Drying Technologies for Mango (*Mangifera indica*): A Scientometric Review

Tecnologías de secado para el mango (*Mangifera indica*): Una revisión cienciométrica

Ana María Amaya-Gámez **
Lucas Daniel Amaya-Gámez ***
Karoll Stefanny Barrera-Rojas ****
Maria Fernanda Castillo-Arenas *****

Recibido: junio 28 de 2025 - Evaluado: agosto 23 de 2025 - Aceptado: septiembre 12 de 2025

Para citar este artículo / To cite this Article
A. M. Amaya-Gamez, L. D. Amaya-Gamez, K. S. Barrera-Rojas, M. F. Castillo-Arenas "Drying Technologies for Mango (*Mangifera indica*): A Scientometric Review", Revista de Ingenierías Interfaces, vol. 8, no.2, pp.1-18, 2025.

Abstract

Currently, the agribusiness is experiencing a high demand for healthy foods that have a long shelf life and are of good quality, driving the search for efficient methods for the sustainable use of mangoes. In this sense, it seeks to promote the development and optimization of various drying techniques to preserve the nutritional values of mango, while increasing their added value. However, although there is related research on different methods of mango dehydration, such as hot air drying, solar drying and freeze-drying. The specific scientific literature on the subject is scarce and dispersed in time, considering its trends and approaches. The main objective of this article is to identify and classify the main scientific methods related to mango drying to carry out a scientometric review based on a search in Scopus and Web of Science databases. The results of the analysis showed that the country with the highest academic production in this area is Brazil and the most important author is Reinhold Carle. It is expected that these results will provide a clearer and more organized view of the current scientific landscape on the different types of drying applied to mango (Mangifera indica), identifying possible gaps and guiding research in this area in the future.

*Artículo inédito: "Drying Technologies for Mango (Mangifera indica): A Scientometric Review".

**anamayag@unal.edu.co; Ingeniería Biológica, Universidad Nacional de Colombia - Sede de La Paz; https://orcid.org/0009-0001-3120-5186; Cesar, Colombia.
***luamaya@unal.edu.co; Ingeniería Biológica, Universidad Nacional de Colombia - Sede de La Paz. https://orcid.org/0009-0005-2259-2486; Cesar, Colombia.
****kbarrerar@unal.edu.co; Ingeniería Biológica, Universidad Nacional de Colombia - Sede de La Paz. https://orcid.org/0009-0001-1692-3710; Cesar, Colombia.
*****mcastilloar@unal.edu.co; Ingeniería Mecatrónica, Universidad Nacional de Colombia - Sede de La Paz; https://orcid.org/0009-0008-2098-2917; Cesar, Colombia.

Keywords. Dehydration, mango, nutritional properties, freeze-drying, solar drying, hot air drying, Scopus, Web of Science, scientometric.

Resumen

En la actualidad, la agroindustria experimenta una alta demanda de alimentos saludables que tengan una larga duración y sean de buena calidad, impulsando la búsqueda de métodos eficientes para el aprovechamiento sostenible del mango. En este sentido, se busca promover el desarrollo y la optimización de diversas técnicas de secado para preservar los valores nutricionales del mango, al mismo tiempo que aumenta su valor agregado. Sin embargo, aunque existen investigaciones relacionadas sobre diferentes métodos de deshidratación de mango, como el secado por aire caliente, el secado solar y la liofilización, entre otros, se evidencia que en la literatura científica específica sobre el tema es escasa y está dispersa en el tiempo, considerando sus tendencias y enfoques. El objetivo principal de este artículo es identificar y clasificar los principales métodos científicos relacionados con el secado del mango para realizar una revisión cienciometría a partir de la consulta de las bases de datos Scopus y Web of Science. Los resultados del análisis arrojaron que el país con la mayor producción académica en esta área es Brasil y el autor más importante es Reinhold Carle. Se espera que estos resultados permitan tener una visión más clara y organizada del panorama científico actual sobre los distintos tipos de secados aplicados al mango (*Mangifera indica*), identificando posibles brechas y orientando la investigación en esta área en el futuro.

