

Tropaeolum: research trends, gaps, and future perspectives

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- CiteSpace
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Palavras-chave:

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Abstract

Tropaeolum (Tropaeolaceae) comprises nearly 95 species with a neotropical distribution, a few of which are of economic, gastronomic, medicinal, and landscape importance. In this study, we present a scientometric analysis of this genus using data from the Web of Science (1945-2024) to evaluate the research trends, gaps, and emerging topics. After screening, 490 documents were analyzed using CiteSpace and Microsoft Excel. The results revealed limited collaboration between Brazilian institutions and its impact on research, in contrast to those in the USA and European countries. Studies on the chemistry, biochemistry, and molecular biology of species in this genus have aroused the interest of the scientific community because of their specific characteristics, such as the presence of compounds such as glucosinolate, benzyl isothiocyanate, isothiocyanate, anthocyanin, and antioxidants. In this context, *Tropaeolum majus* and *Tropaeolum tuberosum* are the most extensively studied species; however, many others in this group, such as *Tropaeolum pentaphyllum* and *Tropaeolum azureum*, remain underexplored, highlighting the need for further research to address the knowledge gaps and unlock the potential of lesser-known species. These findings reinforce the importance of exploring the full potential of *Tropaeolum*, contributing to advancing scientific knowledge and discovering new applications of this promising genus.

Resumo

Tropaeolum (Tropaeolaceae) compreende cerca de 95 espécies com distribuição neotropical, algumas das quais possuem importância econômica, gastronômica, medicinal e paisagística. Este estudo apresenta uma análise cientométrica do gênero, utilizando dados da Web of Science (1945–2024) para avaliar tendências, lacunas e temas emergentes na pesquisa. Após triagem, 490 documentos foram analisados usando CiteSpace e Microsoft Excel. Os resultados mostraram pouca colaboração e influência das instituições brasileiras na pesquisa, em contraste com as dos Estados Unidos e países europeus. Estudos sobre a química, bioquímica e biologia molecular das espécies do gênero despertaram o interesse da comunidade científica devido às suas características específicas, como a presença de compostos como glucosinolatos, isotiocianato de benzila, isotiocianato, antocianinas e antioxidantes; nesse contexto, *Tropaeolum majus* e *Tropaeolum tuberosum* são as espécies mais investigadas, enquanto muitas outras do grupo (como *T. pentaphyllum* e *T. azureum*) ainda precisam ser exploradas, indicando a necessidade de mais

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pesquisas para preencher lacunas de conhecimento nas espécies existentes e expandir o potencial das espécies relacionadas. Os achados reforçam a importância de explorar todo o potencial de *Tropaeolum*, contribuindo para o avanço o conhecimento científico e para a descoberta de novas aplicações para este gênero promissor.

Introduction

Tropaeolum (Tropaeolaceae) comprises approximately 95 species (Pacheco *et al.* 2020) with a Neotropical distribution from Mexico to Patagonia, mainly along the Andes Mountains (Fabbri & Valla 1998; Bayer & Appel 2003). Based on phylogenetic analyses (Andersson & Andersson 2000), *Tropaeolum* is the only genus in this family and is divided into two sections: *Tropaeolum* sect. *Tropaeolum* and *Tropaeolum* sect. *Chilensia*. The species are annual, perennial, scaly, or prostrate herbs that form rhizomes and tubers with the characteristic smell of mustard oil (Andersson & Andersson 2000; Bayer & Appel 2003). Some of these plants, such as nasturtium (*Tropaeolum majus* L.), mashua (*Tropaeolum tuberosum* Ruiz & Pav.), and crem (*Tropaeolum pentaphyllum* Lam.), are of economic, gastronomic, medicinal, and landscape importance and have attracted attention, particularly for their nutritional and pharmacological properties (Rogalski *et al.* 2021).

