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# Exploring the potential of chestnut (*Castanea sativa* Mill.): a comprehensive review and conceptual mapping

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## Abstract

**Background** *Castanea sativa* Mill. is important for ecosystems and societies. Its rich historical and cultural significance, remarkable ecological contributions, and diverse applications have inspired scientific research. This comprehensive review and conceptual mapping of chestnut research consolidates existing knowledge, identifies emerging trends, and highlights untapped potential to inform future investigations. First, the Scopus database was searched to retrieve all data-driven articles in English related to *C. sativa* published in English from 1951 to 2023. Second, the R language, Scopus Analytics, and VOSviewer were used to analyze the year of publication, authors, countries, affiliations, keywords, and citations. Finally, network analysis was performed to evaluate the hotspots and developmental trends of *C. sativa*. A total of 1889 research articles were recovered.

**Results** The articles showed an exponential progression, with a regression coefficient of 0.9435 (R<sup>2</sup>) and an annual growth rate of 6.28%. Italy (19.87%), Spain (15.56%), Portugal (13.39%), Turkey (6.92%), and Switzerland (5.17%) were the most prolific countries. *C. sativa* (798), sweet chestnut (54), cryphonectria parasitica (44), honey (38), phenolic compounds (35), chestnut blight (33) and antioxidant activity (31) are the keywords that occur the most frequently. The main research groups in the thematic map are "forest management," "Cryphonectria parasitica," "wood," "Spain" and "ethnobotany." Research on *C. sativa* has all the basic, motor, niche, and emerging or declining themes. Forest management, drought, *Gnomoniopsis smithogilyvi*, *C. sativa* shells, amino acids, honey, phenolic compounds, hydrolyzable tannins, antioxidant capacity, antioxidants, and extractives are trending topics.

**Conclusions** This bibliometric analysis highlights the importance of *C. sativa* research, revealing its ecological contributions, cultural significance, and diverse applications. Future studies should focus on forest management, drought resistance, and bioactive properties to ensure sustainable utilization.

**Keywords** Bibliometric analysis, *Castanea sativa*, Conceptual and intellectual structure, Hotspots, Trending research

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## Background

The genus *Castanea* comprises several species, but *C. sativa*, which is native to Europe and Asia Minor, stands out as one of the most prominent representatives of this family. *C. sativa* has historically been used as a valuable source of timber, food, and medicinal products (Aglietti et al. 2022). In addition, durable wood of *C. sativa* has been used in construction, furniture making, and even as a source of tannins (Afonso et al. 2022). Beyond its practical applications, *C. sativa* is also of immense ecological importance. As a dominant species in certain forest ecosystems, it contributes to biodiversity by providing habitat and food sources for numerous animal species. Additionally, the extensive root systems of trees aid in soil stabilization, prevent erosion, and promote water infiltration (Papaioannou et al. 2022).

The chestnuts derived from this tree have been a staple food in many cultures, providing sustenance and nourishment throughout generations. Chestnut kernels are popular and sought-after nuts during the seasonal period in many countries. They are enjoyed fresh or prepared using various cooking methods, such as roasting, boiling, or frying. Although chestnuts are known for their perishability, advances in technology have made it possible to find them on the market throughout the year owing to the availability of frozen and boiled-frozen chestnuts. In addition, there are other notable chestnut products available, including the highly regarded "Marrons Glacés," which are candied chestnuts, and chestnut flour made by grinding dried chestnuts. Chestnut flour is particularly useful for using smaller chestnuts or those with double embryos, allowing their effective utilization and value creation (Afonso et al. 2022; Aglietti et al. 2022).

In addition to being considered a delicacy, chestnuts are gaining importance as food commodities owing to their rich nutrient composition. They are particularly valued because of their high carbohydrate content and gluten-free nature. However, when considering the weight of fresh chestnuts, water was the primary component, typically accounting for more than 50% of their weight. In terms of dry matter, chestnuts are predominantly composed of starch, making them an excellent source of this polysaccharide, surpassing that of potatoes or wheat. The three main sugars in chestnuts are fructose, glucose, and sucrose. The concentration of each sugar varies depending on the chestnut cultivar, with sucrose ranging from 3.71 to 24.17 g/100 g of dry weight, glucose from 0.96 to 6.81 g/100 g of dry weight, and fructose from 0.57 to 5.32 g/100 g of dry weight, as reported in different studies (Barreira et al. 2020; Caprarulo et al. 2021; Ferreira 2023; Papaioannou et al. 2023).

Chestnuts have several pharmacological properties. Its leaves contain tannins and flavonoids that have

antioxidant and anti-inflammatory properties (Cerulli et al. 2021). The bark of the plant exhibits antimicrobial, anticancer, and antiviral activities (Odieka et al. 2022; Santulli et al. 2018). Furthermore, chestnut extracts have demonstrated antidiabetic properties by regulating blood glucose levels. Aescin, a triterpene compound found in *C. sativa* seeds, contributes to its anti-edematous and venotonic effects (Odieka et al. 2022). Chestnuts and their various parts, including the kernel, outer shell (pericarp), inner skin (integument), burs, male flowers, and leaves, contain bioactive compounds with potential health benefits.

In recent decades, the scientific community has increasingly recognized the vast potential of *C. sativa* and has intensified research efforts to unravel its multifaceted attributes (Ferreira 2023). Despite the recognition of the potential of *C. sativa*, there is a need to comprehensively assess existing knowledge. There are gaps in our understanding of publication trends, key authors, influential journals, and emerging research areas related to *C. sativa*. To comprehensively assess the existing body of knowledge on this tree species, this study employed bibliometric analysis, which is a quantitative method for evaluating scientific publications (Van Eck and Waltman 2010; Varzgalis et al. 2017). The objectives included quantifying the volume of research on *C. sativa*; examining its growth rate and distribution over different periods; analyzing the geographic distribution of research output; identifying influential authors, institutions, and journals; exploring the thematic content of *C. sativa* research; and highlighting emerging trends and research gaps to guide future investigations. By achieving these objectives, this study aimed to improve our understanding of *C. sativa*, promote further research, and unlock its full potential of this valuable plant.

## Methods

### Database selection and search strategy

Scopus was selected as the appropriate database for gathering bibliographic data because it covers a wide range of subjects, including scientific, technological, and medical domains. Scopus offers a broader range of research literature than databases such as Web of Science (WoS) and PubMed (Schmidt et al. 2016), ensuring a more thorough and varied collection of pertinent studies on *C. sativa*. The search for bibliographic information from the Scopus database used a systematic approach following the PRISMA recommendations (Selçuk 2019).

### Search strategy

With appropriate Boolean operators, pertinent search terms such as "*C. sativa*," "sweet chestnut," or "European chestnut" were used. Filters were used to restrict

the search to publications in English and to include only original studies. A predetermined strategy was used to conduct the search, ensuring thorough coverage of all pertinent articles on *C. sativa*. Following the strict guidelines outlined by PRISMA, the resulting set of original English-language studies was retrieved and used for subsequent analysis (Fig. 1). The decision to focus on English publications was based on practical considerations, including our team's language proficiency and the accessibility of English literature in the field. English is widely used for scientific communication, and a substantial amount of relevant research has been published in English. The data were extracted in BibTex and CVS formats.

### Data analysis

Scopus analytics, VOSviewer and Bibliometrix were utilized to analyze the bibliographic data (Aria and Cuccurullo 2017; Burnham 2006; Van Eck and Waltman 2010).

### Intellectual structure

Intellectual structure was analyzed using the Scopus-related feature. Scopus Analytics was used to quantify the volume of *C. sativa* research and understand its growth rate and distribution over time. Second, this analysis examined the geographic distribution of research output to identify regions and countries interested in studying *C. sativa*. Third, this Scopus feature identified the field's most influential authors, institutions, and journals.