Palabras claves. Deshidratación, mango, propiedades nutricionales, liofilización, secado solar, secado por aire caliente, Scopus, Web of Science, cienciométrico.

1. Introduction

The global agro-industrial sector is undergoing a significant transformation, driven by increasing demand for nutritious, high-quality products with extended shelf life. Within this context, mango (*Mangifera indica*), one of the most valued tropical fruits worldwide, stands out for its appealing sensory attributes, high nutritional value, and versatility in various processing methods, among which dried mango holds a prominent position [1], [2], [3].

In many countries, mango production serves as an important source of income for farming communities, agricultural workers, and local economies. *Mangifera indica* plays a key role in the food industry due to its content of natural antioxidants, essential vitamins, minerals, and dietary fiber. The growing awareness of the benefits of healthy eating has led to increased demand for products containing functional ingredients with enhanced nutritional and techno-functional properties [4], [5]. Among these, mango-derived products -particularly dried mango- have gained relevance, as they retain much of the fruit's nutritional properties [6], [7].

However, the high moisture content of mango makes it a highly perishable product [8]. This characteristic leads to significant postharvest losses and poses a challenge to its sustainable utilization within the agro-industrial sector. In response to this issue, drying technologies have emerged as an effective preservation strategy. These technologies not only extend the product's shelf life -reducing the risk of spoilage and microbial proliferation [9]- but also enhance its added value by transforming it into a product with new characteristics, applications, and presentations, including pharmaceutical uses [10].

Over the past two decades, various mango dehydration techniques have been explored and implemented, such as hot-air drying [11], solar drying [12], which harnesses solar energy, freeze-drying [11], [13] for preserving nutrients, structure, and bioactive compounds, and emerging hybrid methods [14] that combine multiple technologies. These drying methods have been primarily evaluated based on their ability to preserve bioactive compounds, maintain sensory attributes (such as color, texture, and flavor), and optimize energy efficiency in mango processing to reduce both costs and environmental impact [15].

Nevertheless, despite the growing number of publications in this field, the scientific output related to mango drying remains scattered and fragmented across different journals, years, and methodological approaches. This dispersion hinders the identification of clear patterns, thematic trends, and relevant research collaborations.

A total of 404 records related to the main topic of this paper were retrieved from the databases used. Over the past 21 years, the annual growth rate in the number of publications on mango drying has been 10.06%. India leads in research output on this topic, with a total of 56 publications, while Food Chemistry stands out as the most influential journal in the field, with 10 published articles and an h-index of 348.

This study not only provides a detailed overview of the current state of knowledge in the field of mango drying technologies but also offers valuable synthesized information for the scientific community, serving as a resource for researchers interested in exploring this area of study. Furthermore, the findings of this analysis will be highly useful for technologists and engineers seeking to implement or optimize mango dehydration processes at an industrial level. The study presents relevant information to support decision-making aimed at achieving sustainable and technologically advanced development within the tropical agro-industrial sector.

The results of this scientometric review are expected to provide a clearer and more detailed understanding of the overall research landscape surrounding mango drying technologies. This includes an analysis of the global collaboration network among leading countries, the most prominent journals, the most influential authors, and the annual scientific output on this topic. Such insights allow for the identification of the most active research areas and potential opportunities for international collaboration.

2. Methodology

This scientometric study analyzes the scientific output related to mango and its various drying methods. To this end, a systematic search was conducted in the WoS and Scopus databases, both widely recognized for their comprehensive coverage and scientific rigor [16]. The keywords used are listed in Table 1. The initial focus was on articles with the word *mango* in the title, followed by terms associated with dehydration processes. Subsequently, filters were applied to limit the results to original research articles published in English, covering the period from 1976 to 2025.

Table I. Search parameters used in Web of Science and Scopus.