Nasturtium, also known as capuchin or *capuchinha* in Brazil, is the most widespread and well-known representative of the genus. It is cultivated throughout the world and has become naturalized in certain areas. Its leaves and flowers are incorporated into salads or used in infusions to enrich the diet and to extract bioactive compounds of high medicinal value with antibacterial, antifungal, antioxidant, and anticancer properties (Pintão *et al.* 1995; Garzón & Wrolstad 2009; Butnariu & Bostan 2011; Bazylko *et al.* 2013; Valsalam *et al.* 2019), in addition to antihypertensive, natriuretic, and diuretic effects (Gasparotto Junior *et al.* 2009, 2011, 2012). Prominent among these phytochemicals are polyphenolic compounds, such as anthocyanins and the flavonoids quercetin and kaempferol (Bazylko *et al.* 2014; Garzón *et al.* 2015), the glycosides glucosinolate, benzyl glucosinolate, isothiocyanates, and benzyl isothiocyanate (Ludwig-Muller *et al.* 2002; Schreiner *et al.* 2009; Platz *et al.* 2016), and the carotenoid lutein (Niizu & Rodriguez-Amaya 2005; Butnariu *et al.* 2016).

Mashua, characterized by colorful tuber varieties, possesses antibacterial, antioxidant, and anti-inflammatory activities against venereal, respiratory, urinary, and liver diseases (Ticona *et al.* 2020). Pharmacological studies have highlighted the significant phytochemical richness of mashua, with

notable concentrations of phenolic compounds, anthocyanins, and carotenoids (Campos *et al.* 2006; Chirinos *et al.* 2006, 2007a, 2007b, 2008a, 2008b). Phytochemicals include hydroxybenzoic acids, tannins, flavonoids, glucosinolates, isothiocyanates, phytosterols, fatty acids, and alkamides (Ticona *et al.* 2020). Its anti-aphrodisiac action is due to isothiocyanates, which reduce testosterone / dihydrotestosterone levels in the blood of rats after consumption of mashua tubers (Johns *et al.* 1982).

Except for the aforementioned species, other species remain neglected and poorly studied regarding their potential food, economic, industrial, and medicinal uses. Scientometrics is a quantitative approach to scientific research (Nalimov & Mulchenko 1969) that seeks to assess the growth and trends of scientific production through the analysis of parameters such as authors, research topics, institutions, countries, and journals, allowing the verification of relationships and collaboration within these categories. Studies on this genus and its species are scarce, and no systematic review has yet been conducted.

Thus, in this study, we aimed to conduct a scientometric review of the genus *Tropaeolum*, to investigate the state-of-the-art scientific knowledge available on one of the largest global scientific platforms on this subject and thus identify research connections, emerging trends, and gaps in this field. Therefore, we sought to answer the following questions: How is research on the genus taking place? Which species has attracted the most interest over time? Which areas and research topics provide information about the genus?

Material and Methods

Data was collected from the Web of Science (WoS) from Clarivate Analytics, using the Core Collection as a base for literature search and indexing (Fig. 1), because of its reputation for providing consistent and standardized data and being recognized for its superior citation-based criteria compared with that of other databases (Wang & Waltman 2016). WoS provides multiple databases covering interdisciplinary research, exploring areas of expertise in many disciplines. WoS was chosen as it is the most complete and influential data source, including the main journals in scientific literature and comprehensive metadata

comprising author lists, abstracts, references, number of citations, institutions, journal impact factor, and countries, which are all required for entry in CiteSpace. Moreover, this is the default database used by CiteSpace. Institutional access was provided by the Brazilian Coordination of Superior Level Staff Improvement (CAPES), allowing the inclusion of various sub-datasets in the Core Collection, such as Emerging Sources Citation Index (ESCI, 2019 to present), Science Citation Index Expanded (1945 to present), Social Science Citation Index (1956 to present), Arts and Humanities Citation Index (1975 to present), Conference Proceedings Citation Index - Science (1990 to present), and Conference Proceedings Citation Index - Social Science & Humanities (1990 to present).

