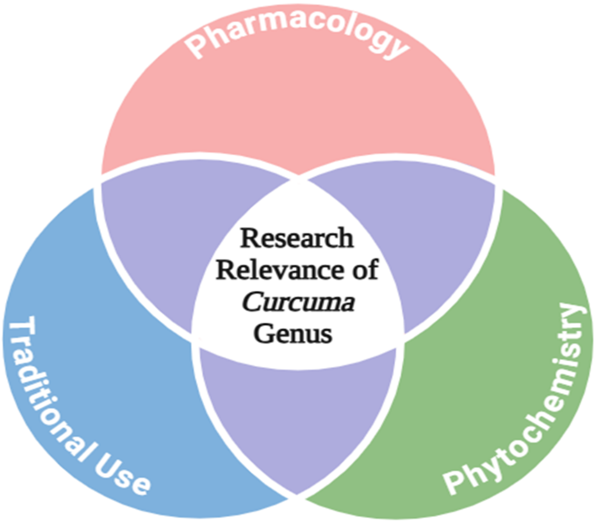

Figure 1. Unifying tradition, chemistry and pharmacology- this Venn diagram highlights the integrative research relevance of the *Curcuma* genus.

Modern biomedical research and increasing pharmacological studies have strongly validated these traditional claims by analysing and highlighting the phytochemical profiles of various species belonging to the genus *Curcuma*. It is highly evident from these phytochemical profiles that the therapeutic efficacy of the genus is due to the presence of wide array of secondary metabolites or bioactive compounds such as curcuminoids, alkaloids, terpenoids, flavonoids, essential oils, phenolic compounds etc. which offers a broad spectrum of pharmacological actions (or bioactivities) including antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, anticancer, antiproliferative, analgesic and neuroprotective effects [9].

Among the members of the genus *Curcuma, C. longa* L. has received global recognition and is the most widely studied species because of its lead bioactive compound, curcumin [10]. Moreover, some other species, such as *C. aeruginosa* Roxb., *C. amada* Roxb., *C. caesia* Roxb., *C. zedoaria* (Christm.) Roscoe, etc., are also extensively studied and are well-known to exhibit a wide range of bioactivity [11]. This clearly shows the rich and versatile pharmacological profile of the genus.

Despite this potential, a substantial portion of the genus has not yet undergone comprehensive scientific evaluation and remains underrepresented in terms of phytochemical and pharmacological profiles. Recognising this gap, the present review aims to offer a critical and comprehensive synthesis of current knowledge on the genus *Curcuma*, focusing on its taxonomy, biogeographical insights, ethnomedicinal usage, literature-reported compounds, and biological/ pharmacological activities.

To complement this synthesis and highlight the importance of the genus, a mini bibliometric analysis (a quantitative and statistical technique used to map and evaluate research trends and scientific publications over time) has been carried out to evaluate recent research trends and global scientific engagement with the genus [12]. The analyses carried out in this study specifically emphasises three key aspects: countries' scientific production, annual publication trends, and country-wise citation impact. Though the bibliometric analysis is not an exhaustive one, this targeted analysis provides a snapshot and overview of evolving interest in the *Curcuma*-related research domain, justifying the importance of the genus. Also, a clinical trial landscape analysis is included for better understanding the whole translational perspective of the genus.

Thus, this review aims to provide a clear understanding of the genus *Curcuma*, its global research scenario, to map the explored and unexplored species and to understand the clinical trials landscape of the genus. It also emphasises on the necessity for more comprehensive and continued scientific exploration of underexplored species to unfold the latent therapeutic potential of the genus.

2. Methodology

This study is designed as a multi-tiered narrative review (four-tier framework), which integrates taxonomic, biogeographical as well as thematic literature compilation, bibliometric performance analysis, species-wise evidence mapping of reported compounds and/or biological/pharmacological activities, as well as clinical trial data analyses for comprehensively evaluating the genus *Curcuma*. The retrieval of data for different components of this study was performed at different time points, which corresponds to the respective analyses.

In the first tier, an updated list of accepted species of the genus *Curcuma* was retrieved from the Plants of the World Online (POWO) database (https://powo.science.kew.org/ (accessed on 7 April 2026)). Along with the list of accepted species, some other associated taxonomic as well as biogeographical information (including native distribution, introduced regions and genus as well as species-level synonymy), were gathered from POWO and compiled for ensuring a current as well as validated taxonomic framework. Furthermore, a comprehensive literature search was carried out using databases such as ScienceDirect, PubMed and Google Scholar for gathering information regarding botanical characteristics, nutritional attributes, health-promoting attributes, ethnomedicinal usage across traditional systems of medicine (Ayurveda, Unani, and Homeopathy), as well as for gathering information about the reported biological and pharmacological activities of the genus. The combinations of keywords which were used during the literature search were: "*Curcuma*", "Zingiberaceae", "medicinal plants", "ethnobotanical plant", "bioactive compounds", "bioactivity", "pharmacological action", "phytochemicals" and "health benefits".

In the second tier, for highlighting the importance of *Curcuma*-focused research and to enhance the scientific depth of the study, a concise bibliometric analysis (performance analysis) was conducted utilising the Scopus-indexed articles from 2014 to 2024. The initial search was conducted on 23 June 2025 using the broad keyword "*Curcuma*" for capturing the complete research landscape of the genus across multiple domains. This retrieved a total of 15,318 documents. A sequence of filtering steps was applied to refine the dataset. Limiting the publication years to 2014–2024 reduced the dataset to 9778 documents. Furthermore, selecting relevant subject areas such as "Medicine", "Pharmacology, Toxicology & Pharmaceutics", and "Immunology & Microbiology" narrowed down the dataset to 5407 documents. Filtering for 'articles' only in the document type to capture only the original research yielded 3733 documents. Restricting the search to publications in the English language reduced the count to 3509 documents. Moreover, selecting the source type as journal only narrowed the results to 3505 articles. Finally, including articles at the final publication stage only brought the dataset down to 3496 documents, as shown in Figure 2. This final refined dataset (3496 documents) was then exported in the Comma-Separated Values (CSV) format on the same day of search (23 June 2025) and subjected to bibliometric performance analysis using Biblioshiny (the interactive GUI of the Bibliometrix R package, 2024.09.1 Build 394) [13]. Key performance analysis indicators such as 'annual scientific output', 'countries' scientific production' and 'most cited countries' were evaluated for establishing the research relevance as well as the growth trajectory of the genus.

In the third tier, based on the curated list of 180 accepted species obtained from POWO, an extensive species-wise literature search was carried out on 7 April 2026 across the scientific databases ScienceDirect, PubMed and Google Scholar. Each species was individually queried for identifying reported chemical constituents as well as associated biological and/or pharmacological activities. Sources include peer-reviewed articles, review papers, book chapters, as well as reputed scientific publications. Apart from these, the search was exclusively confined to articles that were published in the English language. Open-access articles and literature with full-text availability were prioritised for the study. In those cases where full access to certain articles was unavailable, abstracts were reviewed to extract key points. The data were compiled and tabulated for assessing the extent of scientific exploration across the genus and for clearly identifying the explored and the underexplored species of the genus *Curcuma*.

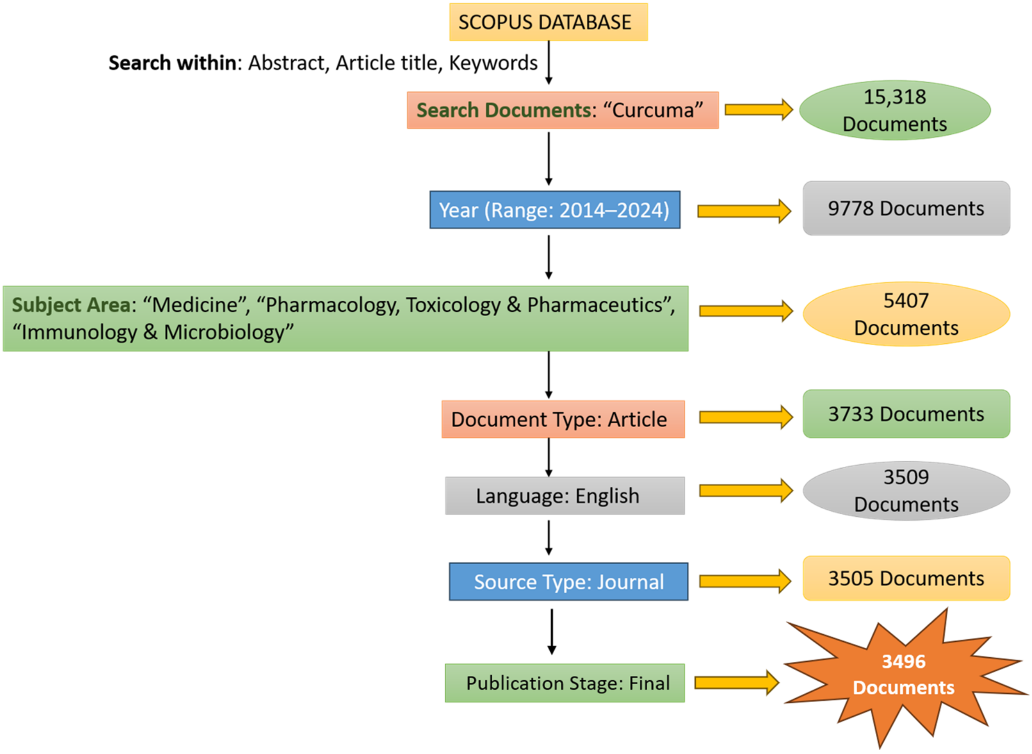

Figure 2. Data search approach in the Scopus Database for Bibliometric analysis.

In the fourth tier, clinical trial data related to *Curcuma* were retrieved on 6 April 2026 from the ClinicalTrials.gov (https://clinicaltrials.gov/) database using the search term "*Curcuma OR Curcumin OR Turmeric*" under the "Intervention/treatment" category. This resulted in a total of 491 studies, which were used for further understanding of the clinical research landscape of the genus.

3. The Genus *Curcuma*: Botanical Overview, Biogeographical Insights & Synonymy

Curcuma, a genus of the family Zingiberaceae, has high value in the fields of food, economy and medicinal aspects [14]. The ethnomedicinal potential of this genus has been extensively recognised and documented in diverse traditional healthcare systems such as Ayurveda, Unani and Traditional Chinese Medicine (TCM).

3.1. Botanical Overview of the Genus Curcuma

Carl Linnaeus (a Swedish taxonomist), in the year 1753, first mentioned and formally introduced *Curcuma* as a genus in his publication '*Species Plantarum*' [15]. The term *Curcuma* is derived from the Latinised form of the Arabic word '*kurkum*' (which means yellow), referring to the vibrant hue and characteristic colour of the rhizome [5]. *Curcuma* is also known as 'Golden Spice' as it is widely used in traditional medicines [16]. The species of the genus *Curcuma* are enormously cultivated in Thailand, Vietnam, Sri Lanka, China, India, Taiwan, the West Indies, Peru, Indonesia, Australia and are typically found in South and Southeast Asia (tropical and subtropical regions) [17].

Systematic position:

Kingdom: Plantae
    Clade: Tracheophytes
        Clade: Angiosperms
            Clade: Monocots
                Clade: Commelinids
                    Order: Zingiberales
                        Family: Zingiberaceae
                            Subfamily: Zingiberoideae
                                Tribe: Zingibereae
                                    Genus: *Curcuma*

Curcuma is a rhizomatous plant that mainly grows annually or perennially (predominantly perennially) [4]. The chromosome number in the genus *Curcuma* exhibits considerable variation, ranging from 2n = 20 to 2n = 105 [18].

The morphological and reproductive characteristics of the genus *Curcuma* include [4,19]:

- Height: approx. 50–200 cm.
- Rhizomes: branched, aromatic, and fleshy.
- Flowers: flexible single anthers, spiral bracts, and spike inflorescences.
- Two flowering cycles: Lateral flowers from rhizomes for short flowering plants and Terminal flowers from leafy shoots for delayed flowering plants.
- Reproduction: asexually via rhizomes, unable to produce seeds.

3.2. Biogeographical Insights of the Genus Curcuma

As per the Plants of the World Online (POWO) database (https://powo.science.kew.org (accessed on 7 April 2026)) maintained by the Royal Botanic Gardens, Kew, the genus *Curcuma* comprises 180 currently accepted species, which are distributed all over the world. In India, approximately 40 species of *Curcuma* are found, including *C. amada* Roxb.*, C. longa* L*, C. haritha* Mangaly & M.Sabu*, C. oligantha* Trimen*, C. zedoaria* (Christm.) Roscoe*,* etc. [20].

Based on the data retrieved from the POWO database, a comprehensive table detailing the scientific names and the native as well as introduced ranges of these 180 species is provided in the Supplementary File S1 (Table S1). To highlight the key geographical distribution patterns, Figure 3 represents a clustered column chart, illustrating the countries with the highest number of native *Curcuma* species, while Figure 4 depicts a funnel chart, showing the number of countries where selected *Curcuma* species have been introduced.