### Bibliometric mapping

Bibliometrix is an R package (version 4.3.1) for quantitative scientometric and bibliometric research. The software package was implemented in the R programming language, which is a freely available open-source environment and ecosystem. The package was used to

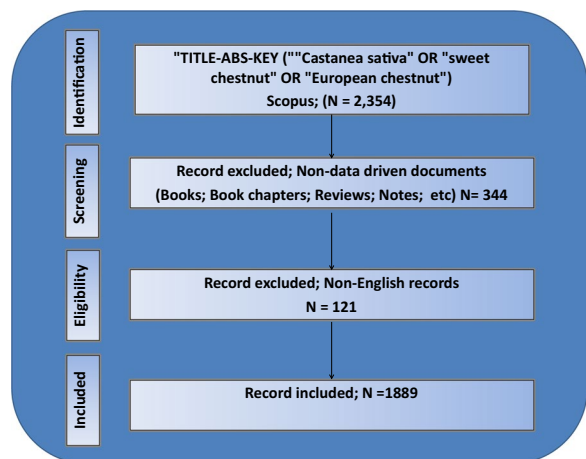
analyze keywords, thematic evolution, trending topics, and research topics prevalent in the literature to identify the critical focus areas within the field (Zhao and Li 2023). VOSviewer (1.6.20) is a popular software tool for visualizing bibliographic networks, enabling researchers to explore relationships and patterns among authors, institutions, and keywords based on co-occurrence or co-citation patterns. It provides various visualizations like co-authorship networks and keyword co-occurrence maps to identify key research areas, influential authors or institutions, and emerging trends (Van Eck and Waltman 2010). To enhance the visual representation of collaboration networks in the investigation of *C. sativa*, VOSviewer was used to depict the networks of the authors and countries involved in this field.

### Conceptual mapping

In the analysis of the conceptual structure and diffusion of knowledge using Bibliometrix, the underlying conceptual relationships and spread of knowledge within a research field were examined based on bibliographic data. Key concepts and themes were identified by analyzing the co-occurrence patterns of keywords, and the relationships among different concepts were visualized through co-occurrence networks. Additionally, citation networks were analyzed to understand the diffusion of knowledge, track influential papers or authors, and observe the dissemination of ideas over time. This analysis provides a comprehensive understanding of the intellectual landscape, identifies emerging trends, maps research trajectories, and evaluates the impact of concepts and publications. Ultimately, this approach supported informed decision-making, strategic planning, and the advancement of knowledge in the field (Afuye et al. 2021; Aria and Cuccurullo 2017).

### Thematic map analysis

Callon density and centrality are measures used in bibliometric analysis, specifically in thematic map analysis. Callon density assesses the connectivity and interrelations among thematic clusters, indicating the strength of intellectual connections within a cluster. A higher callon density indicates a cohesive and interconnected cluster. Centrality measures the prominence of a thematic cluster within the overall research landscape based on the number of citations by other clusters. Thematic map analysis with Bibliometrix allows the calculation of these measures, providing information on the structure, dynamics, and influence of research fields (Aria and Cuccurullo 2017).



**Fig. 1** Search strategy according to PRISMA guidelines (Selçuk 2019)

**Three-field plot**

The thickness of the lines connecting authors from different countries represents the number of papers that they have co-authored. The thickness of the lines connecting countries and sources represents the number of papers from each country that have been published in each source. Each rectangle represents a single node. The size of a rectangle represents the importance of a node in the network. This figure was generated using the Bibliometrix application and BibTex data file.

**Results**

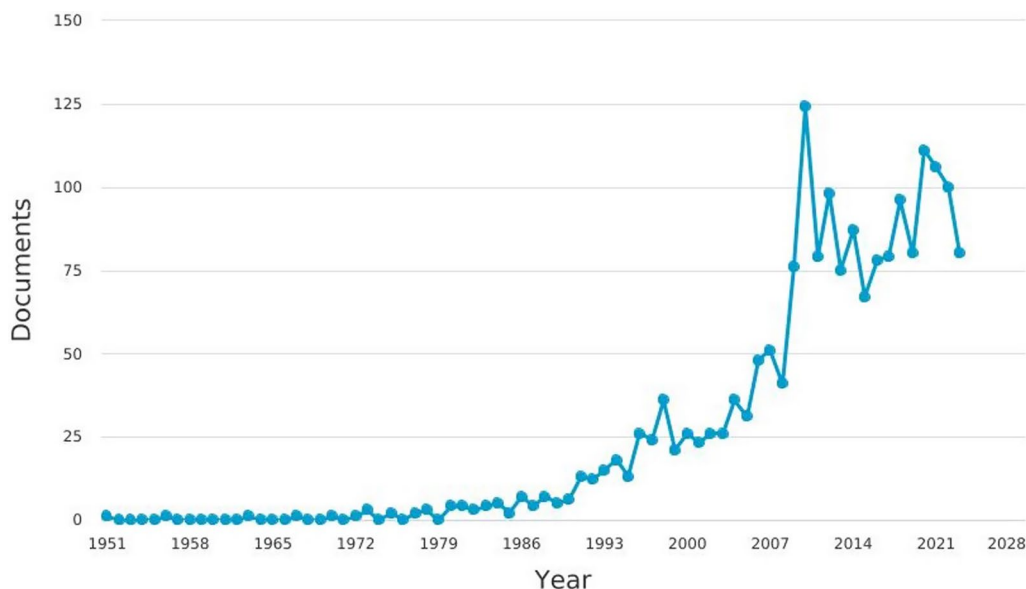
**Main information and annual trends**

The bibliometric findings of this study will be exclusive to previous studies conducted in English, excluding those in other languages. This consistency will be maintained throughout the remainder of this study. A comprehensive search of the Scopus database, following the PRISMA guidelines, resulted in the identification of 1889 research documents extracted from original studies conducted between 1951 and 2023. These studies involved a cohort of 5005 scientists, and the documents were sourced from 685 different publications. The analysis revealed an annual growth rate of 6.28% and an average publication age of 11.9 years.

The research documents were classified into 24 subjects according to the Scopus classification and indexing system. The dominant subject areas that included publications related to *C. sativa* were agricultural and biological sciences (46.25%), environmental science

(12.47%), and biochemistry, genetics, and molecular biology (11.84%). Interestingly, there was a relatively lower percentage of research in the fields of medicine and pharmacology, toxicology, and pharmaceuticals, accounting for only 4.46% of the total publications.

On average, there are 4.91 authors per document. During the regression analysis, it was observed that there was a significant increase in *C. sativa* research, showing an exponential growth pattern ( $R^2=0.9435$ ). Figure 2 shows the publication year and distribution of publications in the dataset. The data showcase a range of publication years, spanning from 1951 to 2023. The majority of publications were concentrated in more recent years, with a peak in the 2020s. For instance, by 2023, there were 80 publications, accounting for 4.24% of the total. Similarly, by 2022, there were 100 publications, representing 5.29% of the total. The distribution indicates that research output varied over time, with fluctuations in the number of publications. There were periods of increased activity, such as between 2010 and 2014, when the number of publications saw a substantial rise. Conversely, earlier years, particularly the 1960s and earlier, had smaller numbers of publications, with percentages below 1%. These findings emphasize the temporal spread of publications, with a focus on recent years and recognition of the historical body of literature. The data in Fig. 2 provides insights into the publication trends and the evolving nature of research in the field.



**Fig. 2** Annual publications trends on *C. sativa* research (19,551–2023). Y-axis: the number of articles published. X-axis: the years since the first article published on the topic of this paper

### Performance and impact analysis

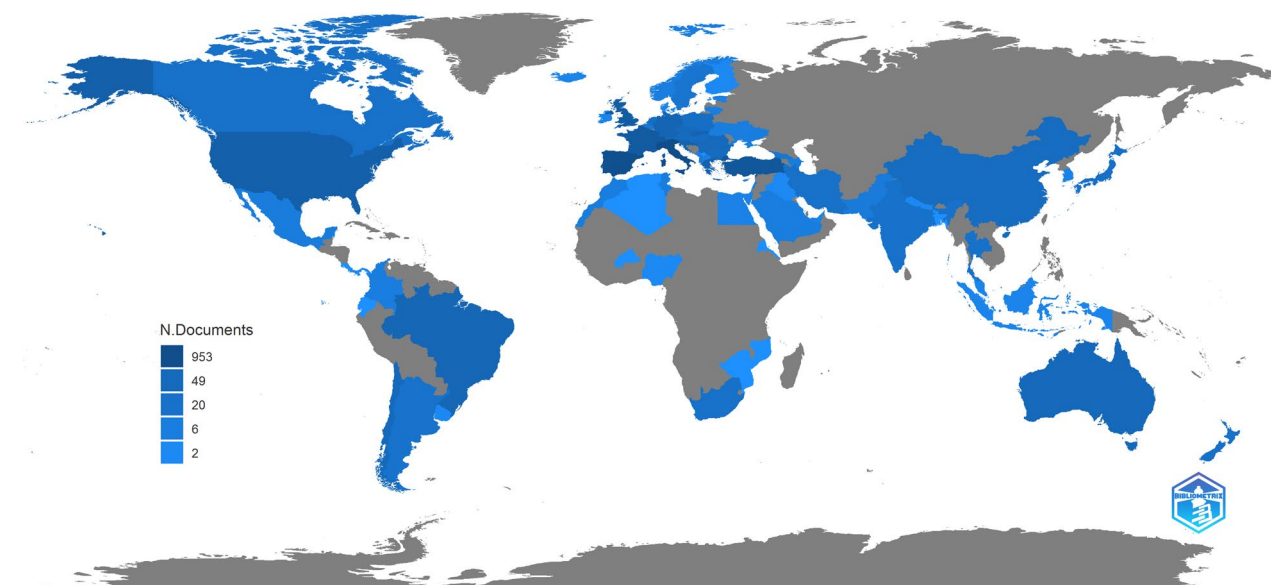
Italy (19.87%), Spain (15.56%), Portugal (13.39%), Turkey (6.92%), and Switzerland (5.17%) were the most prolific countries, accounting for 61% of the total knowledge related to *C. sativa*. Of the scholarly discourse, 87.23% was generated in Europe. Figure 3 shows the global production of research related to *C. sativa*. The National Research Council (Italy), the Swiss Federal Research Institute for Forests, Snow, and Landscape (WSL, Switzerland), and the Polytechnic Institute of Bragança (Portugal) are the three productive affiliations. M. Conedera affiliated with the Swiss Federal Research Institute for Forests, Snow, and Landscape (WSL), is the most influential author, followed by F. Villani (Italy) and I.C.F.R. Ferreira (Portugal). *Acta Horticulturae*, *Forest Ecology and Management*, *Food Chemistry*, *Forests*, *Forest Pathology*, *Scientia Horticulturae*, and *Grana* included more than 20 documents related to *C. sativa*.