The search term “Topic: (*Tropaeolum*)” was used, which led to the generation of 625 records between 1945 and December 2024, the total period available for consultation. Subsequently, the database was refined by selecting articles, resulting in 546 documents. Manual refinement was then conducted to select only studies that addressed the genus *Tropaeolum*, reading the title and abstract to include only articles related to the genus, which

resulted in 490 documents in the database. The PRISMA (preferred reporting items for systematic reviews and meta-analyses) declaration guidelines were followed as closely as possible and adapted to our sample universe (Moher *et al.* 2009; Page *et al.* 2021). The adapted guidelines refer to the non-fulfillment of items specific to meta-analyses and those relatively more related to studies with epidemiological bias or studies on human beings, which cannot be achieved in research with the currently selected items. Such items include those in the checklists, *e.g.*, participant and intervention characteristics, effect size, methods used to explore possible causes of heterogeneity among study results, missing results, and summary statistics for each group.

As the objective was to perform a complete scientometric review to obtain all information regarding the genus *Tropaeolum*, as an inclusion criterion, any research that effectively considered the genus as an object of research was selected, regardless of the research area. The exclusion criteria were defined by removing articles that only vaguely cited the genus and did not study it directly, such as those cited superficially or within non-specific sections of the study (*e.g.*, in the discussion). Thus, 490 valid documents were obtained. All data were downloaded in plain text from the WoS-marked list. The documents were analyzed based on the categories available in the WoS Results Analyzer tool, *i.e.*, the predominant language of the publications, the number of publications and citations per year, countries, keywords, and the analysis of research areas. The data were processed using Microsoft Office Excel (version 365 Personal) and CiteSpace 6.3. R1 software. The former was used to build graphs and tables from the compiled WoS data.

CiteSpace facilitates the understanding and interpretation of network patterns, including the identification of thematic areas, detection of specific points, and labeling of selected terms. The software enables the mapping and detection of networks of authors, countries, and journals, helping verify the main factors contributing to knowledge development in the research area under study (Chen 2014). The CiteSpace program was used to build citation network graphs to present possible interactions among institutions, countries, research areas, and keywords visually and dynamically in the studies selected and exported for analysis.

Co-citation graphs created using CiteSpace are based on the frequency with which an article is cited in other studies, making it possible to establish networks between the studies included in the dataset. Cluster graphs were obtained by grouping terms in the articles that constituted the datasets. These groupings were performed based on the

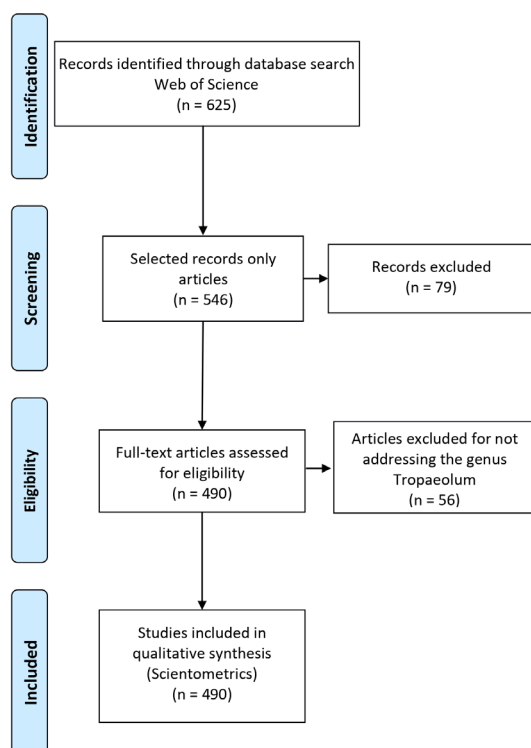


Figure 1 – Flowchart of literature search and indexing, showing the search methodology and refinement adopted for selecting results. Based on the PRISMA (preferred reporting items for systematic reviews and meta-analyses) 2009 flow diagram.

terms found in the titles, abstracts, and keywords. They are classified by the significance of the terms and are titled with “#” followed by a number, such as “# 0”, where relevance is decreasing, so cluster “# 0” is the most relevant, followed by “# 1” and others in that order. For the journal analysis, the impact factor used to ensure the quality and prominence of journals was obtained from WoS Journal Citation Reports.