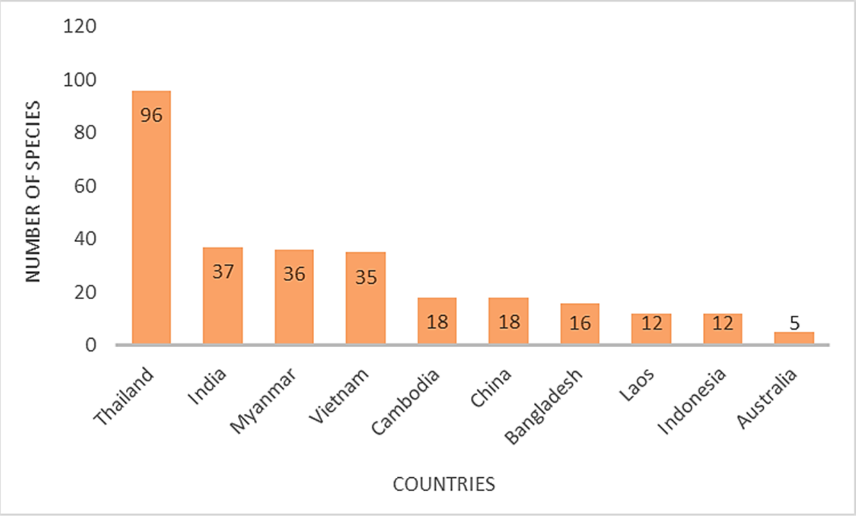

Figure 3. Countries with the highest number of native *Curcuma* species (Data retrieved from the POWO database).

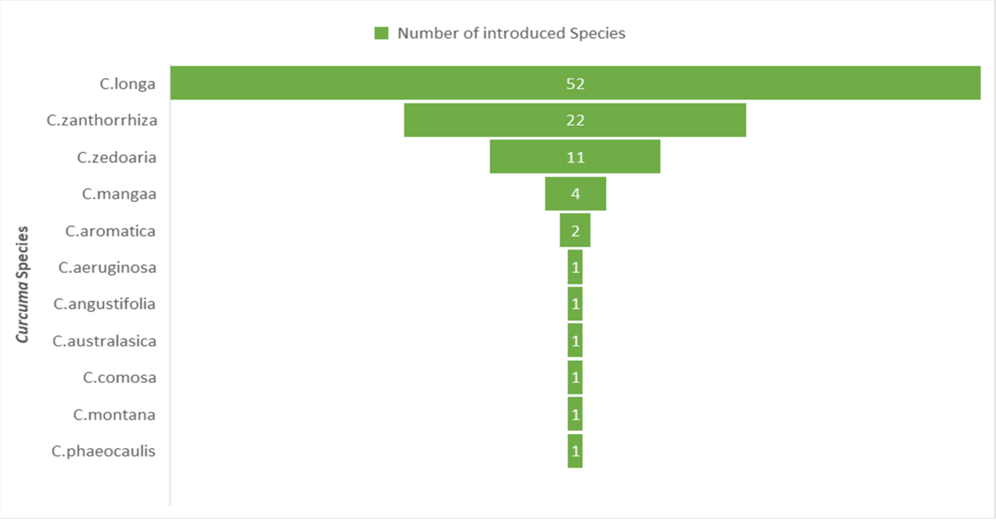

Figure 4. Number of countries where selected *Curcuma* species have been introduced. The data highlights the widespread distribution of species like *C. longa* L. and *C. zanthorrhiza* Roxb. (Data retrieved from POWO database).

3.3. Botanical Synonyms of the Genus Curcuma

As per the POWO database, among the 180 species, 41 species possess documented synonyms, which may be either Homotypic (Nomenclatural) or Heterotypic (Taxonomic) or, in some cases, both. In addition to species-level synonymy, the genus *Curcuma* itself has 11 recognised generic synonyms. The records of these synonyms, extracted from the POWO database, are presented in Table 1, which is divided into two parts: genus-level synonymy and species-level synonymy.

Table 1. represents the botanical synonyms recorded for the genus Curcuma (data retrieved from the POWO database). The table is divided into two sections: genus-level synonymy and species-level synonymy.

Genus-Level Synonymy			
SL No.	**Genus**	**Synonym Type**	**Synonym**
1	*Curcuma* genus	Heterotypic synonym	*Dischema* Voigt
			Erndlia Giseke
			Hitchenia Wall.
			Hitcheniopsis (Baker) Ridl.
			Kua Rheede ex. Medic.
			Laosanthus K. Larsen & Jenjitt
			Paracautleya R.M.Sm.
			Smithatris W.J. Kress & K. Larsen
			Stahlianthus Kuntze
			Stissera Giseke
			Zedoaria Raf.
Species-Level Synonymy			
SL No.	**Species**	**Synonym Type**	**Synonym**
1.	*C. alismatifolia* Gagnep.	Homotypic synonym	*Hitcheniopsis alismatifolia*
2.	*C. amada* Roxb.	Heterotypic synonym	*Curcuma amada var. glabra*
3.	*C. andersonii* (Baker) Škorničk.	Homotypic synonym	*Kaempferia andersonii*
			Stahlianthus andersonii
4.	*C. aromatica* Salisb.	Heterotypic synonym	*Curcuma wenyujin*
			Curcuma zedoaria Roxb.
5.	*C. aurantiaca* Zijp	Heterotypic synonym	*Curcuma ecalcarata*
6.	*C. bhatii* (R.M.Sm.) Škorničk. & M.Sabu	Homotypic synonym	*Paracautleya batii*
7.	*C. caesia* Roxb.	Heterotypic synonym	*Curcuma kuchoor*
8.	*C. campanulata* (Kuntze) Škorničk.	Homotypic synonym	*Kaempferia campanulata*
			Stahlianthus campanulatus
9.	*C. candida* (Wall.) Techapr. & Škorničk.	Homotypic synonym	*Kaempferia candida*
10.	*C. cannanorensis* R.Ansari, V.J.Nair & N.C.Nair	Heterotypic synonym	*Curcuma cannanorensis var. lutea*
			Curcuma lutea
			Curcuma oligantha var. lutea
11.	*C. caulina* J.Graham	Homotypic synonym	*Hitchenia caulina*
12.	*C. clovisii* Škorničk.	Homotypic synonym	*Stahlianthus thorelii*
13.	*C. euchroma* Valeton	Heterotypic synonym	*Amomum zerumbet*
			Curcuma officinalis
			Curcuma zerumbet
			Erndlia subpersonata
14.	*C. glauca* (Wall.) Škorničk.	Homotypic synonym	*Dischema glaucum*
			Hitchenia glauca
		Heterotypic synonym	*Curcuma glaucophylla*
15.	*C. gracillima* Gagnep.	Homotypic synonym	*Hitcheniopsis gracillima*
		Heterotypic synonym	*Curcuma gracillima var. elatior*
16.	*C. graminifolia* (K.Larsen & Jenjitt.) Škorničk.	Homotypic synonym	*Laosanthus graminifolius*
17.	*C. grandiflora* Wall. ex Baker	Homotypic synonym	*Hitcheniopsis grandiflora*
18.	*C. harmandii* Gagnep.	Heterotypic synonym	*Curcuma burttii*
19.	*C. inodora* Blatt.	Heterotypic synonym	*Curcuma purpurea* Blatt.
20.	*C. involucrata* (King ex Baker) Škorničk.	Homotypic synonym	*Kaempferia involucrate*
			Stahlianthus involucratus
		Heterotypic synonym	*Kaempferia hainanensis*

Table 1. *Cont.*

Species-Level Synonymy			
SL No.	**Species**	**Synonym Type**	**Synonym**
21.	*C. kudagensis* Velay., V.S.Pillai & Amalraj	Heterotypic synonym	*Curcuma thalakaveriensis*
22.	*C. kwangsiensis* S.G.Lee & C.F.Liang	Heterotypic synonym	*Curcuma chuanyujin*
			Curcuma kwangsiensis var. affinis
			Curcuma kwangsiensis var. puberula
23.	*C. longa* L.	Homotypic synonym	*Kua domestica*
			Stissera curcuma
		Heterotypic synonym	*Amomum curcuma*
			Amomum latifolia
			Curcuma brog
			Curcuma domestica
			Curcuma longa var. vanaharidra
			Curcuma ochrorhiza
			Curcuma soloensis
			Curcuma tinctoria
24.	*C. macrochlamys* (Baker) Škorničk.	Homotypic synonym	*Kaempferia macrochlamys*
			Stahlianthus macrochlamys
25.	*C. myanmarensis* (W.J.Kress) Škorničk.	Homotypic synonym	*Smithateris myanmarensis*
26.	*C. neilgherrensis* Wight	Heterotypic synonym	*Curcuma aungustifolia* Dalzell & A. Gibson
27.	*C. parviflora* Wall.	Homotypic synonym	*Hitcheniopsis parviflora*
28.	*C. pedicellata* (Chaveer. & Mokkamul) Škorničk.	Homotypic synonym	*Stahlianthus pedicellatus*
29.	*C. petiolata* Roxb.	Heterotypic synonym	*Curcuma petiolaris*
30.	*C. pseudomontana* J.Graham	Homotypic synonym	*Curcuma grahamiana*
		Heterotypic synonym	*Curcuma ranadei*
31.	*C. putii* Maknoi & Jenjitt.	Heterotypic synonym	*Curcuma thailandica*
32.	*C. reclinata* Roxb.	Heterotypic synonym	*Curcuma sulcata*
33.	*C. roscoeana* Wall.	Homotypic synonym	*Hitchenia roscoeana*
			Hitcheniopsis roscoeana
		Heterotypic synonym	*Curcuma kurzii*
34.	*C. rubescens* Roxb.	Heterotypic synonym	*Curcuma erubescens*
			Curcuma longiflora
			Curcuma rubricaulis
35.	*C. scaposa* (Nimmo) Škorničk. & M.Sabu	Homotypic synonym	*Hedychium scaposum*
			Kaempferia scaposa
			Monolophus scaposus
36.	*C. sichuanensis* X.X.Chen	Heterotypic synonym	*Curcuma albicoma*
37.	*C. sparganiifolia* Gagnep.	Homotypic synonym	*Hitcheniopsis sparganiifolia*
38.	*C. strobilifera* Wall. ex Baker	Heterotypic synonym	*Curcuma strobilina*
39.	*C. supraneeana* (W.J.Kress & K.Larsen) Škorničk.	Homotypic synonym	*Smithatris supraneeanae*
40.	*C. vamana* M.Sabu & Mangaly	Heterotypic synonym	*Curcuma peethapushpa*
41.	*C. zedoaria* (Christm.) Roscoe	Homotypic synonym	*Amomum latifolium*
			Amomum zedoaria
			Curcuma speciosa
			Zingiber truncatum
		Heterotypic synonym	*Costus luteus*
			Costus nigricans
			Curcuma malabarica
			Curcuma pallida
			Curcuma porphyrotaenia
			Curcuma raktakanta
			Erndlia zerumbet
			Roscoea lutea
			Roscoea nigrociliata

4. Bibliometric Insights into *Curcuma* Research (2014–2024): A Decade-Plus of Scientific Exploration across Biomedical and Pharmaceutical Sciences Using the Scopus Database

4.1. Main Informetric Parameters: A Quantitative Synopsis of Curcuma-Related Research Output from Scopus Data (2014–2024)

The main informetric parameters and findings of our analysis are shown in Table 2. Between the time frame 2014 to 2024, the research output in this domain of research includes 3496 documents that were published across 962 journals (sources). The annual growth rate of publications during this period (2014–2024) was 2.19%. Furthermore, the average citations per document is 19.56, and the number of references cited in the studies is 147,790. The percentage of international co-authorship was 18.25%. Apart from these, an average document age of 6.67 years clearly indicates a moderately recent as well as actively evolving field. The mean citation rate of 19.56 citations per document is suggestive of the fact that the field has a reasonable level of scientific impact and visibility. Furthermore, an average of 5.82 co-authors per document is indicative of the fact that there exists a collaborative research environment, which likely involves multidisciplinary contributions.

Table 2. shows the main informetric parameters on Curcuma and its related biomedical research.

SL No.	Description	Results
1.	Timespan	2014–2024
2.	Sources (Journals)	962
3.	Documents	3496
4.	Annual Growth Rate %	2.19
5.	Average citations per paper	19.56
6.	References	147,790
7.	International co-authorships %	18.25
8.	Document Average Age	6.67 years
9.	Average citations per document	19.56
10.	Co-authors per document	5.82

4.2. Annual Publication Trends

The annual scientific production trend on *Curcuma* research (2014–2024) in the fields of medicine, pharmacology, toxicology, pharmaceutics, immunology and microbiology is presented in Figure 5. Between 2014 and 2019, scientific output (number of publications) remained relatively stable, with an average of around 280 publications per year. A sharp spike occurred in 2020 and 2021, with a noticeable surge from 284 publications in 2018 to 347 publications in 2020 and 428 publications (the highest recorded in the timespan) in the year 2021. This spike coincides with the COVID-19 pandemic period, reflecting a global surge in research activities, especially in biomedical domains, leading to increased scientific output. Although it is seen that there is a slight decline in the number of publications after 2021, the publication rate remained significantly higher than in the earlier years. This clearly depicts a steady, impactful and upward trend in research productivity over the decade.