The analysis focused on the differential production of countries and their researchers and the distribution of their output in highly regarded academic journals. The examination was conducted using a three-field plot. The plot visualizes the main elements of three fields (e.g., authors, countries, and journals) and how they are related through a Sankey diagram (Fig. 4). The findings align with those in the preceding section, providing further evidence to substantiate the assertion that Europe is a prominent hub in this domain. Researchers typically publish their research in highly reputable and

widely circulated academic journals, which are noted as journals specializing in forest sciences. Most of the scholarly investigations conducted on *C. sativa* focus primarily on its importance in the field of forests.

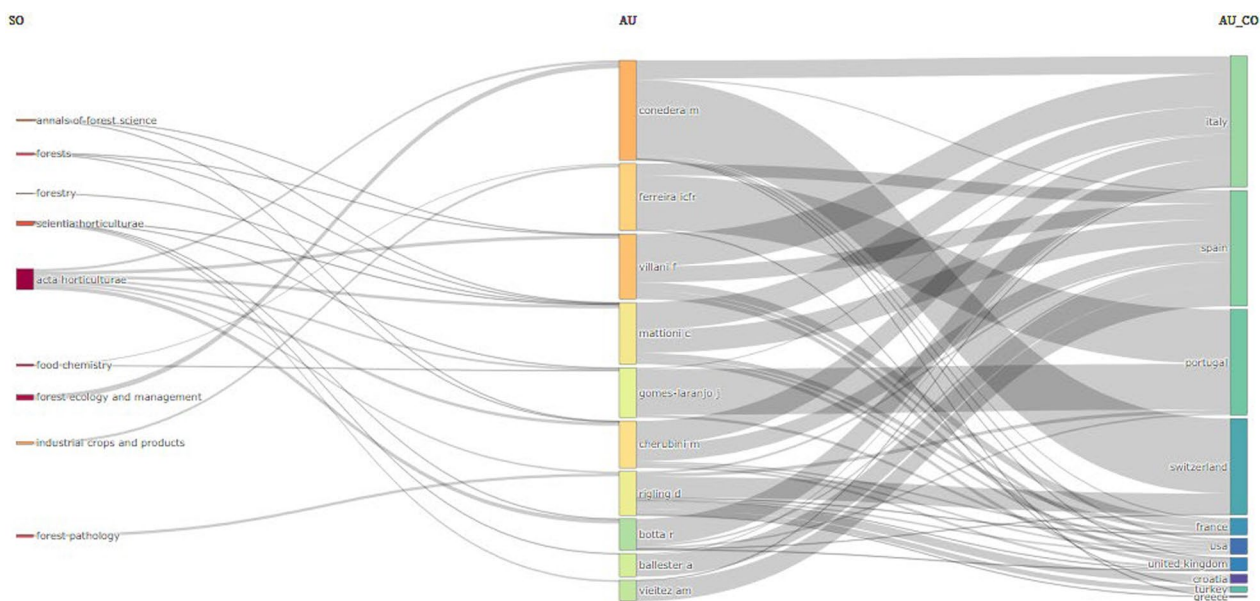
According to the current study, Italy emerges as the most-cited country. Spain, Portugal, Switzerland, and France are considered among the leading countries in the present context. The results indicate that the countries at the forefront are responsible for most references, as shown in Fig. 5.

Citations are one method of measuring the impact of an article, but they are not the only method. The topics covered in the most-cited articles (Table 1) are diverse and span various aspects of forests, plants, and natural resources. The articles address subjects such as knowledge gaps and research needs in Mediterranean forests, the influence of cellulose content on tensile strength in tree roots, physicochemical properties and antioxidant capacities of Turkish honeys, antioxidant activity and phenolic content of chestnut shell and eucalyptus bark extracts, fruit germplasm resources in Turkey, the cultivation history of *C. sativa* in Europe, antidiabetic effects of natural plant extracts, pollen consumption in worker honeybees, limitations of CO<sub>2</sub> assimilation in tree leaves, and traditional knowledge of wild edible plants in the Iberian Peninsula. Each article sheds light on specific aspects of these broad topics, contributing to the overall understanding of these subjects. More details are presented in Table 1.

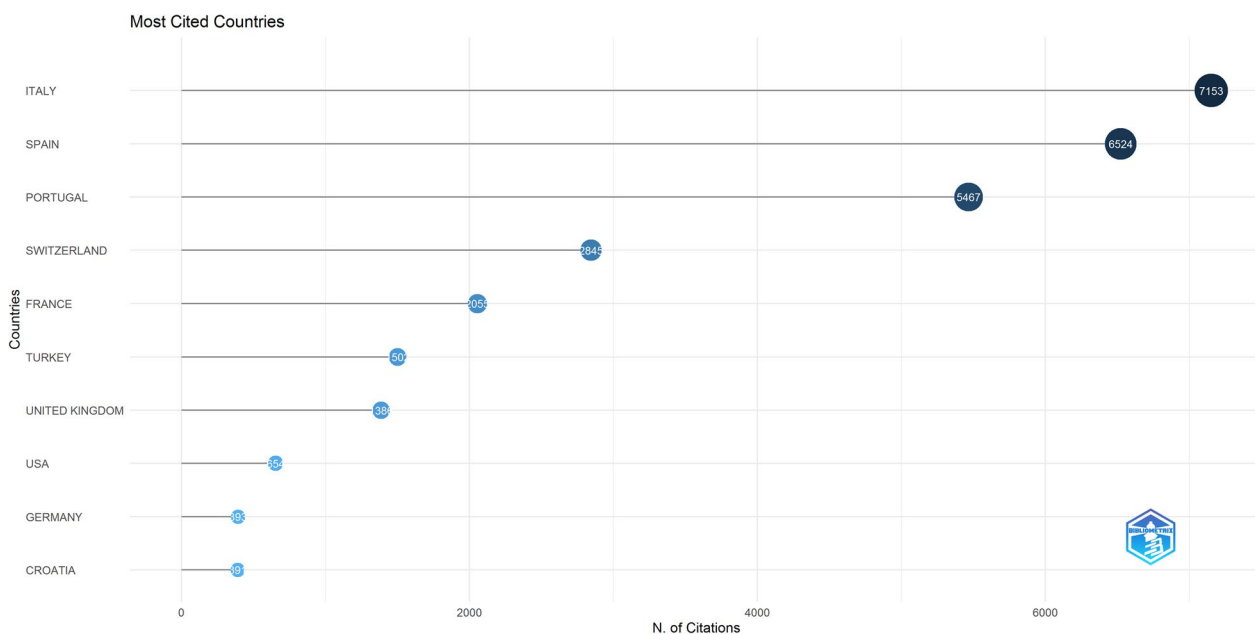


**Fig. 3** Overview of global scientific production in *C. sativa* research. Dark blue color represents countries with the highest research productivity, while countries outside the blue category indicate no contributions in this area. This figure was generated using the Bibliometrix application and the BibTeX data file