For an appropriate interpretation of the graphs obtained through the program, explaining the items that compose them is necessary. Each point (node) represents a term connected by a line (or link). These lines connect the nodes, and their thickness represents the strength of the interaction between the terms addressed, such as the relationship of scientific contributions between countries or institutions. The coloring of the links expresses time, with cold colors representing older interactions and warmer colors representing more recent interactions. The font size refers to the publication frequency of the nodes. The red halos around the nodes represent bursts, also called citation bursts, which are periods in which a specific parameter shows sharp growth in publications or citations. The more internal the red halo within the node, the older the citation burst, and the more external the halo, the more recent it is. The strength of a burst can be described by its duration relative to the number of citations during that period.

Results and Discussion

A total of 490 valid articles on the genus *Tropaeolum* were obtained between 1945 and 2024. The predominant language was English with 456 (93.06%) records, followed by Spanish with 10 (2.04%), German with eight (1.63%), French and Portuguese with seven each (1.43%), and Polish and Russian with only one each (0.20%). The articles selected from the marked list had 11,849 citations, with an average of 24.18 citations per item and an h-index of 57.

Quantitative analysis of the literature

The number of annual publications remained low between 1945 and 2005, with values generally not exceeding 10 records, except for a few scattered peaks where the count reached between four and nine publications (Fig. 2). Since 2006, the growth of the topic became exponential, with a sharp and noticeable growth curve that recorded 266 publications up to 2024, peaking in 2021 and 2022 (25 and 26 publications, respectively). In general, the annual growth rate in the number of publications was 5.8%, which highlights the development of research and expansion of interest in *Tropaeolum* over time.

The number of citations increased steadily from 100 to 619 during 1958 to 1969 (Fig. 2). In the following year, in 1970, the number dropped to 31 and did not exceed 80 citations until 1993,

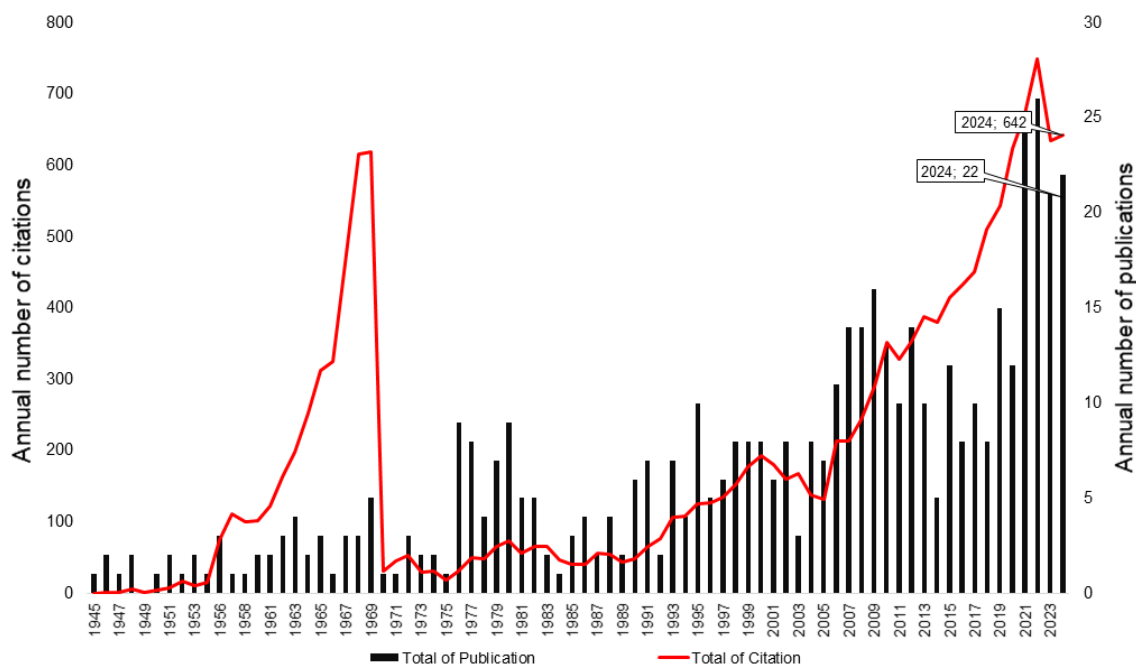


Figure 2 – Publication history of the genus *Tropaeolum*, showing the relationship between the annual number of publications and the annual number of citations from 1945 to late 2024.

after which a new trend emerged, with a steady increase in the number of citations of works until reaching the highest mark in 2022 with 750 citations. The increase in the number of citations in the last decade highlights the significant growth in scientific interest in the genus *Tropaeolum*, where even with a low number of publications, there was a steady increase in citations. The data also show that recently published works are among the most cited new publications, demonstrating the increasing impact of research on this subject.