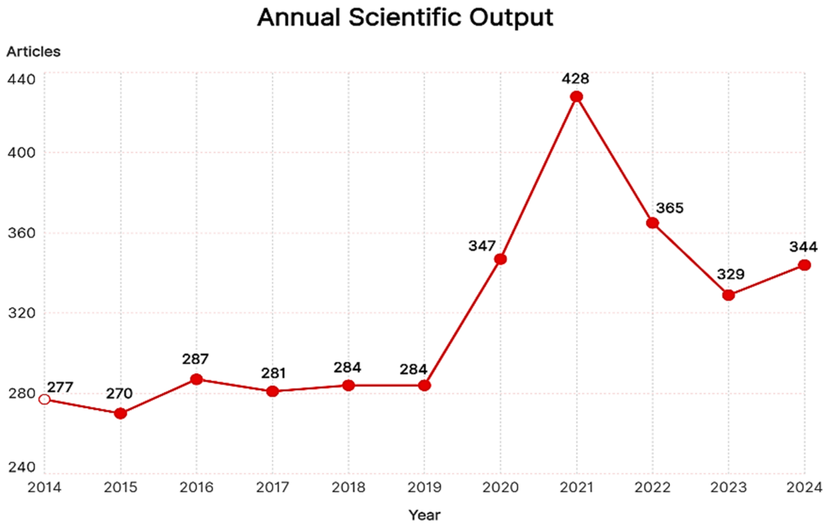

Figure 5. The annual scientific production trends of curated documents on *Curcuma* research in the biomedical domains (Created using SCImago Graphica *Beta* 1.0.53) [21].

4.3. Countries' Scientific Production

The leading ten countries based on author affiliations, contributing to *Curcuma* research are illustrated in Figure 6 and Supplementary File S1 (Table S2). Here, the dominant contributor is China with 5077 author occurrences, followed by India, which is the second-highest contributor with 3506 author occurrences. Indonesia ranks third (1619), followed by Thailand (910) emphasising the noteworthy role of Southeast Asia towards *Curcuma* research, which might be due to the region's rich ethnobotanical scenario and heritage.

Western countries have also shown strong engagement in terms of research participation, with the United States (USA) contributing 883 author occurrences, and Brazil (755). South Korea (877), Iran (827) and Japan (474) also show strong engagement. Italy (565) leads among the European nations, likely due to its herbal medicine traditions as well as functional food research. This geographical distribution clearly highlights that Asia is the central hub of *Curcuma* research, especially in countries where turmeric holds cultural, medicinal as well as dietary significance. Simultaneously, the increasing engagement from non-Asian countries implies a global recognition of *Curcuma's* ethnobotanical and pharmacological importance, driven by interdisciplinary research in medicine, pharmacology, microbiology and related biomedical fields.

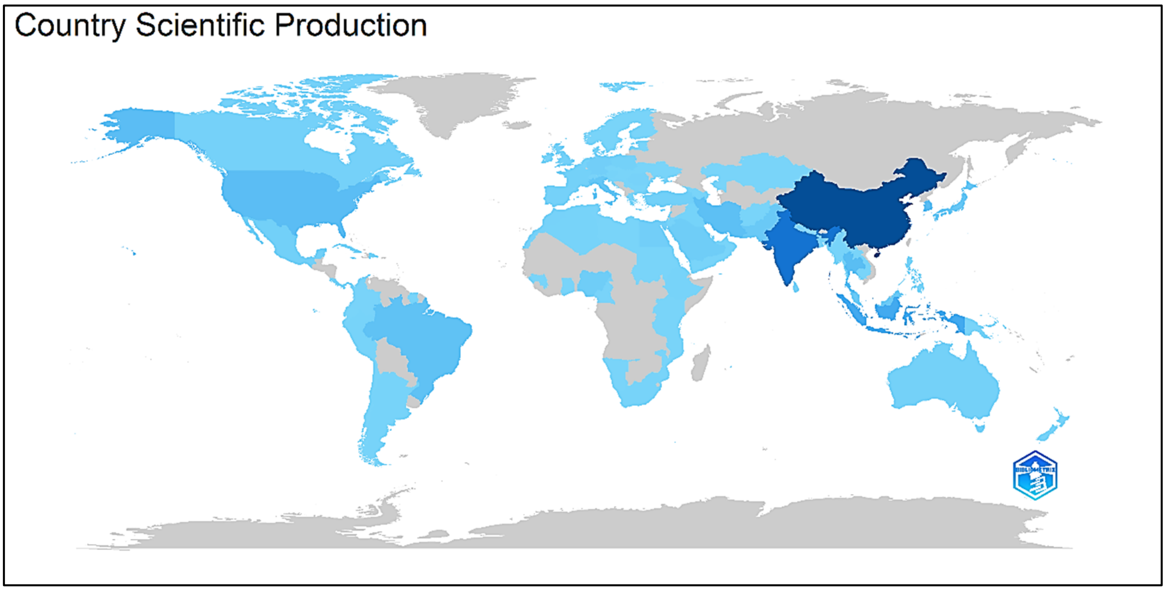

Figure 6. Top 10 countries' scientific production on *Curcuma* research in the biomedical fields based on the curated dataset (Generated using Biblioshiny, Bibliometrix R package, 2024.09.1 Build 394).

4.4. Most Cited Countries

The top 10 most cited countries are presented in Figure 7. The citation analysis depicts not just the volume but also the impact as well as the visibility of a country's research output in the global scientific community. China leads with 14181 citations, indicating both a high volume of publications as well as significant impact, visibility and academic influence. India follows with 10191 citations, which truly justifies its traditional and scientific engagement with *Curcuma* as a phytomedicine. Iran ranks third with 4631 citations. The USA, although fifth in terms of publication volume, ranks fourth in citations (3739), indicating a relatively higher citation rate per article.

South Korea (2668) and Indonesia (2185) also show strong citation profiles, indicating the growing international relevance of their research. Countries such as Thailand (2025), Italy (1823) and Brazil (1544) have a consistent citation impact, which shows that their works are being acknowledged and referenced widely in global literature. Malaysia (1483) also demonstrates a substantial citation count, likely due to its blend of traditional medicine and modern research.

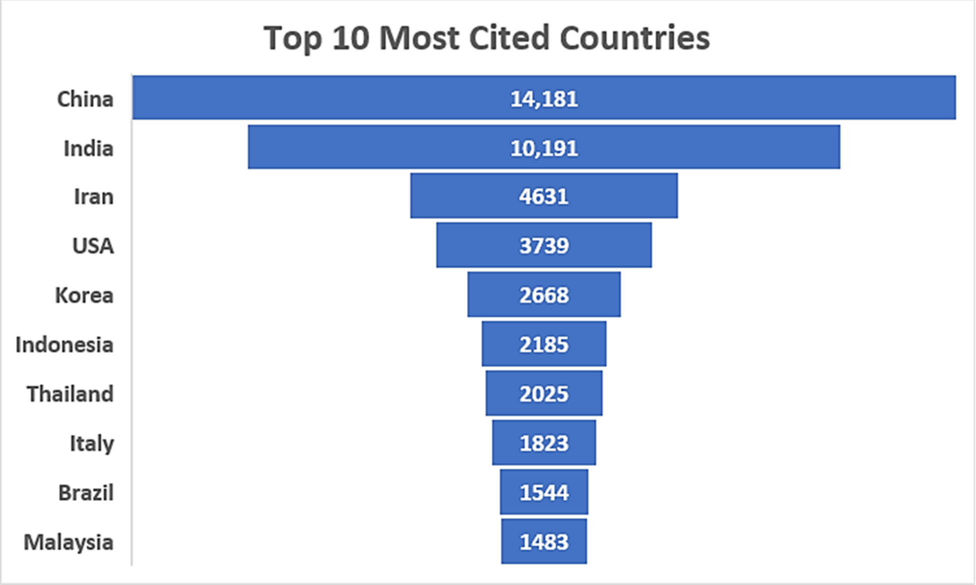

Figure 7. Top 10 most cited countries in terms of *Curcuma* research.

5. Nutraceutical and Health-Promoting Attributes of the *Curcuma* Genus

5.1. Nutritional Attributes of the Genus Curcuma

The *Curcuma* genus holds immense nutraceutical potential because of its rich nutritional as well as bioactive composition [22]. Several edible species, such as *Curcuma augustifolia* Roxb., *C. caulina* J.Graham, *C. leucorrhiza* Roxb., as well as *C. zanthorrhiza* Roxb., are valuable sources of starch, proteins, dietary fibre, and essential sugars. The rhizomes and inflorescences are abundant in essential minerals such as iron, zinc, calcium, magnesium, manganese, copper, phosphorus, potassium, sodium, sulphur, and nitrogen, along with vitamins A, C, E, B1, B2, B3 and B6. Beyond macronutrients, *Curcuma* species are reservoirs of bioactive phytochemicals like curcuminoids, essential oils, terpenoids, and sesquiterpenes, which offer anti-inflammatory, antioxidant, hepatoprotective, and various metabolic health benefits [23]. The edible species of the genus *Curcuma* and their edible parts are depicted in Figure 8. This synergistic blend of nutrition and bioactivity underpins the positioning of *Curcuma* species as natural nutraceuticals, which are vital in preventive healthcare and functional food development.

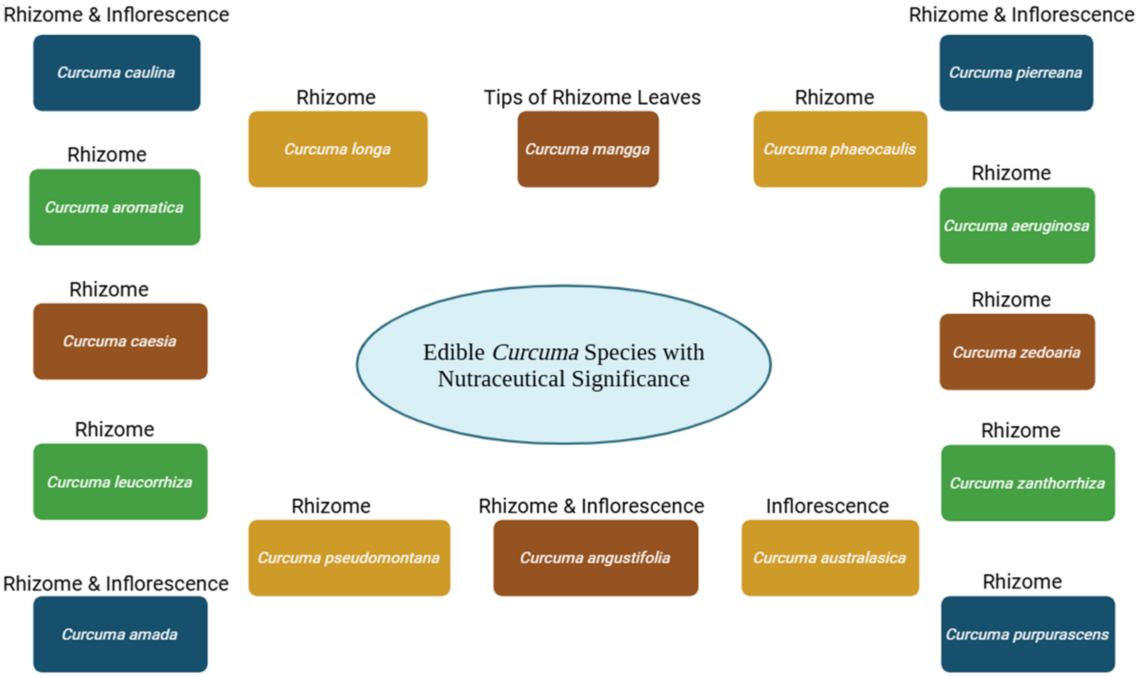

Figure 8. Edible *Curcuma* species exhibiting nutraceutical relevance and their parts used [23].

5.2. Ethnomedicinal Roles of the Curcuma Genus across Unani, Ayurveda, and Homoeopathy System of Medicines

The *Curcuma* Genus is widely known for its diverse health-promoting attributes as well as age-old therapeutic applications. Several species are extensively utilised in traditional, complementary, and alternative medicine (TCAM) systems such as Unani, Ayurveda, and Homoeopathy for treating a wide range of ailments.

In Unani medicine, *Zard Chob* (*Curcuma longa* L.), *Zaranbad* (*Curcuma zedoaria* (Christm.) Roscoe) is well known for its core actions (*Afa'al*) such as anti-inflammatory (*Mohallil-e-Waram*), wound healing (*Mudammil-e-Qurooh*), blood-purifying (*Musaffi-e-Dam*), expectorant (*Munaffis-wa-mukharrij-e-balgham*), carminative (*Kasir-e-Riyah*), hepatoprotective (*Muqavvi-e-Jigar*), anti-allergic, antiseptic (*Daf-e-Taaffun*), and antipyretic (*Daf-e-Humma*) properties, which are frequently used for therapeutic applications (*Mawaq-e-Istemal*) such as skin diseases, respiratory issues, gastrointestinal ailments, uterine tonic (*Muqavvi-e-Reham*), arthritis, wound healing as well as antidote for various toxins [24,25]. The recommended Unani dosage (*Miqdar-e-Khuraq*) ranges from 1–7 g (for *C. longa* L.) and 1–4 g (for *C. zedoaria* (Christm.) Roscoe) [24].