**Fig. 4** Three-field plot. AU: authors; AU\_CO: country of the authors; SO: sources. The thickness of the lines connecting authors from different countries would represent the number of papers that they have co-authored. The thickness of the lines connecting countries and sources would represent the number of papers from each country that have been published in each source. Each rectangle represents a node. The size of the rectangle represents the importance of the node in the network. This figure was generated using the Bibliometrix application and the BibTex data file



**Fig. 5** Top countries cited. Nodes represent the number of total citations. This figure was generated using the Bibliometrix application and the BibTex data file

**Societal analysis**

Societal analysis was performed using both VOSviewer and Bibliometrix applications. The maps (Figs. 6A, B) were generated using the VOSviewer software with

a minimum of 10 documents as input. This process resulted in the distribution of 34 countries, which were classified into four distinct groups. The total link strength (TLS) value for these clusters was calculated as 1088,

**Table 1** The most-cited articles

Rank	Title	Source	Year	Citations	Citation average*
1st	Forests of the Mediterranean region: Gaps in knowledge and research needs (Scarascia-Mugnozza et al. 2000)	Forest Ecology and Management	2000	412	17.17
2nd	The influence of cellulose content on tensile strength in tree roots (Genet et al. 2005)	Plant and Soil	2005	342	18.00
3rd	An investigation of Turkish honeys: Their physicochemical properties, antioxidant capacities and phenolic profiles (Can et al. 2015)	Food Chemistry	2015	310	34.44
4th	Antioxidant activity and phenolic content of chestnut ( <i>C. sativa</i> ) shell and eucalyptus ( <i>Eucalyptus globulus</i> ) bark extracts (Vázquez et al. 2008)	Industrial Crops and Products	2008	303	18.94
5th	The fruit germplasm resources of Turkey (Ercisli 2004)	Genetic Resources and Crop Evolution	2004	289	14.45
6th	The cultivation of <i>C. sativa</i> (Mill.) in Europe, from its origin to its diffusion on a continental scale (Conedera et al. 2004)	Vegetation History and Archaeobotany	2004	282	14.10
7th	Antidiabetic effects of natural plant extracts via inhibition of carbohydrate hydrolysis enzymes with emphasis on pancreatic alpha amylase (Genet et al. 2005)	Expert Opinion on Therapeutic Targets	2012	279	23.25
8th	Pollen consumption and utilization in worker honeybees ( <i>Apis mellifera carnica</i> ): Dependence on individual age and function (Can et al. 2015)	Journal of Insect Physiology	1992	275	8.59
9th	Limitation of net CO <sub>2</sub> assimilation rate by internal resistances to CO <sub>2</sub> transfer in the leaves of two tree species ( <i>Fagus sylvatica</i> L. and <i>C. sativa</i> Mill.) (Epron et al. 1995)	Plant, Cell & Environment	1995	272	9.38
10th	Traditional knowledge of wild edible plants used in the northwest of the Iberian Peninsula (Spain and Portugal): A comparative study (Pardo-de-Santayana et al. 2007)	Journal of Ethnobiology and Ethnomedicine	2007	235	13.82

\*The citation average for an article refers to the average number of times that article has been cited by other scholarly publications within a specific period. It is a quantitative measure used to assess the impact and influence of a particular article within the academic community

with a total of 332 links identified. Shapes represent the strength of international collaboration and are expressed as TLS, whereas lines represent the links between countries. Italy, Spain, and Portugal were the most collaborating countries, as evidenced by their TLS values of 261, 257, and 163, respectively. Spain and Portugal occupied the green cluster (Fig. 6A). France and Germany led the red cluster, whereas Serbia and Poland anchored the blue cluster. Italy and the United Kingdom anchored the purple cluster. The presence of green, red, blue, and purple clusters (Fig. 6A) indicates that the level of international cooperation between countries that share the same color is more robust compared to those of clusters with a different hue.

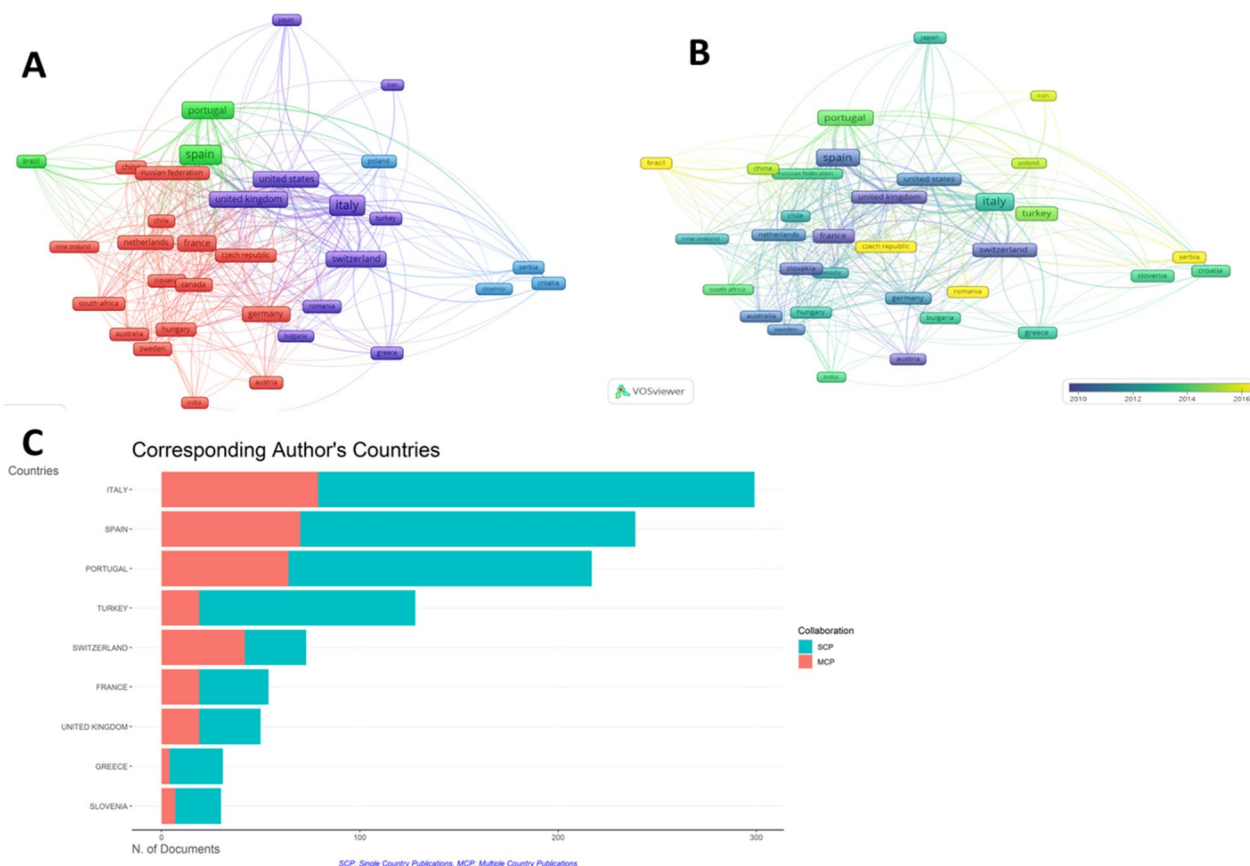
Figure 6B depicts the temporal dynamics of global collaboration in *C. sativa* research, in which each node represents a country. The color spectrum of the nodes, ranging from purple to yellow, signifies the collaborative oldness of each country. In this context, the yellow nodes indicate the most recent countries to join the international community for *C. sativa* research. Notably, Serbia, Brazil, the Czech Republic, and Romania have recently emerged as active participants, collaborating with their partners to advance their knowledge and understanding of *C. sativa*.

Figure 6C shows the analysis of multiple publications (MCP) and single countries (SCP). The MCP ratio is used as an indicator of national and global networking. Switzerland and the Czech Republic had the highest MCP ratios. With an MCP ratio of zero, India, Australia, Bosnia, and Morocco did not collaborate internationally in their research on this particular plant species. The limited extent of India's international collaboration in *C. sativa* research can be ascribed to several factors, including geographic distance, research priorities that emphasize indigenous species, the relatively low economic importance of *C. sativa*, and the need for more active institutional networks and funding opportunities. Moreover, the current study revealed that international co-authorship is 26.88%. International co-authorship is a metric used to evaluate a nation's level of global research involvement, which is determined through a bibliometric analysis of the scientific output produced by its researchers.