The observed increase in the number of publications on *Tropaeolum* reflects a growing global interest in plants with bioactive compounds and medicinal properties. This pattern is similar to that observed in other botanical genera, such as *Solanum*, which has also experienced a significant increase in the number of studies in recent decades (Kaunda & Zhang 2019). However, although families such as Asteraceae already have a solid research base (Bessada *et al.* 2015), the genus *Tropaeolum* is still in the expansion phase, with many species still poorly explored. This suggests that this genus has significant potential for future research, especially in areas such as chemistry and molecular biology, which are key to advancing knowledge of other genera and families.

Analysis of authors and institutions

The author Emerson Luis Botelho Lourenço from the Universidade Paranaense (Brazil) is the leader in publications, with nine records (Tab. 1), followed by Arquimedes Gasparotto Junior with eight publications. Fourth were Rosana Chirinos and David Campos, each with six records (Tab. 1). The Brazilian institutions Universidade Paranaense and Universidade Federal do Paraná with eight and seven publications, respectively, were the most representative, and Université catholique de Louvain (Belgium) occupied the third place with 10 records. The Federal University of Viçosa (Brazil), along with the Spanish Universidad Complutense de Madrid and Universidad Autónoma de Madrid, stood out as the only institutions with publications within the last decade, which may suggest increasing institutional engagement in this area of research in the coming years (Tab. 1).

The CiteSpace network analysis revealed a significant gap, as Brazilian institutions, despite leading in publications, exhibited limited collaboration with international researchers (Fig. 3). This isolation limits the potential impact of Brazilian research on *Tropaeolum*, demonstrating the need for stronger collaborative networks to expand its scope and reach its findings. In contrast, families such as Brassicaceae have seen accelerated advancements in knowledge owing to extensive international collaborations (Shankar *et al.* 2019). Establishing

similar partnerships for *Tropaeolum* could drive progress in key areas, such as biotechnology and pharmacology, where collaboration is essential for developing new applications.

Country-based analyses

Although Brazil and Germany had a higher frequency, as observed by the sizes of their nodes, they presented low centrality and weak connectivity with other countries, as observed in the thin links. By contrast, the United States shows both high frequency and centrality, as demonstrated by the presence of a thick purple halo around its node, indicating the importance of this country in the research field. In addition, the USA, Canada, and England presented the coolest-colored links, indicating that they possessed foundational documents of the field, that is, the earliest records of the genus.

In Figure 4, the country network can be observed, showing the frequency and centrality of nodes. Brazil stood out, with a burst strength of 11.58 between 2011 and 2018; England, with a burst strength of 7.69 between 1985 and 2004; and the United States, which reached 6.63 between 1995 and 2007. The USA, Spain, and Brazil had the highest centralities, which considerably exceeded their frequency values (Fig. 5). Brazil exhibited the highest frequency of publications but lower centrality than that in the case of the USA and Spain (Fig. 5). Despite being a country where the genus naturally occurs (Rogalski *et al.* 2022) and having many species, Brazil could achieve greater international prominence. Brazil stood out in terms of the frequency of publications because three Brazilian universities led the research on the *Tropaeolum* genus, as shown in Table 1 and Figure 3.

Analysis of research areas

According to the WoS categories, *Tropaeolum* is most frequently addressed in Plant Sciences, with approximately twice as many publications as other categories. Next, we had Biochemistry and Molecular Biology, Food Science and Technology, followed by Agronomy, Applied Chemistry, Multidisciplinary Sciences, Medical Area of Pharmacy and Pharmacology, Multidisciplinary Agriculture, Medicinal Chemistry, and Entomology, with a decreasing number of publications in that order (Fig. 6).