Ayurveda describes *Curcuma* (*Haridra*) as a potent *Rasayana* (rejuvenator) with multifaceted actions such as anti-inflammatory, anti-skin diseases (*Kusthagna*), anti-obesity (*Lekhaniya*), anti-toxic (*Visaghna*), anti-cancer, antioxidant, hepatoprotective, wound healing, widely used for a plethora of skin disorders, liver diseases, diabetes (*Prameha*), respiratory disorders, metabolic syndromes, as well as a blood purifier [26,27]. The rhizome of *C. longa* is a key ingredient of formulations like "Narayana gula", "Nalpamaradi thailam", etc., whereas the rhizome of *C. zedoaria* is an active ingredient of "Braticityadi kwatha", which is used in high fever [28].

In Homoeopathy, *Curcuma longa* L. is recognised for its nano-pharmacological effects, exhibiting antifungal, anti-melanin, and anti-inflammatory activities, validated for various conditions such as functional dyspepsia and skin pigmentation disorders [29,30]. *C. zedoaria* (Christm.) Roscoe (White Turmeric) is popular in Bali as an alternative therapy for breast cancer, which is often preferred because of cultural beliefs as well as limited access to early-stage medical screening [31].

The pharmacological claims of *Curcuma* in Unani, Ayurveda and Homoeopathy are now increasingly supported through contemporary biomedical studies and modern pharmacological research. Though all three systems differ in their medical philosophies and ideologies, they converge on the same intersection point in managing inflammation, skin disorders, and metabolic imbalances, thereby promoting overall health

5.3. General Ethnomedicinal and Health Benefits of Notable Curcuma Species

Beyond system-specific therapeutic applications, notable *Curcuma* species exhibit a wide array of general health benefits, which are attributed to their diverse pharmacological properties. These are illustrated in Figure 9.

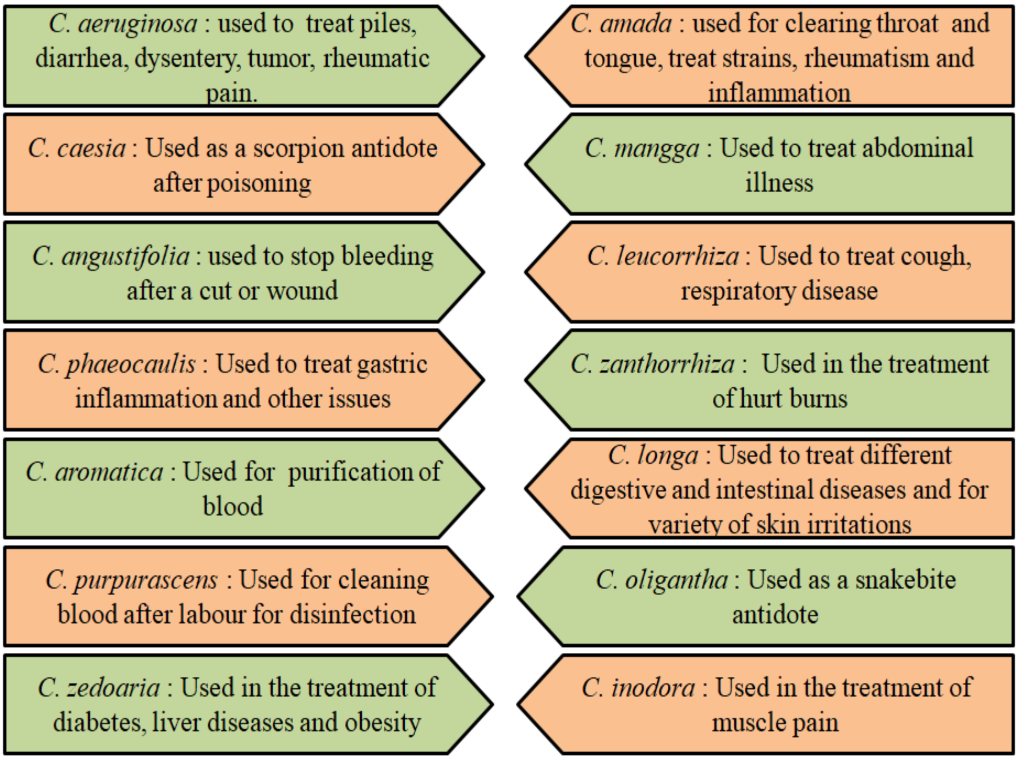

Figure 9. General ethnomedicinal and health benefits of notable *Curcuma* species [32–44].

6. Pharmacological Spectrum of the Genus *Curcuma*

The genus *Curcuma* exhibits a broad spectrum of pharmacological or biological activities. Their potent antioxidant activity is mainly due to curcuminoids and phenolics via free radical scavenging, ferric ion reduction, and lipid peroxidation inhibition, with *C. longa* L. (Variety: Khulna's mura) showing the strongest 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity (IC_{50}: 1.08 µg/mL) and *C. zanthorrhiza* Roxb. (ethanolic extract) showing 64% scavenging at 1 mg/mL concentration [45]. Anti-inflammatory effects, mainly by *C. longa* L. (curcumin), occur as a result of PPAR-γ (Peroxisome Proliferator-Activated Receptor Gamma: a nuclear receptor involved in regulating inflammation) upregulation, which downregulates Tumor necrosis factor-alpha (TNF-α) expression and leads to inhibition of Nuclear factor kappa B (NF-κB) activity, while activating the p38 mitogen-activated protein kinase (p38 MAPK) and caspase-3 to promote neutrophil apoptosis. This dual action reduces proinflammatory cytokine production and cellular inflammation [46]. Regarding antibacterial effects, curcumin inhibits bacterial cytokinesis by targeting the Filamenting temperature-sensitive Z (FtsZ) protein (key player in bacterial cytokinesis), which performs a role analogous to eukaryotic tubulin (cytoskeletal protein) and polymerises to form a contractile Z-ring at the division site. Curcumin disrupts FtsZ protofilament assembly, enhances its guanosine triphosphatase (GTPase) activity, reduces filament bundling, and interferes with its secondary structure, which ultimately prevents Z-ring formation and induces filamentation in *Bacillus subtilis*, suggesting curcumin's immense potential as an antibacterial agent [47]. Antiviral mechanisms demonstrated by curcumin include inhibition of Human immunodeficiency virus (HIV) integrase/protease (in HIV, suppression of Tat acetylation (in HIV), haemagglutination blockade (in influenza virus), and disruption of the ubiquitin-proteasome system (in *Coxsackievirus*) [48]. In a study by Chen et al. (2018), the alcohol extract of *C. longa* exhibited broad-spectrum antifungal activity, showing strongest inhibition against *Fusarium graminearum*. Via investigation of the active compounds of *C. longa* like curdione, curcumenol, curzerene, isocurcumenol, and curcumol individually and in combinations, it is observed that the extract disrupted fungal cell membranes, inhibited ergosterol synthesis, NADH oxidase, SDH (Succinate dehydrogenase) and respiration, and altered expression of proteins related to energy as well as glucose metabolism [49]. A study by Ekawardhani et al. (2020) suggests that curcumin combats malaria through multiple mechanisms, functioning both as a direct antiparasitic agent as well as a modulator of host immune and inflammatory responses. It boosts reactive oxygen species (ROS) generation, activates PPAR-γ/nuclear factor erythroid 2-related factor 2 (Nrf2), and upregulates CD36 in order to enhance phagocytosis of infected red blood cells (RBCs). It also suppresses proinflammatory cytokines and reduces adhesion molecule expression in endothelial cells. In case of direct parasite targeting, curcumin inhibits *Plasmodium falciparum* ATPase 6 (PfATP6) (*Plasmodium* SERCA), impairing calcium regulation, blocks β-hematin formation and Glycogen synthase kinase 3 beta (GSK-3β), ultimately interfering with parasite survival. Moreover, it also acts as a HAT (Histone Acetyltransferase Inhibitor) which affects parasite gene expression [50]. From a study by Simamora et al. (2022) with *C. zanthorrhiza* Roxb., it is clearly evident that XTZ (Xanthorrhizol) exhibits potent anticancer activity by modulating key signalling pathways, targeting kinases, apoptotic proteins, various transcription factors as well as inflammatory cytokines, thereby suppressing angiogenesis as well as metastasis and inducing apoptosis and cell cycle arrest [51]. In a study by Khorsandi et al. (2008), *C. longa* L. extract has been shown to mitigate acetaminophen-induced nephrotoxicity, primarily via its antioxidant properties, restoration of reduced glutathione (GSH) as well as glutathione S-transferase (GSTase) activation [52]. A more recent study by Intan et al. (2025), demonstrated that a combined effect of *C. longa* L. and *C. zedoaria* (Christm.) Roscoe offers enhanced renoprotective effects in rats against Cisplatin-induced nephrotoxicity, which acts via suppression of TNF-α, kidney injury molecule-1 (KIM-1), and caspase-3 pathways [53]. Regarding anticoagulant activity, in a study by Kim et al. (2012), curcumin and bisdemethoxycurcumin showed significant anticoagulant activity by prolonging PT (Prothrombin Time) and aPTT (Activated Partial Thromboplastin Time) as well as inhibiting thrombin and FXa (Activated Factor X) generation, with curcumin outperforming bisdemethoxycurcumin (BDMC), which signifies the functional importance of its methoxy group [54]. The antidiabetic effect of *Curcuma aromatica* Salisb. has been demonstrated through *in vitro* and *in vivo* studies by Srividya et al. (2012). In an *in vitro* study*,* the toluene extract of *C. aromatica* Salisb. significantly inhibited α-glucosidase activity, which led to delayed carbohydrate breakdown as well as reduced postprandial glucose spikes. In an in vivo study, diabetic rats were treated with the extract which showed reduced serum glucose, triglycerides, and cholesterol levels, while elevating antioxidant enzymes like GSH, superoxide dismutase (SOD), and catalase. It also lowers thiobarbituric acid reactive substances (TBARS) levels, which indicates protection against oxidative stress. Together, these effects contribute to improved glycemic control as well as cellular protection in diabetic conditions [55]. Furthermore, in a study by Mahattanadul et al. (2008), Bisdemethoxycurcumin (BDMC) from *C. longa* L. exhibits antiulcer activity via inhibition of iNOS (inducible nitric oxide synthase) expression, which reduces gastric acid secretion and promotes mucosal regeneration. It shows efficacy comparable to curcumin, though curcumin also inhibits TNF-α at the post-transcriptional level [56]. In a study by Shahid et al. (2019), it was observed that in a BALB/c mouse model of ovalbumin-induced allergic asthma, curcumin showed anti-asthmatic effects by suppressing pro-inflammatory and pro-fibrotic cytokines (IL-4, IL-5, TNF-α, TGF-β), Heat shock protein 70 (HSP70) and eotaxin (chemokine), while upregulating Aquaporin-1 and Aquaporin-5 expression, which subsequently resulted in reduced airway inflammation, pulmonary oedema, and leukocyte infiltration [57]. Apart from these, various other studies have demonstrated that Curcuma species also exhibit a wide range of additional pharmacological activities, including anti-protozoan, anti-helminthic, analgesic, anti-tumour, anti-ageing, anti-depressant, anti-fertility, anti-venom activities and several others, highlighting the broad-spectrum medicinal potential of the genus.

7. Research Coverage in *Curcuma*: The Known 69 and the Hidden 111

Table 3 presents a selective compilation of literature-reported compounds and biological/pharmacological activities across *Curcuma* species for mapping the research coverage (explored vs. unexplored). It presents the 69 species (out of 180 recognised species within the genus *Curcuma*) that have literature-reported compounds and biological/pharmacological activities. However, it does not represent an exhaustive account of all the reported constituents or activities. Species that are supported solely by ethnobotanical evidence without any sort of phytochemical or biological evaluation were excluded. In certain cases, where only preliminary phytochemical screening (e.g., presence of compound classes) and/or quantification of total phenolic content and total flavonoid content were available, without identification of specific compounds, it was taken into consideration.

Out of the 180 accepted species of *Curcuma*, literature-reported compounds and biological/pharmacological activities have been reported only for 69 species, while 111 species remain largely underexplored in this regard, as depicted in Figure 10. The structures of some of the important literature-reported compounds are shown in Figures 11 and 12.

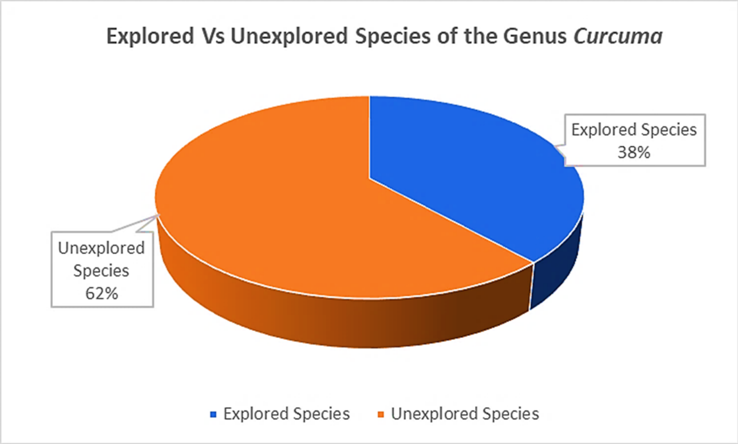

Figure 10. A pie chart illustrating the distribution of reported compounds and biological/pharmacological research across the *Curcuma* genus. Among 180 recognised species, 61.6% (~62%) remain unexplored, while only 38.3% (~38%) have reported works on either metabolite profiling or biological/pharmacological evaluation.