### Conceptual structure and diffusion of knowledge

#### Keywords co-occurrence

The study utilized 5005 keywords and the indexed keywords were 10,007. In this study, Bibliometrix was used to extract the most frequent authors' keywords. *C. sativa*



**Fig. 6** International collaboration; **A** Co-authorship networks among countries was analyzed using VOSviewer, where countries were represented as nodes and collaborations as links. Based on TLS values, Italy emerged as the leading collaborative country in *C. sativa* research. **B** Overlay visualization was performed on VOSviewer to analyze the temporal dynamics of the international collaboration. Countries with yellow color were new to the collaborative research. **C** The analysis for multiple-country (MCP) and single-country (SCP) publications is performed using the Bibliometrix application. Aqua and orange colors represent the MCP and SCP, respectively

(798), sweet chestnut (54), *Cryphonectria parasitica* (44), honey (38), phenolic compounds (35), chestnut blight (33), antioxidant activity (31), wood (29), genetic diversity (26), *Phytophthora cinnamomi* (26), Fagaceae (25), polyphenols (25), starch (21), antioxidant (20), climate change (20), biological control (18), biodiversity (17), fatty acids (17), hypovirulence (17), tannins (17), pollen (16), Spain (16), ink disease (15), conservation (14), *Dryocosmus kuriphilus* (14), forest management (14), growth (14), Italy (14), melissopalynology (14), photosynthesis (14), chestnut coppice (13), chestnuts (13), hydrolysable tannins (13), SSR (13), antioxidants (12), coppice (12), diversity (12), *Fagus sylvatica* (12), micropropagation (12), phenolics (12), pollen analysis (12), quercus (12). These keywords that are the most frequently represent 33% (1648/5005) of the total authors keywords.

**Thematic map**

A theme map, which depicts the conceptual organization of a scientific field based on bibliographic data,

was created using Bibliometrix. There were four quadrants on the thematic maps. Two parameters were used to detect the location of the research themes in each quadrant: density and centrality. Based on Table 2 and Fig. 7, seven groups were considered as the main research topics related to *C. sativa*. Table 2 presents the parameters for themes in the thematic map, including Callon Centrality, Callon Density, Rank Centrality, and Rank Density. The clusters listed were *C. sativa*, *C. sativa* mill, Castanea, forest management, *Cryphonectria parasitica*, wood, Spain, and ethnobotany. Each theme was assigned specific values for these parameters, indicating their centrality, density, and rank. Table 2 displays the themes and their corresponding keywords. The clusters listed were *C. sativa*, *C. sativa* Mill, Castanea, forest management, *Cryphonectria parasitica*, wood, Spain, and ethnobotany. Each theme was associated with specific keywords representing relevant topics. The NK column shows the number of keywords used for each theme.



**Table 2** Parameters for themes in the thematic map and their respective keywords

Cluster	Cluster Label	Callon Centrality	Callon Density	Rank Centrality	Rank Density	Themes	Words	NK
1	<i>C. sativa</i>	0.282	8.170	8	3	Basic	<i>C. sativa</i> , Sweet Chestnut, Genetic Diversity, <i>Phytophthora Cinnamomi</i> , Fagaceae, Climate Change, Biodiversity, Ink Disease, Conservation, Growth, Italy, SSR, Diversity, <i>Fagus Sylvatica</i> , Micropropagation, Dendrochronology, Drought, Microsatellite, <i>Quercus Robur</i> , Morphological traits, Palynology, Selection, Temperature, Morphology, Tissue Culture, Turkey	30
2	<i>C. sativa</i> Mill	0.141	8.863	7	5	Motor	<i>C. sativa</i> Mill, Phenolic Compounds, Antioxidant Activity, Starch, Antioxidant, Fatty Acids, Tannins, Chemical Composition	18
3	<i>Castanea</i>	0.110	7.286	6	1	Motor	<i>Castanea</i> , Honey, Pollen, <i>Quercus</i> , Portugal	6
4	Forest Management	0.059	9.809	4	6	Niche	Forest Management, Photosynthesis, Chestnut Coppice, Coppice, Biomass, Silviculture	6
5	<i>Cryphonectria Parasitica</i>	0.067	7.461	5	2	Basic	<i>Cryphonectria Parasitica</i> , Chestnut Blight, Biological Control, Hypovirulence, <i>Dryocosmus Kuriphilus</i> , Epidemiology	6
6	Wood	0.022	10.423	1	7	Basic	Wood, Mechanical Properties, Ellagitannins, Heat Treatment, Oak	5
7	Spain	0.034	8.780	2	4	Emerging or declining	Spain, Melissopalynology, Pollen Analysis	3
8	Ethnobotany	0.037	12.963	3	8	Niche	Ethnobotany, Medicinal Plants	2

NK number of keywords.

### Thematic evolution

Figure 8 shows the thematic evolution of *C. sativa* research since 1951 in three periods. Before 2004, the main research topics were *Castanea*, *C. sativa* mill, chestnuts, climate change, coppice, digestion, ethnobotany, germination, phenolic compounds, photosynthesis, pollen analysis, polyphenols, rooting, Spain and starch. Biological invasion, chestnut coppice, chestnut shell, chestnut shell, chestnuts, color, *Cryphonectria parasitica*, *Fagus sylvatica*, fungi, gamma irradiation, GC–MS, honey, Italy, medicinal plants, melissopalynology, micropropagation, morphology, nitrogen and wood are the themes between 2004 and 2014. After 2014, the main research themes were agroforestry, antioxidant activity, *C. sativa*, *Castanea* spp., *Castanea*, chestnut coppice, dendrochronology, fatty acids, fungi, heat treatment, honey, palynology, pollen analysis, Turkey, volatile compounds, and wood. Based on the study conducted, it

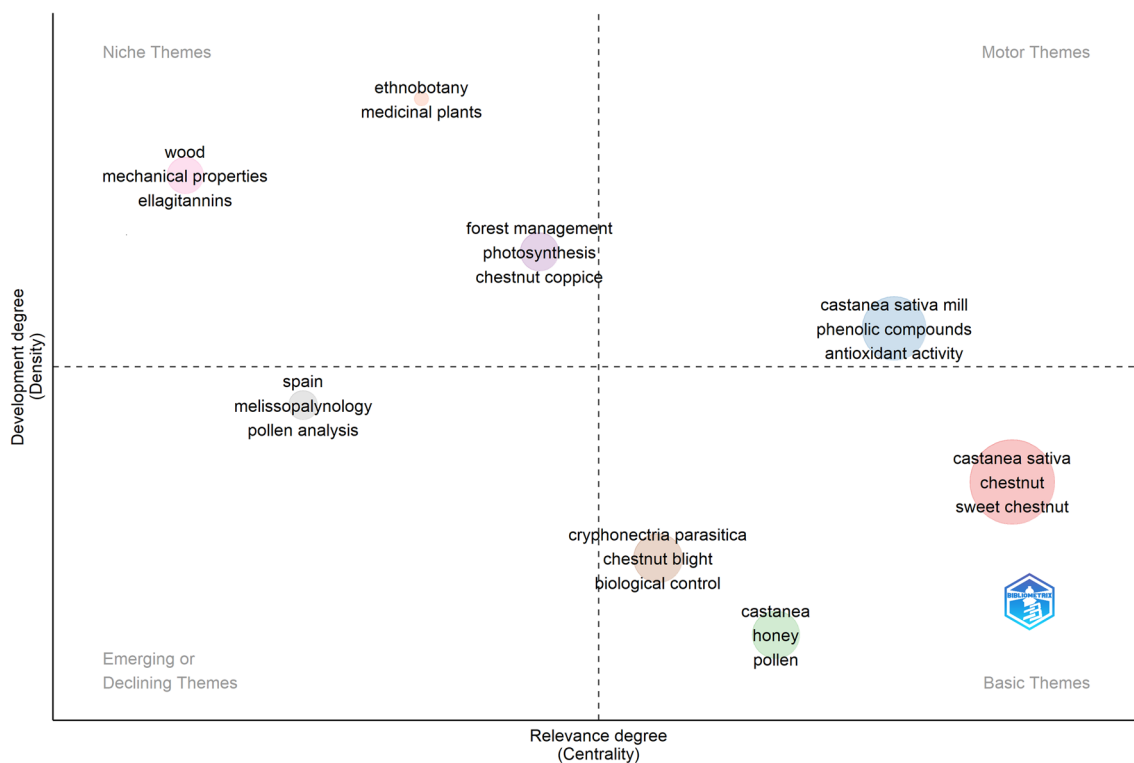
is observed that there exists a persistent oscillation in the research pattern, wherein certain themes have ceased to be prevalent after the year 2004.