These dominant research areas on *Tropaeolum* reflect a trend similar to that observed in other botanical genera, such as *Cotoneaster* and *Rosa* (Rosaceae) (Kicel 2020; Fayaz *et al.* 2024). However, the growing interest in Chemistry, Biochemistry, and Molecular Biology suggests that *Tropaeolum* is following a path similar to that of other genera rich in bioactive compounds, such as

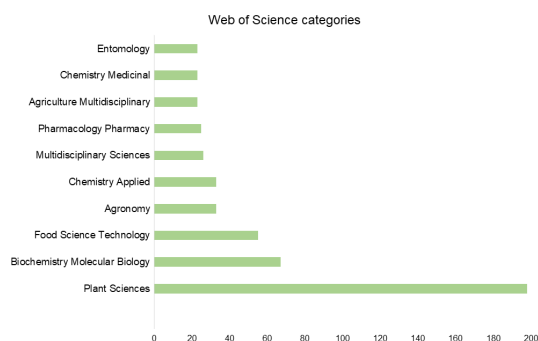
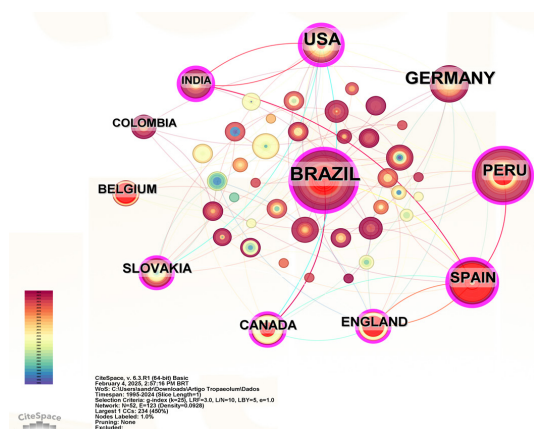


Figure 6 – Distribution of research topics related to *Tropaeolum* based on the Web of Science categories.

Figure 4 – Country collaboration network generated in CiteSpace, showing frequency (node size), centrality (purple rings), and temporal activity (link color) in publications related to *Tropaeolum*. Legend: Bibliometric analysis network generated in CiteSpace (v.6.3.R1), configured with the following parameters: the period from 1995 to 2024 (annual interval), selection criteria based on the g-index ($k = 25$), link retaining factor (LRF) = 3.0, $L/N = 10$, lookback year (LBY) = 5, and $e = 1.0$. The network consists of 52 nodes and 123 connections (Density = 0.0928), with the largest connected component containing 234 nodes (450% of the total).

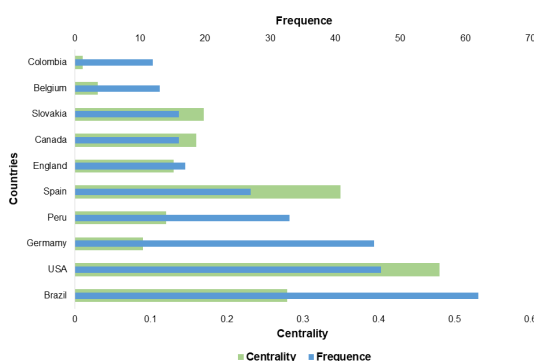


Figure 5 – Frequency and centrality values from the country network in CiteSpace, demonstrating the relationship between country-based publication volume and visibility.

compounds, which closely align with the research on *Tropaeolum*. In contrast, broad-scope journals, such as the *Proceedings of the National Academy of Sciences of the United States of America* cover a wide range of scientific disciplines, resulting in fewer publications on specific topics, such as this genus (Wang & Waltman 2016; Larivière *et al.* 2016). This difference demonstrates the importance of journal scope and specialization in determining the number of publications on a given topic, rather than simply the impact factor.

We also observed that the *Journal of Biological Chemistry*, *Scientific Reports*, and *Biochemical Journal* have shown strong growth in the topic recently, with citation bursts of 8.26, 8.19, and 6.31, respectively, since 1994 (Tab. 2). This may be due to the high content of bioactive compounds reported in certain species of the genus compared to other vegetables used as human food (Aguilar-Galvez *et al.* 2023; Česlová *et al.* 2023).