Table 3. represents documented *Curcuma* species with selected reported compounds and their selected biological/pharmacological activities.

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. aeruginosa Roxb.	Curzerenone Comosone II Methenolone Germacrone Zederone Curcuzederone Furanodienone Curcumenol 13-Hydroxygermacrone Tropolone Demethoxycurcumin	Antioxidant activity Antiproliferative activity Antimicrobial activity Anti-inflammatory activity Antinociceptive activity Antimigratory activity Anticancer activity	[58–60]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. albiflora Thwaites	α-Pinene Caryophyllene Alcanfor α-Bisabolene n-Hexadecanoic acid α-Famesene Camphene Isoborneol	Anti-inflammatory activity Antioxidant activity Antimicrobial activity Antimitogenic activity Anticancer activity Antiprotozoal activity Hepatoprotective activity	[61,62]
C. alismatifolia Gagnep.	(−)-Xanthorrhizol Curcumene α-Cedrene β-Bisabolol	Antioxidant activity Analgesic activity Anti-diarrhoeal activity Neuroprotective activity	[63,64]
C. amada Roxb.	Car-3-ene Cis-ocimene Curcuminoids Curcumin Demethoxycurcumin Bisdemethoxycurcumin Caffeic acid Ferulic acid Difurocumenonol Amadannulen Amadaldehyde	Antioxidant activity Antibacterial activity Antifungal activity Anti-inflammatory activity Platelet aggregation inhibitory activity Antitubercular activity Cytotoxic activity Antiallergic activity Hypotriglyceridemic activity CNS depressant activity Analgesic activity Enterokinase inhibitory activity	[65,66]
C. amarissima Roscoe	Curcumenol Curdione Curzerenone Germacene Isofungermacrene Zedoarone Curcumin Demethoxycurcumin Ferulic acid	Tissue Regenerative activity Antiamoebic activity Anti-enteritic potential Antifungal activity Antioxidant activity Antimicrobial activity Anti-inflammatory activity Collagen-synthesis promoting activity Dermal cell proliferation activity Central/peripheral antinociceptive activity	[67]
C. angustifolia Roxb.	Curzerenone 14-Hydroxy-*δ*-cadinene *γ*-Eudesmol acetate Camphor Germacrone	Antioxidant activity Antiproliferative activity Antimicrobial activity Anticancer activity Anti-ulcerogenic activity Antidiabetic activity	[68–70]
C. antinaia Chaveer. & Tanee	Labdanedialdehyde Labdanelactone	Antivenom (anti-envenomation) activity	[71]
C. aromatica Salisb.	1,8-Cineole ar-Turmerone ar-Curcumene β-Elemene β-Sesquiphellandrene Borneol Camphene Camphor Curcumin Curcumol	Anticancer activity Antidiabetic activity Antioxidant activity Antimicrobial activity Anti-inflammatory activity Antitussive activity Analgesic activity Wound healing activity Antiepileptic activity	[72,73]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. aromatica Salisb.	Curdione Demethoxycurcumin Germacrone Linalool Xanthorrhizol Zingiberene	Anticancer activity Antidiabetic activity Antioxidant activity Antimicrobial activity Anti-inflammatory activity Antitussive activity Analgesic activity Wound healing activity Antiepileptic activity	[72,73]
C. attenuata Wall. ex Baker	Germacrone Velleral Camphor β-Elemene β-Caryophyllene (Z)-β-Farnesene β-Selinene Camphene Germacrene D ar-Curcumene	Antioxidant activity	[74]
C. aurantiaca Zijp	Curcumin Demethoxycurcumin Bisdemethoxycurcumin Germacrone	Anti-inflammatory activity Antiviral activity Anticancer activity	[75]
C. australasica Hook.f.	Zederone Furanodien-6-one	Anti-inflammatory activity Antioxidant activity Cytotoxic activity Antitumor activity Antivenom activity Haematological modulatory (Blood purification) activity	[76]
C. caesia Roxb.	Eucalyptol Camphor Demethoxycurcumin Bisdemethoxycurcumin	Antibacterial activity Antifungal activity Anti-inflammatory activity Antiasthmatic activity Muscle relaxant activity Analgesic activity Locomotor depressant activity Anticonvulsant activity	[77–79]
C. candida (Wall.) Techapr. & Škorničk.	Humulene Furfural Mustakone Caryophyllene Longiverbenone (−)-β-Pipene (E)-β-Farnesene	Anti-HIV	[80]
C. caulina J.Graham	Neoxanthin Madecassic acid Rotoveratrine A Punctaporin B	Hepatoprotective activity (Treatment of Jaundice)	[81]
C. cochinchinensis Gagnep.	Curdione 1,8-Cineole cis-B-elemenone Germacrone	Antiviral activity Anticancer activity	[82,83]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. comosa Roxb.	Curcucomosides A–D Kaempferol 3-*O*-*α*-l-arabinoside Quercetin 3-*O*-arabinopyranoside Kaempferol 3-*O*-*α*-l-rhamnopyranosyl-(1→2)-*O*-*α*-l-arabinopyranoside 4,6-Dihydroxy-2-*O*-(β-D-glucopyranosyl) acetophenone	Nematocidal activity Estrogenic activity Choleretic activity Anti-inflammatory activity Antioxidant activity Antibacterial activity Cytotoxic activity	[84–87]
C. cotuana Luu, Škorničk. & H.Đ.Trần	(*E*)-labda-8(17),12-diene-15,16-dial n-Exadecanoic acid 3,7,11,15-Tetramethylhexadec-2-en-1-yl acetate γ-Sitosterol	Antibacterial activity	[88]
C. decipiens Dalzell	4, 4-Dimethyl-2, 4, 5, 6-tetrahydro-1H-inden-2-yl) acetic acid β-Bisabolene n-Hexadecanoic acid α-Bisabolol Kaur-16-ene	Anti-inflammatory activity Anticancer activity Antibacterial activity Antifungal activity Antiviral activity	[89]
C. elata Roxb.	Germacrone Curzerenone Isofuranodienone Furanodienone Curdione Neocurdione Zederone Curcumenone 13-Hydroxygermacrone Zedoarondiol Diarylheptanoids 3-Hydroxy-5-Platyphyllone 8,9-Dehydro-9-formyl-cycloisolongifolene 1,8-Cineole α-Pinene β-Bisabolene ar-Curcumene	Cytotoxic activity Antimicrobial activity Antioxidant activity Anti-inflammatory activity	[74,90,91]
C. glans K.Larsen & Mood	Germacrone β-Pinene Camphor	Antimicrobial activity	[92]
C. gracillima Gagnep.	*β*-Bisabolol β Caryophyllene *β*-Curcumene 3,4-Dimethylanisole *α*-Curcumene	Anticancer activity α-glucosidase inhibitory activity Antibacterial activity Antifungal activity Antioxidant activity	[93,94]
C. haritha Mangaly & M.Sabu	α-Pinene β-Pinene p-Cymol Camphor Camphene Borneol Pentadecane Tumerone ar-Tumerone	Antimicrobial activity Expectorant activity Astringent activity Antidiarrheal activity Anticoagulant activity	[95]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. harmandii Gagnep.	1,8-Cineole Germacrone Curdione Curcumenol β-Pinene β-Elemene Isocurcumenol	Antioxidant activity Anti-inflammatory activity Antibacterial activity Neuroprotective activity Nephroprotective activity Hepatoprotective activity Estrogenic activity	[96,97]
C. heyneana Valeton & Zijp	Zerumbone Furanodienone Zederone Oxycurcumenolepoxidol Curcumenol Isocurcumenol Curcumanolide Dehydrocurdione Curcumenone Germacrone	Antimicrobial activity Antioxidant activity Tyrosinase inhibitor activity Collagenase inhibitor activity Anti-aging activity	[98–100]
C. inodora Blatt.	Curzerenone Germacrone Curdione 1,8-Cineole β-Eudesmol Farnesol	Anti-inflammatory activity Antipyretic activity Wound healing activity Psychotropic activity Laxative activity Analgesic activity	[101–104]
C. involucrata (King ex Baker) Škorničk.	Soterpinolen β-Ocimene	Antibacterial activity	[105]
C. karnatakensis Amalraj, Velay. & Mural.	(−)-Spathulenol Caryophyllene α-Caryophyllene β-Bisabolene Hexahydrofarnesylacetone β-Elemenone Eremanthin	Antioxidant activity Antiproliferative activity Antimitotic activity Anti-inflammatory activity	[106–108]
C. kwangsiensis S.G.Lee & C.F.Liang	8,9-Dehydro-9-formyl-cycloisolongifolene Germacrone L-camphor 7*β*-Hydroxylabda-8(17),12-diene-14,15,16-triol (12*Z*,14*S*)-7*β*-Hydroxlabda-8(17),12-diene-14,15,16-triol (4*S*)-Hydroxy-(8)-methoxy-(5*S*)-(*H*)-guaia1(10),7(11)-dien-12,8-olide	Antimicrobial activity Anti-inflammatory activity Antinociceptive activity	[109,110]
C. latifolia Roscoe	Germacrone Furanodienon Curzerenone Curdione Zederone	Antidiarrheal activity Thrombolytic activity Anti-inflammatory activity	[111,112]
C. leucorrhiza Roxb.	Germacrone Curdione Camphor 1,8-Cineole Curzerene Linalool *neo*-Curdione Isoborneol	Antioxidant activities Antibacterial activity Antifungal activity	[113–115]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. leucorrhiza Roxb.	Germacrene D	Antioxidant activities Antibacterial activity Antifungal activity	[113–115]
	α-Longipinene		
C. longa L.	Curcumin	Antioxidant activity Hepatoprotective activity Antidiabetic activity Anti-osteoarthritic activity Antimalarial activity Neuroprotective activity	[116–119]
	Demethoxycurcumin		
	Bisdemethoxycurcumin		
	α-Phellandrene		
	2-Carene		
	Eucalyptol		
C. macrochlamys (Baker) Škorničk.	Hexadecanoic acid	Antioxidant activity Antimicrobial activity	[120]
	Dodecanoic acid, methyl ester		
	Methyl Octanoate		
	Myristic acid		
	Phytol		
	Lauric acid		
C. mangga Valeton & Zijp	Myrcene	Antimicrobial activity Cytotoxic activity Analgesic activity Anti-inflammatory activity Antioxidant activity Immunomodulatory activities	[121–124]
	β-Pinene		
	(*E*)-labda-8(17),12-dien-15,16-dial		
	(*E*)-15,16-bisnor-labda-8(17),11-dien-13-on		
	Zerumin A		
	β-Sitosterol		
	Curcumin		
	Demethoxycurcumin		
	Bis-demethoxycurcumin		
C. mutabilis Škorničk., M.Sabu & Prasanthk.	Estrone methyl ether (3-Methoxyestra-1,3,5(10)-trien-17-one)	Anticancer activity Antioxidant activity Antiproliferative activity	[125,126]
	β-Caryophyllene		
	β-Farnesene		
	α-Humulene		
C. nankunshanensis N.Liu, X.B.Ye & Juan Chen	Curdione	Antioxidant activity Analgesic activity Antimicrobial activity Anti-inflammatory activity Insecticidal activity Hemagglutination activity Anticancer activity	[74]
	Germacrone		
	β-Elemenone		
	β-Santalol		
	α-pinene		
	Neocurdione		
	1,8-Cineole		
	Borneol		
	β-Selinene		
	Germacrene D		
	α-Selinene		
	Aromadendrene oxide		
	Caryophyllene oxide		
	β-Caryophyllene		
C. neilgherrensis Wight	Rutin	Antidiabetic activity Antioxidant activity Antiproliferative activity Anthelmintic activity Anti-inflammatory Antiasthmatic activity Gastroprotective activity Carminative activity	[127–130]
	Tamarixetin		
	Embelin		
	Ginkgolide B		
	Traumatic acid		
	Rosmarinic acid		