### Trending topics

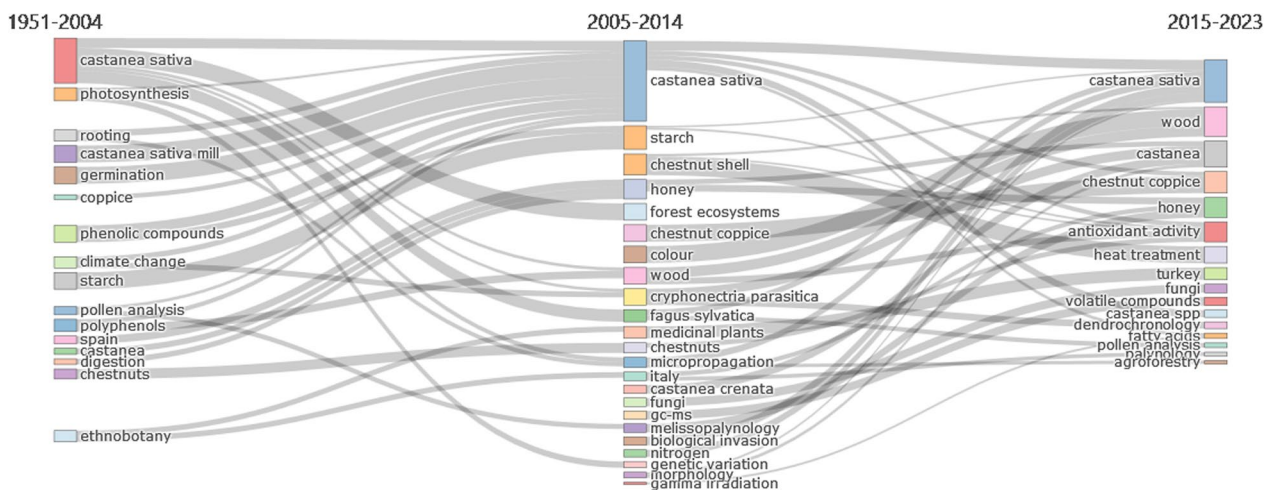
Figure 9 represents the trending topics in *C. sativa* research. The lines in the figure illustrate the life cycle of the research topic, whereas the circles represent its level of strength. Forest management, drought, chestnut rot, *Gnomoniopsis smithogilvyi*, *C. sativa* shells, amino acids, honey, phenolic compounds, hydrolyzable tannins, antioxidant capacity, antioxidants, and extractives are the topics of interest, as shown in Fig. 9.

### Discussion

The objective of this study was to conduct a bibliometric analysis of research articles related to *C. sativa* to highlight its importance and diversity in ecosystems and



**Fig. 7** Thematic map. Thematic maps are divided into four quadrants based on centrality and density, which represent the importance and development of research topics. This figure was generated using the Bibliometrix application and the BibTex data file

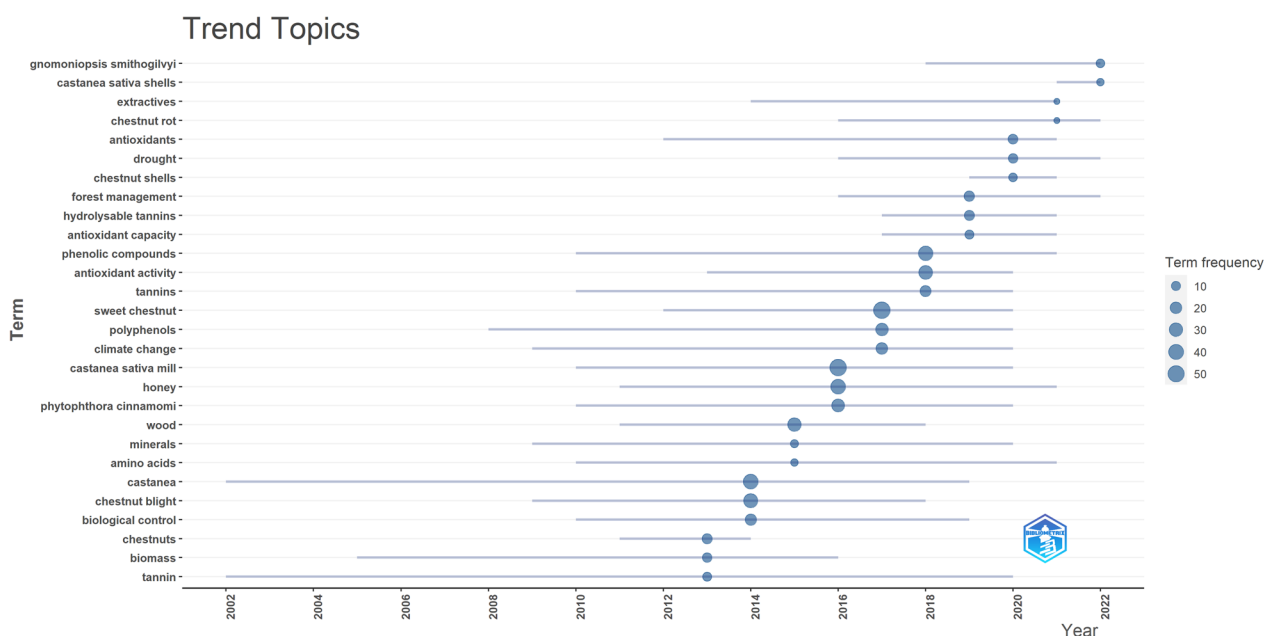


**Fig. 8** Thematic evolution. This figure was generated using the Bibliometrix application and the BibTex data file

societies. The study aimed to analyze various aspects, such as the year of publication, authors, countries, affiliations, keywords, and citations, to provide insights into the research trends and hotspots surrounding *C. sativa*. By examining a comprehensive dataset of 1889 research articles retrieved from the Scopus database, this study

seeks to demonstrate the significant historical, cultural, and ecological contributions of *C. sativa*, as well as its wide range of applications.

Bibliometric analysis of research articles on *C. sativa* Mill. revealed that the dominant subject areas were agricultural and biological sciences (46.25%), environmental



**Fig. 9** Trending topics. The graph depicts the research topic’s time span, with horizontal lines indicating the duration and blue circles representing the frequency of the term. This figure was generated using Bibliometrix and BibTex data files

science (12.47%), and biochemistry, genetics, and molecular biology (11.84%). Surprisingly, research in medicine and pharmacology as well as toxicology and pharmaceuticals accounted for only 4.46% of the publications. This emphasizes the multidisciplinary nature of *C. sativa* research, with a strong focus on its agricultural, ecological, and biochemical aspects. The scarcity of medical research on *C. sativa* does not imply a lack of information on its medicinal properties. This may be indicative of current knowledge gaps and research priorities. The bioactive compounds present in *C. sativa* hold the potential to uncover new therapeutic possibilities, but dedicated research efforts and resources are needed to further explore these avenues (Marrone et al. 2023; Muradoğlu et al. 2023; Papaioannou et al. 2023; Pinto et al. 2023).

87.23% of the scholarly discourse was generated in Europe. European countries have demonstrated a notable level of productivity in *C. sativa* research. This can be attributed to their enduring cultural ties, historical cultivation practices, and commitment to safeguarding and optimizing the tree’s economic and ecological advantages (Piazza et al. 2023). The research output of this tree species is comparable to that of Europe in terms of quantity across all producers, including scientists, institutes, and countries. This finding substantiates Europe’s position as a leader in this domain. *Acta Horticulturae*, *Forest Ecology and Management*, *Food Chemistry*, *Forests*, *Forest Pathology*, *Scientia Horticulturae*, and *Grana* included more than 20 documents related to *C. sativa*.

The analysis focused on the differential production of countries and their researchers and the distribution of their output in highly regarded academic journals. The experiment was conducted using a three-field plot (Madadin et al. 2022). The plot visualizes the main elements of three fields (eg authors, countries, and journals) and how they are related through a Sankey diagram (Fig. 4). The findings align with the preceding section, providing further evidence to substantiate the assertion that Europe is a prominent hub in this domain. Researchers typically publish their research in highly reputable and widely circulated academic journals, which were noted to be journals specializing in forest sciences. Most of the scholarly investigations conducted on *C. sativa* focus primarily on its importance in the field of forest. This emphasis is attributed to the species’ economic worth as a producer of timber and nuts and its relevance in the context of sustainable forest management methodologies (Papaioannou et al. 2023, 2022).