This pattern is similar to that observed for the family Brassicaceae, where journals specializing in plant physiology and biology have been fundamental to the advancement of knowledge (Halkier & Gershenzon 2006; Shankar *et al.* 2019). The recent increase in the number of publications in chemistry journals suggests a growing interest in the pharmacological and nutritional applications of *Tropaeolum*, following a trend observed for other families, such as Lamiaceae and Asteraceae (Bessada *et al.* 2015; Carović-Stanko *et al.* 2016).

Keyword-based analyses

In the network of keywords shown in Figure 7, the species that have been highlighted in this research, including *Tropaeolum majus* and *T. tuberosum* with their respective most common names nasturtium and mashua, as well as their family name (Tropaeolaceae), can be identified. In addition, some of the main compounds already reported for the species, such as glucosinolate, benzyl isothiocyanate, isothiocyanate, anthocyanin, and antioxidants, which are more recent terms, present links with warmer colors in the network.

Table 3 complements this perspective by highlighting the 10 most-cited studies within the WoS, with their respective authors and year of publication, for the genus *Tropaeolum*.

Analysis of cited authors and clusters

The clusters shown in Figure 8 were extracted based on titles in CiteSpace via the

Table 3 – Top 10 most cited articles on *Tropaeolum* in the Web of Science (WoS), with their authors and year of publication.

Article title	Author / Year	Average per year	Total
The slow-growth-high-mortality hypothesis: a test using the cabbage butterfly	Benrey & Denno / 1997	15.72	456
A gene from the cellulose synthase-like C family encodes a β -1,4 glucan synthase	Cocuron <i>et al.</i> / 2007	13.21	251
Optimization of extraction conditions of antioxidant phenolic compounds from mashua (<i>Tropaeolum tuberosum</i> Ruiz & Pavo) tubers	Chirinos <i>et al.</i> / 2007	12.84	244
Comparative deep transcriptional profiling of four developing oilseeds	Troncoso-Ponce <i>et al.</i> / 2011	14.67	220
Structural evidence for the evolution of xyloglucanase activity from xyloglucan <i>endo</i> -transglycosylases: biological implications for cell wall metabolism	Baumann <i>et al.</i> / 2007	11.32	215
Rapid biosynthesis and characterization of silver nanoparticles from the leaf it extract of <i>Tropaeolum majus</i> L. and its enhanced <i>in-vitro</i> antibacterial, antifungal, antioxidant and anticancer properties	Valsalam <i>et al.</i> / 2019	30.43	213
Action of a pure xyloglucan <i>endo</i> -transglycosylase (formerly called xyloglucan-specific <i>endo</i> -(1- β)-glucanase) from the cotyledons of germinated nasturtium seeds	Fanutti <i>et al.</i> / 1993	4.61	152
Physiological and ecological studies in the analysis of plant environment .7. an analysis of the differential effects of light intensity on the net assimilation rate, leaf-area ratio, and relative growth rate of different species	Blackman & Wilson / 1951	1.87	140
Cloning and characterization of an acyl-CoA-dependent <i>diacylglycerol acyltransferase</i> 1 (<i>DGAT1</i>) gene from <i>Tropaeolum majus</i> , and a study of the functional motifs of the DGAT protein using site-directed mutagenesis to modify enzyme activity and oil content	Xu <i>et al.</i> / 2008	7.11	128
Nutritional Composition and Antioxidant Capacity in Edible Flowers: Characterisation of Phenolic Compounds by HPLC-DAD-ESI/MS ^a	Navarro-González <i>et al.</i> / 2015	11.55	127