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. newmanii Škorničk.	Phytochemical classes reported (Alkaloids,Terpenoids, flavonoids, Polyphenol, saponins, tannins); no specific compound identified	Not Reported	[131]
C. oligantha Trimen	β-caryophyllene Phytol α-humulene	Anti-inflammatory activity Immunomodulatory activity Antiatherosclerotic activity Antiosteoporotic activity Antinociceptive activity Antioxidant activity Antiallergic activity Antimicrobial activity	[132]
C. pambrosima Škorničk. & N.S.Lý	β-Pinene Camphene Camphor Isoborneol β-Caryophyllene	Antimicrobial	[133]
C. parviflora Wall.	ar-Turmerone Parviflorene A Parviflorene B Parviflorene C α-Turmerone Parviflorene D Parviflorene E Parviflorene F Cadalenequinone Parviflorenes H Parviflorenes I 8-Hydroxycadalene Parviflorene J	Cytotoxic activity Antivenom activity	[134–136]
C. petiolata Roxb.	2-Methyl-5-pentanol 1*H*-pyrrol-1-amine,2-(4-methoxyphenyl)-N,N,5-trimethyl Curcumol Curcumin Labda-8(17),12 diene-15,16-dial 15,16-Bisnorlabda-8(17),11-diene-13 one 15-epi-Coronarin D Coronarin D methyl ether Stigmasterol Vanillin	Antioxidant activity Antibacterial activity Antifungal activity Anti-inflammatory activity Anticancer activity Lipid peroxidation Inhibitory activity Tyrosinase inhibitory activity	[137–141]
C. phaeocaulis Valeton	8,9-Dehydro-9-formylcycloisolongifolene Germacrone Curlone α-Caryophyllene Curzerene β-elemene	Antioxidant activity Antitumor activity Anti-inflammatory activity Neuroprotective activity	[142,143]
C. pierreana Gagnep.	Isoborneol Isobornyl acetate β-caryophyllene (*Z*)-β-Farnesene Camphor Camphene α-Pinene	Anticancer activity α-glucosidase inhibitory activity Antibacterial activity Antifungal activity Antioxidant activity	[93,144,145]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. plicata Wall. ex Baker	Not specifically reported (only total phenolic/flavonoid content and nutritional parameters reported)	Antioxidant activity Anti-inflammatory, Carminative activity Gastroprotective activity Laxative activity	[146,147]
C. pseudomontana J.Graham	β-Elemenone Pseudocumenol Germacrone 2-(4-methoxyphenyl) N,N-trimethyl-1-pyrrolamine (1,5-Dimethyl-4-hexenyl)-4-methylbenzene Curcumin	Antibacterial activity Antivenom activity Anthelmintic activity Lactogenic activity Antidiabetic activity Anticancer activity Antioxidant activity Hypocholesterolemic activity Anti-inflammatory activity Analgesic activity Antiseptic activity Antiandrogenic activity Antimicrobial activity Sedative activity Anesthetic activity Nematicidal activity Fungicidal activity	[148–152]
C. purpurascens Blume	Turmerone Germacrone ar-Turmerone Germacrene-B Curlone	Antiproliferative activity Antifungal activity Cytotoxic activity	[153]
C. pygmaea Škorničk. & Šída f.	β-Pinene Caryophyllene Xanthorrhizol β-curcumene Humulene	Antibacterial activity	[154]
C. rangjued Saensouk & Boonma	D-Limonene β-Pinene Caryophyllene	Antioxidant activity Anti-inflammatory activity Antidiabetic activity Neuroprotective activity	[155]
C. rhabdota Sirirugsa & M.F.Newman	3-Carene Camphene α-Copaene γ-Terpinene Camphor β-Curcumene Germacrone	Antimicrobial activity	[138,156]
C. rubescens Roxb.	ar-Turmerone Zerumbone Sesquiterpenoids α-pinene 1,8-Cineole Camphor β-Elemene β Selinene Germacrene D Aromadendrene oxide α-Selinene Germacrone	Antioxidant activity Antiviral activity	[74,157]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. rubrobracteata Škorničk., M.Sabu & Prasanthk.	Camphor Germacrone γ-Elemene	Antiseptic activity Analgesic activity Antipruritic activity Antitussive activity Expectorant activity Counterirritant activity Rubefacient activity	[96]
C. sahuynhensis Škorničk. & N.S.Lý	β-Pinene β-Caryophyllene α-Pinene Caryophyllene oxide (*Z*)-β-farnesene,6,10,14 trimethylpentadecan-2-one Phytol 1-ethylbutyl hydroperoxide Isoborneol 1-methylpentyl hydroperoxide Neophytadiene	Antimicrobial activity Cytotoxic activity Antiviral activity	[158–161]
C. sessilis Gage	Not specifically identified	Antimutagenic activity	[162]
C. sichuanensis X.X.Chen	*epi*-Curzerenone Germacrone Isocurcumenol β-Elemene Curzerene 8,9-dehydro-9-formylcycloisolongifolene Curdione Zerumbone ar-Turmerone β-Elemenone	Antioxidant activity	[74,163–166]
C. singularis Gagnep.	Camphor Isoborneol Endo-borneol Terpinen-4-ol Copaene Acoradiene Turmerol	Cardioprotective activity Neuroprotective activity Anti-inflammatory activity Anticancer activity	[167–169]
C. sparganiifolia Gagnep.	α-Copaene Xanthorrhizol	Antiseptic activity Analgesic activity Antipruritic activity Antitussive activity Nasal decongestant activity Expectorant activity Counterirritant activity Rubefacient activity	[96,170]
C. sumatrana Miq.	9-Acetyl-S-octahydrophenanthrene 3-Oxoandrosta-1,4dien-17 beta-spiro-2′-3′-oxo-oxetane	Neuroprotective activity Cognitive-enhancing activity Anticancer activity	[171]
C. sylvatica Valeton	α-Fenchene 1,8 Cineole α-Pinene β-Pinene Camphene Camphor	Antimicrobial activity Anticancer activity Antidiarrheal activity Anti-inflammatory activity	[149,172]
C. thorelii Gagnep.	β-Pinene Caryophyllene	Antimicrobial activity	[173]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. trichosantha Gagnep.	Curdione Curcumol Germacrone Eudesmol Caryophyllene oxide Aristolene Selina-4(14) 11-dien Caryophyllene Linalool 2-Nonalol 8- Cadinene Borneol	Anticancer activity Antibacterial activity Antifungal activity	[149,174]
C. vamana M.Sabu & Mangaly	alkaloids, tannins and flavonoidsand phenolic compounds alkaloids, tannins and flavonoidsand phenolic compounds alkaloids, tannins and flavonoidsand phenolic compounds alkaloids, tannins and flavonoidsand phenolic compounds alkaloids, tannins and flavonoidsand phenolic compounds Phytochemical classes reported (Alkaloids, tannins, flavonoids, phenolics, glycosides, saponins); total phenolic and flavonoid content quantified; no specific compounds identified	Antioxidant activity Hepatoprotective activity	[175,176]
C. viridiflora Roxb.	Furanodiene Dehydrocurdione Germacrone-4,5-epoxide Zedoarondiol	Antileukemic activity	[177]
C. vitellina Škorničk. & H.Đ.Tran	β-Pinene 1,8-Cineole Camphene Limonene Sabinene α-Pinene	Antimicrobial	[178]
C. wallichii M.A.Rahman & Yusuf	Methyl linoleate Zederone Alismoxide Valerenic acid Xanthinin Linderane Harmalacidine Taylarione	Antioxidant activity Anticancer activity Anti-inflammatory activity	[179,180]
C. wanenlueanga Saensouk, Thomudtha & Boonma	Curcumin Demethoxycurcumin Dihydrodemethoxycurcumin Curcumenone Zedoarondiol	Anti-inflammatory activity	[181]
C. xanthella Škorničk.	1,8-Cineole n-Hexadecanoic acid Stigmasterol γ-Sitosterol Neophytadiene	Antioxidant activity Antibacterial activity	[182]

Table 3. *Cont.*

Scientific Name	Selected Reported Compounds	Selected Biological/ Pharmacological Activities	References
C. yunnanensis N.Liu & S.J.Chen	8,9-Dehydro-9-formylcycloisolongifolene ar-Turmerone α-Pinene 1,8-Cineole Camphor β-Elemene β Selinene Germacrene D Aromadendrene oxide α-Selinene Caryophyllene oxide Germacrone β-Caryophyllene	Analgesic activity Antimicrobial activity Anti-inflammatory activity Hemagglutination activity Anticancer activity	[74]
C. zanthorrhiza Roxb.	Xanthorrhizol β-Curcumene ar-Curcumene Germacrone α-Curcumene Furanodienone Zederone Stigmasterol Curcumin Demethoxycurcumin ar-Turmerone	Anticancer activity	[60,149,183,184]
C. zedoaria (Christm.) Roscoe	Curzerenone 1,8-cineole Curzerene *trans*-β-Elemene Camphor Germacrone Curcumin 1–8 Cineole Ethyl p-Methoxycinnamate β-Turmerone B-Eudesmol Zingiberene Dihydrocurcumin α-Phellandrene	Antimicrobial activity Antioxidant Antifungal activity Antivenom activity Antiamoebic activity Analgesic activity Antinociceptive activity Antiallergic activity Antiulcer activity Platelet aggregation activity Hepatoprotective activity Anti-inflammatory Antimutagenic Cytotoxic activity Anticancer	[185–190]

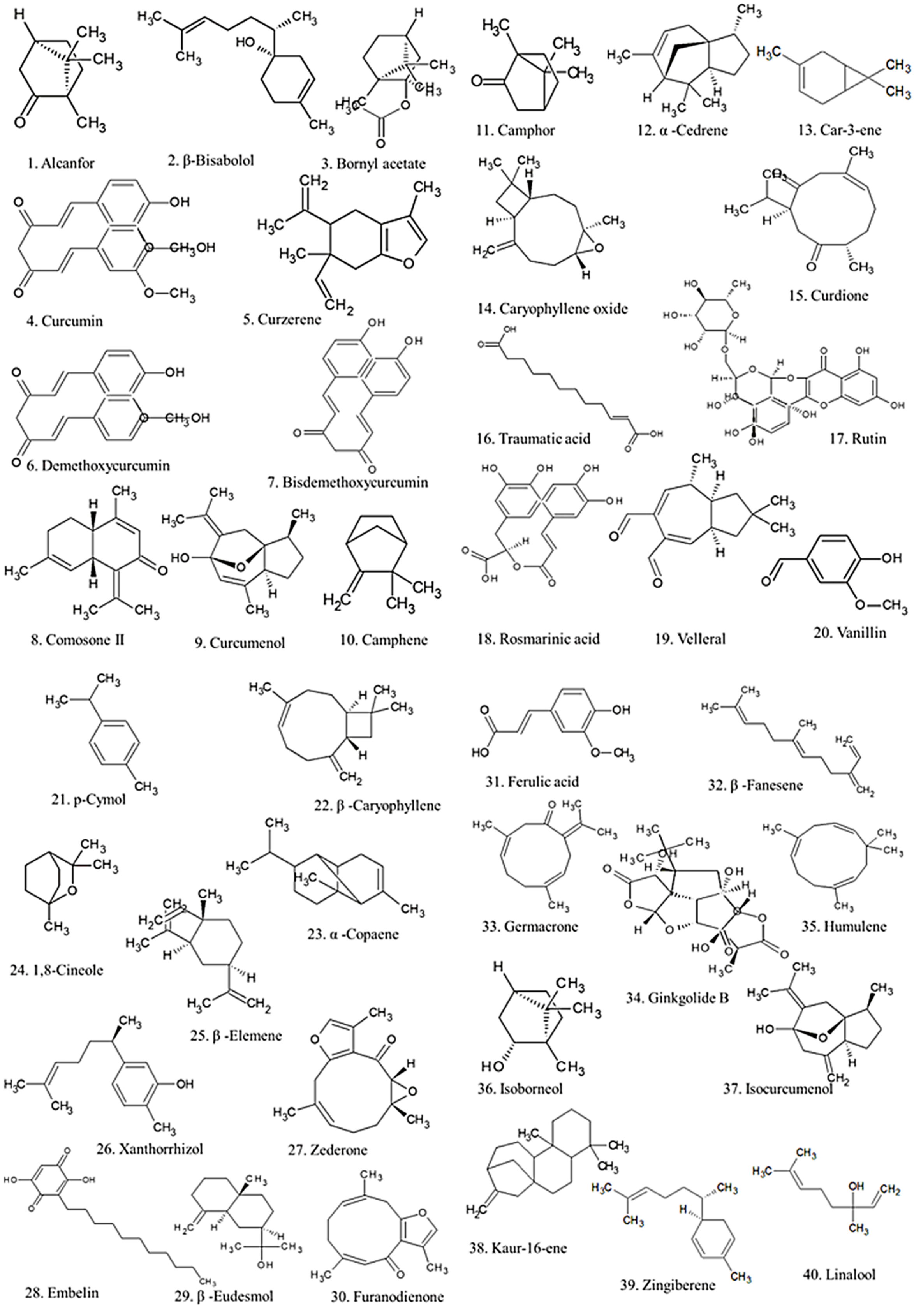

Figure 11. Chemical structures (**1**–**40**) of selected bioactive compounds reported from various *Curcuma* species (Drawn by authors using ACD/ChemSketch (Freeware, 2012) software).