Citation analysis offers a quantitative framework for the evaluation of research output, assessment of its impact, and identification of key contributors and trends within a specific academic discipline. It serves as a valuable addition to conventional qualitative evaluation methodologies, providing valuable insights to guide decision-making processes within academic, funding, and research institutions (Terentieva et al. 2020). According to a survey assessing the influence of countries in the domain of scientific research production, Italy has

emerged as the most influential country. Spain, Portugal, Switzerland, and France are among the leading countries in this context. Italy has a rich and enduring cultural and historical association with *C. sativa*, which has led to a deeper understanding of its ecological dynamics, genetic characteristics, and cultivation practices. Consequently, this has engendered a significant body of influential research in this field (Calandrelli et al. 2023; Caprarulo et al. 2021).

Citations are one method of measuring the impact of an article, but they are not the only one. This is because fewer people have read the more recent article, which has received fewer citations. An article's citation count increases over time (Terentjeva et al. 2020). The cited articles are summarized in Table 1. The study by Scarascia-Mugnozza, which has received the most citations, examines the knowledge gaps and unmet research needs for forests in the Mediterranean region. Several study priorities have been suggested, with a focus on the possible effects of climate change on Mediterranean forest ecosystems. Incontrovertible flaws in Mediterranean woods include their history of overexploitation, drought-prone habitats, and challenging socioeconomic circumstances. However, some distinct and important factors, such as rich biodiversity, attractive landscape, high capacity for producing certain goods, and ecological circumstances, stand out as clear advantages that should be considered. One of the foundational trees of Mediterranean woods is the chestnut tree (Scarascia-Mugnozza et al. 2000).

The cellulose content of chestnut roots was the subject of the second most-cited study (Genet et al. 2005). Owing to its fine fiber structure, cellulose is responsible for the tensile strength of wood. When selecting the right species to improve the soil on unstable slopes, the tensile strength of the roots is a crucial consideration. The tensile strength has been observed to increase when the diameter of the root is decreased, although the exact mechanism underlying this occurrence is unknown. In this study, the root cellulose content of two species, *Pinus pinaster* and *C. sativa*, was quantitatively analyzed. Significant levels of cellulose and lignin have been identified in *C. sativa*.

Food Chemistry was the source of the third document in citation count and the first in citation average. The research was conducted by Can, Z. and his research team. Turkish honeys are discussed in this article along with their physicochemical characteristics, antioxidant potential, and phenolic profiles. Researchers have investigated and examined several types of honey collected from various parts of Turkey. They assessed the antioxidant capacity of honey and its phenolic composition, as well as variables such as moisture content, pH, electrical conductivity, and color. This study showed differences

in the characteristics, antioxidant abilities, and phenolic profiles of honey samples, underscoring the impact of regional origin on honey composition. Research advances the knowledge of Turkish honey and its possible health advantages. *C. sativa* was one of the 13 unifloral honey types chosen (Can et al. 2015). The knowledge imprinted in the remaining documents from the most frequently cited documents included the cultivation of the chestnut tree in Europe and its antidiabetic (Etxeberria et al. 2012) and antioxidant (Vázquez et al. 2008) properties, and how honey bee workers use and consume pollen in the vicinity of the tree (Crailsheim et al. 1992).

Scientific collaboration plays a crucial role in research as it facilitates the consolidation of researchers' experience and resources, thereby boosting innovation, expediting progress, validating findings, and promoting the dissemination of knowledge for the benefit of society (Ambhore and Ofori 2023; Hu et al. 2022). Societal analysis was performed using VOSviewer and Bibliometrix (Ambhore and Ofori 2023; Van Eck and Waltman 2010; Zhao and Li 2023). Italy, Spain, and Portugal are the most collaborating countries, as evidenced by their TLS values of 261, 257, and 163, respectively. Owing to their proximity to *C. sativa*'s natural range, economic importance, institutional networks, and funding opportunities, Italy and some European countries collaborate extensively in this research (Calandrelli et al. 2023; Caprarulo et al. 2021).

Figure 6B shows the temporal dynamics of global collaboration in *C. sativa* research. Serbia, Brazil, the Czech Republic, and Romania are the latest to join their partners to promote knowledge of *C. sativa*. Portuguese colonists introduced the first chestnut trees to Brazil in 1530. However, because of their specific climatic needs, only a few, if any, have managed to live, except for those relocated to higher elevations or the southern regions of the country, where the temperatures are more moderate (Afonso et al. 2022). However, Brazil has recently collaborated with Spain and Portugal (Fernandes et al. 2022), as shown in Fig. 6A, B, to strengthen its research efforts in this particular area.

With an MCP ratio of zero, India, Australia, Bosnia, and Morocco did not collaborate internationally in their research on this particular plant species. Moreover, the current study revealed that international co-authorship is 26.88%. International co-authorship is a metric used to evaluate a nation's level of global research involvement, which is determined through a bibliometric analysis of the scientific output produced by its researchers (Kozak et al. 2015). As previously documented (Ghafouri et al. 2012), the investigation of this plant encompasses a diverse range of disciplines, necessitating collaboration and knowledge sharing among experts in botany,

chemistry, food science, pharmacology, toxicology, and other related fields. This collaborative effort is crucial for effectively harnessing the full potential of this plant and deriving optimal advantages from its properties.

The primary objective of this study was to discern the predominant research patterns on scaffold knowledge embedded in the domain of *C. sativa*. To achieve this objective, the researchers conducted descriptive and co-word analyses on the papers selected from the Scopus database, covering the period from 1951 to 2023. Co-word analysis uses words that frequently occur close to one another to illustrate the conceptual structure of a framework. All words in a sentence can be replaced with terms, keywords plus, and author keywords gleaned from abstracts or titles. The conceptual structure function also generates the conceptual structure map, factors of papers with the most significant influence, and most-cited documents (Ambhore and Ofori 2023). A co-word analysis is predicated on the assumption that keywords provided by authors in academic publications serve as the primary descriptors of research content. The connections among numerous co-occurring keywords represent the focal interest of the research topic in the field. According to the established definition, the co-occurrence of two keywords within the same academic paper indicates a discernible bibliometric relationship between the topics to which the keywords pertain (Hu et al. 2022; Lin et al. 2022).

The theme map depicts the conceptual organization of a scientific field based on bibliographic data. There were four quadrants on the thematic maps. In the thematic map, there are four types of themes: (1) basic themes, which represent the predominate research areas; (2) emerging themes, which show emerging topics or trends; (3) motor themes, which represent less prominent areas; and (4) niche themes, which represent specialized or isolated subjects with little prominence or connection to the more general research areas. These quadrants help researchers locate important research areas, new trends, and potential knowledge gaps as the field matures (Ambhore and Ofori 2023; Zhao and Li 2023). Various algorithms and statistical techniques have been used to find patterns and trends in the literature. One strategy is to analyze the frequency and co-occurrence of keywords or concepts in scholarly publications over time. The software can identify certain terms as emerging themes if they increase in frequency or appear in groups in recent publications. This aids scientists in identifying new and rapidly evolving study fields. Two parameters were used to detect the location of the research themes in each quadrant: density and centrality. Based on Table 2 and Fig. 7, seven groups were considered as the main research topics related to *C. sativa*.

The "*Castanea*" cluster came first in density and sixth in centrality, which was classified as a basic theme. These themes were built based on the co-occurrence of certain keywords. This cluster encompasses several important subthemes. Genetic diversity studies aim to understand the variability and genetic structure of *C. sativa* populations using markers such as SSR (Alcaide et al. 2019; Calandrelli et al. 2023; Casasoli et al. 2006, 2001). Climate change research has investigated the effects of changing environmental conditions, particularly drought, on the growth and survival of chestnut trees (Barreneche et al. 2004; Santos et al. 2017; Silva et al. 2020). Ink disease caused by *Phytophthora cinnamomi* is a significant concern, and researchers have explored its impact, mechanisms of infection, and management strategies (Santos et al. 2017). Conservation efforts have focused on the preservation of *C. sativa* and its role in supporting biodiversity within ecosystems. Growth and morphological studies have investigated growth patterns, wood quality, and desirable traits for commercial and ecological purposes (Aglietti et al. 2022). Techniques such as dendrochronology and palynology provide insights into historical growth patterns and environmental changes (Romagnoli et al. 2004). Micropropagation and tissue culture methods have been explored for the mass production of chestnut plants. Selective breeding strategies aim to improve traits such as disease resistance and nut quality geographic variations within *C. sativa* populations, such as those found in Italy and Turkey, have been studied to understand local adaptations and genetic differentiation (Villani et al. 1994). Finally, the influence of temperature on morphology and growth patterns was examined to assess how chestnut trees respond to climate change (Freitas et al. 2021). These diverse research areas contribute to our understanding of *C. sativa* and aid in its conservation, management, and utilization.