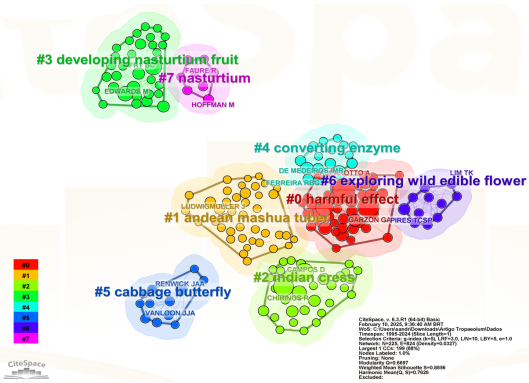


Figure 8 – Cluster network of cited authors in CiteSpace, indicating groupings based on co-citation and topical similarity with chronological coloring and cluster labels. Legend: Co-occurrence network generated in CiteSpace (v.6.3.R1), containing 225 nodes and 324 connections (Density = 0.0327). Period analyzed: 1995–2024 (annual interval); selection criteria: q-index ($k = 5$), link retaining factor (LRF) = 3.0, L/N = 10, lookback year (LBY) = 5, and $e = 1.0$. The largest connected component has 199 nodes (88% of the network). Quality metrics: Modularity ($Q = 0.6697$), weighted average silhouette ($S = 0.8858$), and harmonic mean ($Q,S = 0.7826$, indicating structuring in communities with adequate internal cohesion).

Experiences with other genera, such as *Piper* (Piperaceae), *Rosa*, and *Cotonaster* (Rosaceae), have shown that exploring relatively less-studied species can reveal new bioactive compounds with medicinal and nutritional applications (Sen *et al.* 2022; Kicel 2020; Fayaz *et al.* 2024). This pattern suggests that the genus *Tropaeolum*, which includes species not yet investigated such as *T. pentaphyllum* and *T. azureum* Bertero ex Colla (Watson & Flores 2010; Rogalski *et al.* 2021), may also harbor promising compounds deserving scientific attention.

Practical applications of the bioactive compounds of *Tropaeolum*

Bioactive compounds found in *Tropaeolum* species, such as glucosinolates, anthocyanins, and flavonoids, have significant potential for practical applications in several areas, including nutrition, pharmacology, and agriculture. For example, glucosinolates, which have been widely studied in Brassicaceae (Halkier & Gershenzon 2006), have demonstrated anticancer and antimicrobial properties, suggesting that similar compounds in *Tropaeolum* can be exploited for the development of nutraceutical drugs and supplements. In addition, anthocyanins present in species such as *T. majus* and

Table 4 – Summary of the top 10 clusters, showing their size, silhouette, representative terms used to characterize each cluster, as well as the year each cluster was formed.

Cluster ID	Size	Silhouette	Mean (year)	Representative terms
0	44	0.801	2016	salt stress; harmful effect;
1	42	0.805	2006	bioactive compound; black bean aphid;
2	34	0.906	2013	andean mashua tuber; indian cress;
3	32	0.991	2000	structural xyloglucan; plant cell wall;
4	16	0.934	2012	converting enzyme; antihypertensive effect;
5	12	0.989	1997	diet-dependent sensitivity; larvae;
6	11	0.974	2021	bioactive compound; horticulture;
7	8	0.971	2008	complex; xyloglucan endo-transglycosylases;

T. tuberosum have been used as natural colorants in foods and cosmetics and possess antioxidant properties that can benefit human health (Garzón & Wrolstad 2009; Ticona *et al.* 2020). In agriculture, the bioactive compounds of *Tropaeolum* can be exploited for the development of bioinsecticides or biofertilizers, following the example of other botanical genera such as *Allium* (Alliaceae) and *Medicago* (Fabaceae), where essential oils and phenolic compounds have been used for pest control and plant growth promotion (Tepe *et al.* 2005; Bora & Sharma 2011b).

These initial studies on bioactive compounds represent the first step toward a holistic understanding of *Tropaeolum*'s potential for various applications, including food, ornamental, medicinal, and agricultural. Despite its scientific and economic relevance, this genus remains underexplored, and many species are yet to be thoroughly investigated. Advancing research in this field is essential to bridge existing knowledge gaps and to expand the potential of relatively less-known species. To realize this potential fully, coordinated efforts are required to overcome current limitations. By prioritizing neglected species, expanding research databases, and fostering international collaboration, future studies can unlock the significant applications of *Tropaeolum*, contributing to sustainable solutions in health, agriculture, and beyond.

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Data Availability Statement

In accordance with Open Science communication practices, the authors inform that all data are available within the manuscript.

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