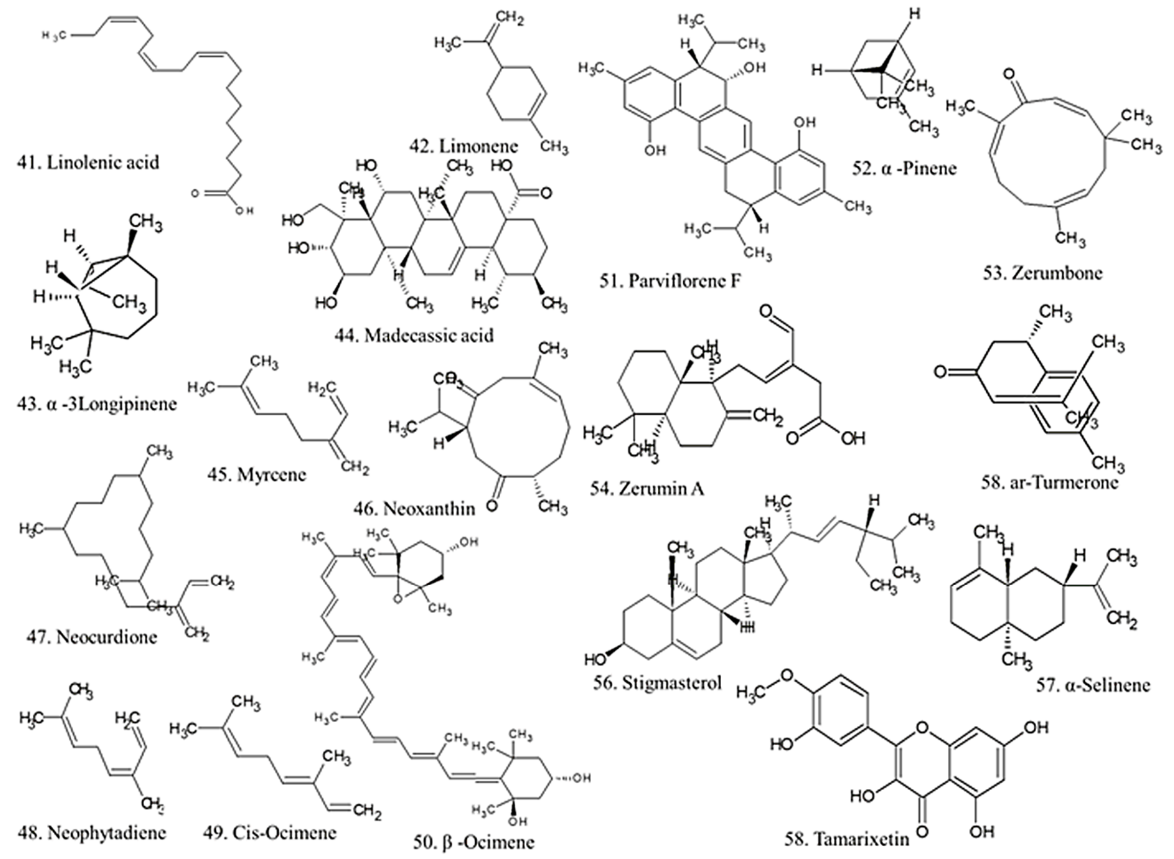

Figure 12. Chemical structures (**41**–**58**) of selected bioactive compounds reported from various *Curcuma* species (Drawn by authors using ACD/ChemSketch (Freeware, 2012) software).

8. Clinical Trials Landscape of the Genus *Curcuma*

A total of 491 clinical studies were identified from ClinicalTrials.gov (https://clinicaltrials.gov/ (accessed on 6 April 2026)) database that were associated with the *Curcuma* genus. The curated dataset is overwhelmingly dominated by interventional trials (97.56%), whereas only a minor proportion of the dataset comprises of observational studies (2.44%). This clearly indicates a very strong translational focus toward therapeutic validation rather than just epidemiological exploration.

Also, the curated dataset shows a mature clinical research landscape, where the majority (58.45%) of the trials have already been completed. However, there is a large 'Unknown' category (17.52%), which reflects data reporting gaps. Furthermore, terminated and withdrawn studies (~8.76%) suggest challenges that may have arisen due to feasibility or efficacy problems during certain trial designs or because of funding issues. The study status distribution is presented in Table 4.

Table 4. Distribution of clinical trials of the Curcuma genus by study status.

Status	Count	Percentage (%)
Completed	287	58.45
Unknown	86	17.52
Recruiting	37	7.54
Terminated	22	4.48
Withdrawn	21	4.28
Not yet recruiting	20	4.07
Active, not recruiting	16	3.26
Enrolling by invitation	2	0.41

Phase-wise analysis, as represented in Table 5, reveals that out of the 491 studies, 248 studies (50.41%) are categorised as "Not Applicable", which is indicative of the fact that over half of the investigations fall outside the conventional drug development pipeline. This can be correlated with the fact that *Curcuma* is consistently evaluated as a nutraceutical, dietary supplement, or adjunct therapy, which typically does not adhere to the formal phase classification.

Among the phase-classified trials, Phase 2 studies constitute the largest group (n = 118; 24.03%), which suggests that the research efforts are concentrated at the level of preliminary efficacy evaluation. Early-stage trials, which includes Phase 1 (n = 65; 13.24%) and Early Phase 1 (n = 22; 4.48%), indicate that ongoing investigation into safety, tolerability as well as dose optimisation. On the other hand, Phase 3 (n = 47; 9.57%) and Phase 4 (n = 18; 3.67%) studies are comparatively less, which reflects that there is a restricted transition (translational bottleneck) toward large-scale confirmatory trials as well as post-marketing evaluation.

Table 5. Phase Distribution of Clinical Trials.

Phase Category	Count	Percentage (%)
Not Applicable	248	50.51
Phase 2	118	24.03
Phase 1	65	13.24
Phase 3	47	9.57
Early Phase 1	22	4.48
Phase 4	18	3.67

However, it is important to note that these phase counts are derived from the ClinicalTrials.gov database and they are not mutually exclusive (e.g., Phase 1/Phase 2 may be counted in both Phase 1 and Phase 2). So, totals may exceed n = 491, and hence, they should not be summed.

Apart from these, it has been observed that the included studies mainly target adult populations (18–64 years; n = 471) with a significant proportion that also targets older adults (≥65 years; n = 354), which indicates relevance to chronic as well as age-associated conditions. In contrast, it has been observed that the pediatric inclusion (0–17 years) is relatively limited (n = 61). Moreover, sex-based eligibility is found to be broadly inclusive, where majority of the trials allowed the participation of both male (n = 442) and female (n = 458) individuals, which in turn enhances the generalizability of findings across populations.

The funding architecture of *Curcuma*-related clinical trials suggests there exists a predominantly academic as well as institution-driven ecosystem, with 435 studies (88.59%) involving individuals or universities or other non-industry organisations. Other than this, 106 trials (21.59%) are industry-funded studies. Government funding (NIH + Federal ≈ 4.89%) is minimal, which shows that *Curcuma*-based interventions yet may not be a major priority in federally funded clinical research pipelines. Importantly, these categories, again are not mutually exclusive as because individual trials may receive support from multiple funding bodies, which indicates a collaborative as well as multi-sectorial research framework. This funding pattern may be a cause for the observed fragmentation in trial scale, limited progression to late-phase studies as well as variability in standardisation, which reinforces the broader translational gap between early clinical promise and robust therapeutic validation.

Apart from these, the geographic distribution of *Curcuma*-related clinical trials, depicted in Figure 13, shows that the research landscape is globally dispersed yet regionally concentrated. North America comes out to be the leading region (n = 197), which is predominantly driven by the United States (168 studies). This indicates that there is a strong contribution from this region which might be because of their advanced clinical research infrastructure as well as institutional capacity. Asia represents the second major hub (n = 129), with contributions mainly from India (21), Israel (19) and Iran (17). This distribution is suggestive of the fact that Asia has a dual influence of traditional ethnomedicinal relevance as well as emerging clinical research capabilities. It is also interesting to note that the contributions from Asia are distributed across multiple Asian countries, which suggests a decentralised but active research network rather than single nation dominance. Europe (n = 86) also demonstrates a well-distributed research presence and consistent engagement from established biomedical research systems, which is led by Italy (19), France (13), and the United Kingdom (13). In contrast, Africa (n = 22) and South America (n = 11) show limited representation, with Africa being heavily dominated by Egypt (21 studies), which shows region-specific concentration rather than a continent-wide participation. Oceania is minimally represented (n = 1), which clearly suggests that there is a near absence of *Curcuma*-based clinical activity in this region. It is important to note that regional counts are not mutually exclusive, as because there may be individual studies with multiple geographical locations which may be indexed under more than one region. Also, studies without reported locations (n = 46) are excluded from the regional mapping. Hence, regional totals are not to be interpreted as additive components of the global dataset.

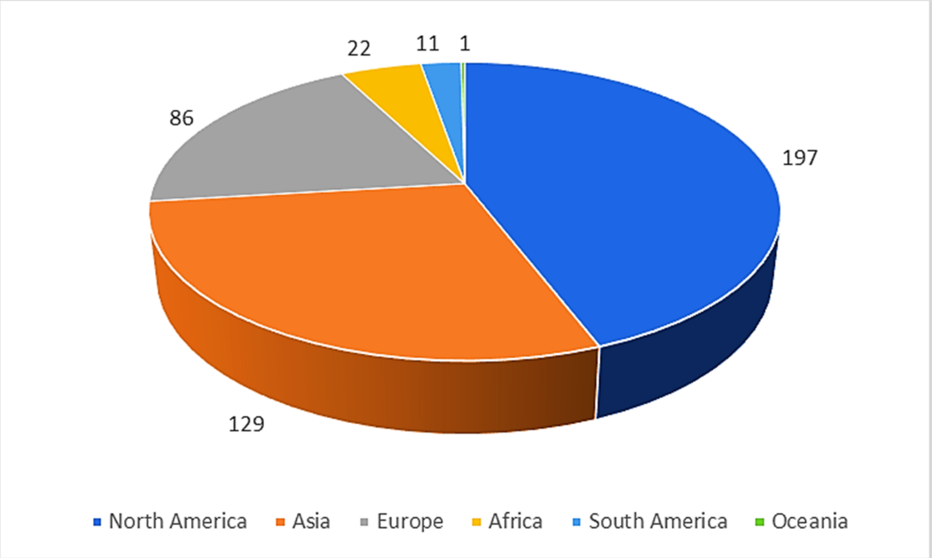

Figure 13. Geographic distribution of *Curcuma*-related clinical trials.

Furthermore, across the 491 curated clinical trials that are analysed, it can be observed that the therapeutic landscape of *Curcuma,* which are primarily curcumin-based interventions, demonstrates a broad therapeutic footprint, with highest representation/strongest concentration of evidence in the case of metabolic-inflammatory as well as musculoskeletal disorders- mainly osteoarthritis, metabolic syndrome, diabetes and chronic inflammatory conditions, followed by metabolic oncology (primarily as adjuvant), neuropsychiatric disorders, and gastrointestinal (GI) diseases such as irritable bowel syndrome (IBS) and inflammatory bowel disease (IBD). It also shows a distinct cluster in oral-dental applications.

The intervention types are dominated mainly by dietary supplement-based interventions. However, it can also be observed that curcumin is rarely positioned as a standalone pharmacological agent in severe disease contexts, rather it is used as an adjunctive therapeutic agent, particularly alongside chemotherapy, radiotherapy, statins, metformins, or antidepressants, where it shows modest but reproducible improvements in biochemical, inflammatory, oxidative stress, as well as metabolic biomarkers.

Despite of having numerous “completed” trials, there still remains a limitation in robust clinical efficacy in hard endpoints (e.g., tumour regression, survival benefit, or disease reversal), especially in the case of oncological as well as neurodegenerative diseases, when it can be observed that the outcomes often remain either inconclusive or trials are discontinued. This brings forward a critical gap between biomarker-level success and clinical-level impact.

A major translational bottleneck that can be observed repeatedly from the curated dataset is the issue of poor bioavailability, which has led to the innovation of advanced formulation strategies such as piperine-enhanced systems, nanocurcumin, liposomal as well as micellar delivery systems. Though these approaches improve the pharmacokinetics, but their superiority in clinical outcomes remains inconsistent because of heterogeneous trial designs, dosing regimens and endpoints.

Also, there is an observed defining trend of extensive usage of multi-component formulations (combination therapies), where curcumin is co-administered with vitamins, polyphenols (such as quercetin, resveratrol), omega-3 fatty acids, or standard pharmacological agents. This clearly reinforces the role of curcumin as a synergistic adjunct rather than a standalone therapeutic agent; even though in such cases, the mechanistic attribution becomes difficult, which limits reproducibility.

Apart from these, it can be observed from the curated dataset that the routes of administration are predominantly oral, but there is also emerging topical, localised (periodontal, intravaginal), as well as experimental delivery systems, which show notable diversification, specifically in dermatological, oral health, as well as in supportive cancer care.

Additionally, the majority of the studies are found to be small-scale, single-centre studies, which are often reliant on surrogate endpoints, with limited population diversity and minimal integration of precision medicine approaches. This weakens the overall strength as well as the generalisability of evidence. Apart from these, there is also evidence of advanced strategies in the curated dataset, such as curcumin-preconditioned stem cells or combination regimens with standard care. These advanced strategies hint at increasing sophistication, but their frequency of usage in trials remains relatively sparse.

In a nutshell, the clinical trial landscape of the genus *Curcuma* reveals a globally active yet predominantly early-to-mid-stage, academically driven research domain with significant gaps, which needs to be addressed for full-scale clinical translation as well as therapeutic integration.

9. Discussion

The genus *Curcuma*, belonging to the family Zingiberaceae, stands as a key taxon holding a significant position in the traditional medicine system and Pharmacognosy. Through extensive literature mining and the compilation of data from the Plants of the World Online (POWO) Kew database (https://powo.science.kew.org (accessed on 7 April 2026)), this review offers a comprehensive profile of the genus, encompassing 180 taxonomically accepted species.

The bibliometric performance analysis using Scopus-indexed literature from 2014–2024 showed that the annual growth rate % in *Curcuma*-related works in the context of biomedical sciences is 2.19, which clearly indicates modest but sustained scholarly engagement. The peak in annual scientific production was observed in the year 2021 (428 articles), which indicates a potential pandemic-driven surge in plant-based therapeutics. Geographical analysis in terms of author occurrences also revealed Asia as the primary hub (China and India leading), followed by significant contributions from Indonesia, Thailand, and Western countries such as the USA, Brazil, South Korea, Iran and Japan. Italy leads among European nations with respect to *Curcuma*-related research. In terms of citation impact, China, India and Iran are the top three contributors.