The "wood" cluster was classified as a niche theme due to the highest Callon density (10.423). These themes were built based on the co-occurrence of certain keywords. Wood, especially in the context of mechanical properties, is highly relevant to chestnuts. Researchers have often studied the mechanical properties of chestnut wood to understand its strength, hardness, and elasticity. These properties play a crucial role in determining wood suitability for various applications (Ates et al. 2010; Prospero et al. 2006; Walsh-Korb and Avérous 2019). Furthermore, the study of ellagitannins, which are polyphenolic compounds found in chestnut wood, is of particular interest. Ellagitannins contribute to the natural durability of chestnut wood, making it highly resistant to decay, fungal attacks, and insect infestations. Research on ellagitannins helps to understand the chemical composition and protective mechanisms of chestnut wood, which is



valuable for its long-term preservation and utilization (Žitek Makoter et al. 2024). Heat treatment is another research topic related to chestnut wood. Heat treatment processes, such as thermal modification, can enhance the properties of chestnut wood. Heat-treated chestnut wood exhibits improved dimensional stability, reduced moisture absorption, increased resistance to decay, and improved mechanical properties. This study contributes to optimizing the use of chestnut wood in applications where stability and durability are essential (Métoyer et al. 2024). Overall, the study of wood, its mechanical properties, and the impact of heat treatment and ellagitannins is directly relevant to understanding and utilizing chestnut wood effectively.

Six keywords formed the "forest management" cluster: "forest management," "photosynthesis," "chestnut coppice," "coppice," "biomass," and "silviculture." Forest studies encompass a wide range of topics, including but not limited to the ecology, conservation, management, and exploitation of *C. sativa* (Caprarulo et al. 2021; Papaioannou et al. 2022; Scarascia-Mugnozza et al. 2000). This includes examining various aspects of chestnut trees, such as their growth patterns, habitat preferences, reproductive biology, genetic variability, susceptibility to pests and diseases, silvicultural practices, and the feasibility of utilizing chestnut resources sustainably for commercial purposes (Papaioannou et al. 2023, 2022).

The conceptual map in this study includes an additional theme regarding the antioxidant properties of chestnuts. Antioxidant activity, a widely studied characteristic of chestnuts and their constituents (Silva et al. 2022, 2020), plays a crucial role in combating oxidative stress associated with various human diseases. Different parts of the chestnut, such as the seed, skin, bur, leaf, and flower, have been extensively examined for antioxidant activity using various assays. Phenolic compounds, including gallic acid, ellagic acid, rutin, quercetin, apigenin, and tannins, are commonly associated with the observed antioxidant activity in chestnuts. These compounds are distributed across different parts of the chestnut plant. Chestnut kernels are known for their rich content of moisture, starch, sugars, protein, and fat, as well as organic acids, minerals, vitamins, fiber, and tocopherols, particularly  $\gamma$ -tocopherol, which possesses anti-inflammatory properties. Additionally, chestnuts contain glucan, lignin, xylan, arabinan, protein, and ash, and their antioxidant-rich phenolic compounds have potential applications in skincare formulations. Chestnut flowers, leaves, and bark also contain various bioactive compounds, demonstrating antioxidant activity and potential therapeutic effects. In summary, chestnuts and their various components contain a diverse range of bioactive compounds that offer potential health benefits through their antioxidant,

anti-inflammatory, cytotoxic, and antimicrobial properties (Barreira et al. 2020; Silva et al. 2022, 2020).

In Spain, melissopalynology and pollen analyses have provided valuable information on various aspects related to chestnut trees. Melissopalynology helps to identify floral sources of honey in different regions of Spain, contributing to the understanding of honey production and supporting apicultural practices. Pollen analysis of environmental samples, such as sediments and archeological sites, allows the reconstruction of the historical distribution and land use patterns of chestnut trees in Spain. It also helps monitor allergenic pollen, including chestnut pollen, providing important information for allergy management and understanding the temporal and spatial patterns of allergenic pollen in the country. These research areas contribute to the conservation, sustainable management, and public health initiatives related to chestnut trees in Spain (Minini et al. 2024; Terrab et al. 2019).

Bibliographic data allow researchers to track the evolution of a research topic. Bibliometrix uses co-word analysis and co-citation networks to identify new themes, evolving themes, and research area connections. This helps to understand intellectual structure and knowledge development (Duan 2023; Moral-Munoz et al. 2018). Figure 8 shows the thematic evolution of *C. sativa* research since 1951 in the three periods. Before 2004, the main research topics were *Castanea*, *C. sativa* mill, chestnuts, climate change, coppice, digestion, ethnobotany, germination, phenolic compounds, photosynthesis, pollen analysis, polyphenols, rooting, Spain and starch. Biological invasion, chestnut coppice, chestnut shell, chestnut shell, chestnuts, color, *Cryphonectria parasitica*, *Fagus sylvatica*, fungi, gamma irradiation, GC-MS, honey, Italy, medicinal plants, melissopalynology, micropropagation, morphology, nitrogen, and wood were the themes between 2004 and 2014. After 2014, the main research themes included agroforestry, antioxidant activity, *C. sativa*, *Castanea* spp., *Castanea*, chestnut coppice, dendrochronology, fatty acids, fungi, heat treatment, honey, palynology, pollen analysis, Turkey, volatile compounds, and wood. Based on the study conducted, it was observed that there exists a persistent oscillation in the research pattern, wherein certain themes ceased to be prevalent after 2004. Exploration of the pharmacological properties of chestnuts gained momentum after 2005.

Through analysis, Bibliometrix can identify keywords that exhibit a substantial increase in frequency, thereby signifying emerging or trending research topics. This provides researchers with valuable insights into prevailing patterns and central areas of interest within their respective fields of inquiry. The shells of *C. sativa* are the subject of research that focuses on their potential use in the production of biofuels, activated carbon, agricultural

amendments, and as a renewable resource in various industries (Muradoğlu et al. 2023; Pinto et al. 2023; Silva et al. 2022).

There are some restrictions on bibliometric studies that use the data obtained from the Scopus database. First, since the database contains only English-language publications, there may be a language bias and valuable non-English research may be missed. This may have reduced the comprehensiveness and global representation of this study. Second, Scopus may not include pertinent journals from all fields, leaving out important sources of research. Additionally, the reliability and comparability of bibliometric analyses can be affected by variations in the consistency and accuracy of the data extraction and classification. To expand the scope and validity of bibliometric studies, it is important to consider these limitations when interpreting results.

## Conclusions

In conclusion, bibliometric analysis of *C. sativa* revealed several key findings. Europe has emerged as the dominant region for studying *C. sativa*, with Italy, Spain, Portugal, Turkey, and Switzerland leading in research output. The National Research Council (Italy), the Swiss Federal Research Institute for Forests, Snow, and Landscape (WSL, Switzerland), and the Polytechnic Institute of Bragança (Portugal) are prominent affiliations in this field. Influential authors, such as M. Conedera (WSL), F. Villani (Italy), and I.C.F.R. Ferreira (Portugal) made a significant contribution to the literature. Collaboration patterns demonstrate strong cooperation among Italy, Spain, and Portugal, while emerging countries such as Serbia, Brazil, the Czech Republic, and Romania actively participate. Thematic analysis identified key research areas, including forest management, wood, Spain, and ethnobotany. Furthermore, evolving trends indicate a shift from climate change and chestnut-related topics to areas such as antioxidant activity, dendrochronology, and volatile compounds. These findings provide a comprehensive overview of *C. sativa* research and highlight its importance, collaborative networks, and emerging research directions. Ultimately, this analysis contributes to our understanding of *C. sativa* and supports sustainable management, conservation, and utilization efforts in the face of environmental challenges and societal needs.

## Abbreviations

AU	Authors
AU_CO	Country of the authors
CSV	Comma-separated values
MCP	Multiple-country publications
MS Excel	Microsoft excel
SCP	Single-country publications
SO	Sources
TITLE-ABS-KEY	TITLE + ABSTRACT + KEYWORDS
TLS	Total link strength

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s42269-024-01238-7>.

Additional file1 (BIB 5556 kb)

Additional file2 (CSV 20170 kb)

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## Author contributions

SIA, MMET, AF, IA, BO, HA, AA, and YB planned the investigation. SIA and MMET evaluated the findings, wrote the article, and oversaw the administrative aspects. SIA gathered the information and revised the text. All authors have read and approved the manuscript.

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## Availability of data and material

The datasets used and/or analyzed during the current study are available as supplementary materials.

## Declarations

### Ethics approval and consent to participate

There is no form of human subject involved in this manuscript; therefore, ethics approval is not required.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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