Moreover, the species distribution analysis based on data from the POWO database (https://powo.science.kew.org (accessed on 7 April 2026)) has shown that the native range of *Curcuma* is primarily concentrated in Southeast Asia, with Thailand (96 species), India (37 species), and Myanmar (36 species) being the major hotspots. Along with this, the wide introduction of *Curcuma longa* L. in over 52 non-native geographical locations and other economically important species such as *C. zanthorrhiza* Roxb. *and C. zedoaria* (Christm.) Roscoe further signifies their ethnomedicinal importance. This global dispersion of selected *Curcuma* species not only justifies their adaptability but also gives a clear picture of their relevance in cross-cultural medicinal systems. Furthermore, the traditional uses of various *Curcuma* species across diverse medicinal systems such as Ayurveda, Unani, and Homoeopathy are increasingly aligning with modern-day scientific findings, as because many of their historically documented therapeutic applications are now being validated via contemporary pharmacological research.

Apart from these, when an extensive species-wise literature search was conducted, it was found that out of the 180 accepted species of *Curcuma*, metabolite profiling and/or biological/pharmacological activity have been reported only for 69 species, while 111 species remain largely underexplored in this regard. This disparity critically highlights a significant research gap in the pharmacological investigation of this genus, despite its rich ethnomedicinal legacy across Southeast Asia, the Indian subcontinent and parts of China.

The underrepresentation of approximately 62% of the genus in ethnopharmacological research raises a very significant question: Are we underutilising a vast reservoir of phytochemicals that can offer potential solutions to modern therapeutic challenges?

The identified bioactive compounds from the 69 species (such as curcumin, germacrone, curdione, xanthorrhizol, etc.) offer a plethora of bioactivities such as antioxidant, antimicrobial, anticancer, anti-inflammatory, antihelminthic, anticarcinogenic, antiulcerogenic, antimalarial, antivenom, antidepressant, antidiabetic, antinephrotoxic, antiasthmatic, anticoagulant, antitumour, anti-fertility, antitubercular, antiproliferative, neuroprotective, immunomodulatory effects, etc. [191]. This biochemical versatility undoubtedly suggests that *Curcuma* species are not only pharmacologically active because of a few well-known phytochemicals but may represent a vast chemical library of structurally diverse secondary metabolites, many of which are yet to be explored and studied in depth.

Furthermore, a skewed research focus becomes highly apparent where a few notable species like *C. amada* Roxb*., C. aromatica* Salisb.*, C. caesia* Roxb.*, Curcuma longa* L.*, C. zedoaria* (Christm.) Roscoe *and* dominate the literature presence*,* which are often repeatedly investigated across similar pharmacological dimensions. This "popular species syndrome" actually sidelines the lesser-explored/unexplored species of the *Curcuma* genus, many of which may contain novel phytochemicals and might have immense pharmacological benefits.

The 111 underexplored species without any reported biological/pharmacological activity are a key highlight of this review. Eight (*C. ferruginea* Roxb., *C. kudagensis* Velay., V.S.Pillai & Amalraj, *C. lithophila* Škorničk. & Soonthornk., *C. nivea* Saensouk, P. Saensouk & Boonma*, C. ornata* Wall. ex Baker*, C. pedicellata* (Chaveer. & Mokkamul) Škorničk., *C. phrayawan* Boonma & Saensouk *and C. roscoeana* Wall.) of these 111 species are reported as ornamental plants, though ornamentation and pharmacology are not mutually exclusive, as because among the identified 69 species, there were also the presence of species (e.g., *Curcuma amada* Roxb.*, C. alismatifolia* Gagnep.) which are aesthetically valuable but have parallelly shown pharmacological activities too [192–196]. So, this opens up a chance that those eight ornamental species may also show significant pharmacological activities, if explored properly. Moreover, two species were found having only ethnomedical usage reports, but no phytochemical profiling or pharmacological studies have been reported in the literature, so they were not included in the 'explored species' section. These species were *C. picta* Roxb. ex Škorničk. (having reports of cosmetic use and treatment of pimples) and *C. clovisii* Škorničk., which is used in musculoskeletal disorders, blood-related conditions, digestive/ metabolic disorders, nervous system, as well as in respiratory issues, but these are mere ethnomedicinal usage reports and do not have any pharmacological validation [197,198]. Thus, the silent majority of the genus, as well as less explored species, could be important leads for reverse pharmacology, metabolomics-aided profiling, or computer-aided approaches.

Apart from these, the clinical trial evidence shows that *Curcuma*-derived interventions are safe, biologically active, as well as moderately effective, mainly for managing inflammation-driven conditions, but they are constrained by pharmacokinetic limitations, methodological heterogeneity, etc. This gives an idea that although the field is maturing, it still resides in a translational phase between exploratory nutraceutical use and rigorously validated therapeutic application.

Thus, this review gives a clear picture regarding the importance and trends of *Curcuma* research and also highlights the research gap that a vast majority of the species within the genus *Curcuma* (i.e., ~62%) is still underexplored, which can uncover a plethora of novel scaffolds or rare phytochemicals that can be blended with the modern medicinal system. Also, it highlights the fact that there is a need for more clinical trials of the reported compounds to fully uncover the therapeutic potential of the genus.

10. Future Prospects and Technological Interventions

The genus *Curcuma* (with only ~38% of the explored species till date) has a rich pool of phytochemicals (including curcumin, bisdemethoxycurcumin, xanthorrhizol, etc.) which show significant and diverse pharmacological as well as therapeutic potential, such as antioxidant, anti-inflammatory, antimicrobial, anticancer, neuroprotective, hepatoprotective, antidiabetic effects, etc. The remaining 62% of the genus is yet to be explored, which, if sincerely explored by the research community, has a strong possibility for the discovery of novel phytocompounds. So, it is the need of the hour to shift the research focus from studying 'only a few repeated species' to a more balanced and fruitful approach that includes both 'well-established species' as well as the systematic exploration of the 'under-explored/unexplored species' of the genus.

Another important concern is that, despite extensive research, clinical translation of *Curcuma*-based compounds still remains inadequate, which is mainly due to a lack of bioavailability, target specificity and pharmacokinetic stability of phytochemicals. To overcome these limitations and enhance the therapeutic efficiency, nanotechnology could pave the path for the future. Formulations like curcumin-loaded nanoparticles, micelles, liposomes, dendrimers and solid lipid nanoparticles have shown increased solubility, stability, as well as targeted delivery, specifically in the case of cancer and neurodegenerative models [199,200]. Recently, gold and silver nanoparticles with *Curcuma* extracts also exhibit anti-microbial activity and combinatorial drug delivery system [150,201].

Quantum dot-based smart nanocarriers and stimuli-responsive systems can also efficiently deliver bioactives of *Curcuma* and monitor their therapeutic outcomes time-to-time [202]. Moreover, CRISPR/ Cas-based genome editing technologies can help in the precise modulation of biosynthetic pathways in *Curcuma* species [203]. Metabolic engineering can also contribute to elevating the yield of pharmacologically relevant compounds or creating novel derivatives with the help of improved therapeutic activities [204].

The integration of omics technologies (genomics, transcriptomics, metabolomics and proteomics) can further help in understanding the complex biosynthetic networks for secondary metabolite production that is used in industrial-scale production of rare or unstable compounds [205]. Computational tools such as *in-silico* molecular docking, machine learning-based absorption, distribution, metabolism, excretion and toxicity (ADMET) prediction and network pharmacology models can give lead molecules, novel targets and reveal multi-targeted therapeutic potentials [206–208].

Apart from these, artificial intelligence (AI) generative models show curcumin analogues with enhanced stability and receptor binding affinity profiles. Moreover, platforms like 3D bioprinting of plant tissues and microfluidic organ-on-a-chip systems can be applied for high-throughput screening and real-time pharmacokinetic assessment of *Curcuma*-derived compounds that help to stimulate gut-liver-brain axes [209,210].

Moreover, microbiome-targeted therapies can regulate host metabolism in diseases like diabetes and obesity [211]. Moreover, Internet of Things (IoT) technology and blockchain technology can be used in tracing, authenticating and standardizing raw *Curcuma* bioactive materials for gaining absolute customer trust. They can help in real-time monitoring of environmental factors and also with the integration of these technologies with machine learning, they can give information regarding precise fertilizer, irrigation practices, which can increase yield as well as resource efficiency [212]. Lastly, incorporation of pharmacogenomic insights and personalised medicine principles may contribute highly to the detailed assessment of the therapeutic application of *Curcuma*-based treatments [213].

11. Limitations of the Study

The study has certain limitations. First of all, the bibliometric analysis was restricted to performance-analysis only with just minimal assessment of parameters. This was done, not with the intention to provide a comprehensive descriptive or network-based bibliometric evaluation but just to highlight the research trends and to showcase the relevance of the genus *Curcuma.* Furthermore, the analysis was based on a single database (Scopus), which though is a widely used comprehensive database for bibliometric analysis, but since other databases like PubMed and Web of Science were not evaluated, it can introduce database-dependent bias. Also, restricting the dataset to English language can result in language bias too. Apart from these, title, abstract, and full-text screening were not performed because of the large volume of records and also because of the fact that the bibliometric analysis for this study was designed for providing a broad trend mapping, rather than systematic evidence mapping. Also, reliance on tools such as Biblioshiny may contribute to methodological bias.

Secondly, for species-specific evidence mapping, literature retrieval was limited to PubMed, Google Scholar and ScienceDirect databases; hence the exclusion of some more databases such as Scopus and Web of Science may influence the scope as well as the representation of the retrieved literature; however, the selected databases collectively provide broad and multidisciplinary coverage of the literature.

Also, the reported compounds in the study were compiled from published literature, which includes analytical techniques such as GC-MS-based identifications; hence the reported data should be considered indicative rather than fully validated phytochemical profile. Similarly, biological/pharmacological activities were compiled from available reports, and in some cases, it may include preliminary or ethnopharmacological evidence; however, species that is solely supported by ethnobotanical claims without any sort of experimental validation were not included. Also, the reported compounds and biological/pharmacological activities are not exhaustive and are just representatives of the respective species.

12. Conclusions

The genus *Curcuma* represents a pharmacologically rich yet unevenly explored medicinal resource that possesses a strong ethnomedicinal relevance as well as growing scientific attention. Despite sustained research output, the investigations remain concentrated on a few well-known species, leaving ~62% of the taxa underexplored in terms of chemical characterisation and biological/pharmacological evaluation. Existing studies imply diverse bioactivities, but the translational progress is hindered by pharmacokinetic as well as methodological constraints. Importantly, the large pool of uncharacterised species within the genus suggests that there might be substantial unexplored phytochemical diversity. Therefore, it is the need of the hour to address this imbalance via systematic phytochemical, pharmacological, and clinical studies. Overall, if current research gaps are strategically addressed, the genus *Curcuma* can provide us with novel therapeutics in the coming future.

Supplementary Materials

The additional data and information can be downloaded at: https://media.sciltp.com/articles/others/2606251428254895/NPA-26040135-SI.pdf.

Author Contributions

D.I., and T.A.: Data curation, methodology, data analysis, writing—original draft & preparation. A.D.T.: writing—reviewing and editing, methodology and conceptualization. S.K. and S.P.: Writing- original draft, formal Analysis, writing—reviewing and final editing. D.N.: writing—reviewing and editing, methodology, formal Analysis, conceptualization, visualization, investigation and supervision.

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Data Availability Statement

Data that support the findings of this study are available in the supplementary material of this article.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

Abbreviations

POWO	Plants of the World Online
CSV	Comma-Separated Values
TCM	Traditional Chinese Medicine
TCAM	Traditional, Complementary and Alternative Medicine
DPPH	2,2-diphenyl-1-picrylhydrazyl
PPARγ	Peroxisome proliferator-activated receptor gamma
TNF	Tumor Necrosis Factor-alpha
NF-kB	Nuclear factor kappa B
p38 MAPK	p38 mitogen-activated protein kinase
FtsZ	Filamenting temperature-sensitive Z
GTPase	Guanosine Triphosphatase
HIV	Human immunodeficiency virus
SDH	Succinate dehydrogenase
Nrf2	Nuclear Factor Erythroid 2-related Factor 2
ROS	Reactive Oxygen Species
PfATP6	Plasmodium falciparum ATPase 6
GSK-3	Glycogen synthase kinase 3 beta
HAT	Histone Acetylcholinesterase Inhibitor
XTZ	Xanthorrhizol
GSH	reduced glutathione
GSTase	Glutathione S-transferase
KIM-1	Kidney injury Molecule-1
PT	Prothrombin Time
aPTT	Activated Partial Thromboplastin Time
FXa	Activated Factor X
BDMC	bisdemethoxycurcumin
SOD	Superoxide Dismutase
TBARS	Thiobarbituric acid reactive substances
iNOS	Inducible nitric oxide synthase
HSP70	Heat Shock Protein 70
IBS	Irritable Bowel Syndrome
IBD	Inflammatory Bowel Disease
ADMET	Absorption, Distribution, Metabolism, Excretion and Toxicity

AI	Artificial Intelligence
IoT	Internet of Things

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