Parameter	Web of Science	Scopus
Range	1976 - 2025	
Date	April 10, 2025	
Document Type	Paper	
Words	TITLE(mango) AND TITLE("drying" OR "dehydration" OR "dried mango" OR "mango chips" OR "mango slices" OR "hot air drying" OR "solar drying" OR "freeze drying" OR "drying kinetics" OR "drying technology" OR "drying process" OR "drying methods" OR "drying characteristics" OR "quality of dried mango" OR "nutritional properties" OR "physicochemical properties" OR "value-added mango") AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English")	
Results	322	357
Total (Wos+Scopus)	404	

A total of 404 documents were retrieved, the majority of which were research articles (97.30%), while review papers accounted for only 0.98%. Only six documents fell into other categories. These findings highlight the importance of combining WoS and Scopus when conducting literature reviews, as 11.63% (47) of the articles were indexed in WoS but not in Scopus.

Figure 1 presents a flow diagram summarizing the methodology used to retrieve bibliographic information and manage the resulting data, based on the PRISMA methodology [17]. To merge the results from Scopus and WoS, web scraping was performed on the WoS references to extract data such as author and title. For organizing the Scopus references, text mining techniques were applied. The outcome of these two processes enabled the standardization of references and the integration of both datasets. This process generated an Excel file comprising 22 sheets with structured data ready for analysis.

The results are categorized into the analysis of annual scientific output, country-level analysis, journal analysis, and scientific collaboration network analysis. Finally, with the assistance of Google Colab, a network was constructed to consolidate the collected data. These results were used to build the conceptual structure of the research field (mango drying) through tables and figures, identify key studies, and support the selection of the most relevant literature. These type of scientometric analysis are popular in several academic areas [18], [19].

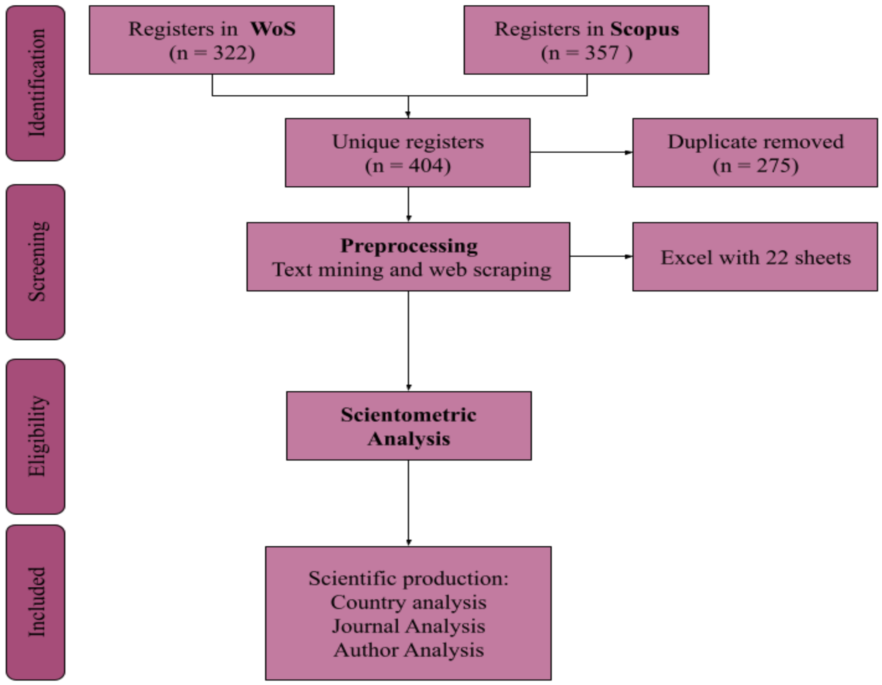

Figure 1. Flowchart

3. Results

Scientific Annual Production

Figure 2 illustrates the scientific production from 2004 to 2025 associated with drying technology for mango. **Figure 2** allows for the analysis of the performance and scientific quality of research using the WoS (salmon bars) and Scopus (blue bars) analytical tools over the past 21 years, as well as the total number of publications (red line) and total citations (plum line) across both databases.

It can be observed in Figure 2 that both Scopus and WoS exhibit considerable output in this research area. Although there has been a notable decline in total citations (plum line) from 2022 to 2025, the total number of publications has remained stable in recent years. Taking this into account, three crucial periods in the annual scientific production of articles on mango dehydration techniques were identified and will be described later. Overall, the graph shows an average annual growth rate of 10.06% over the past 21 years.

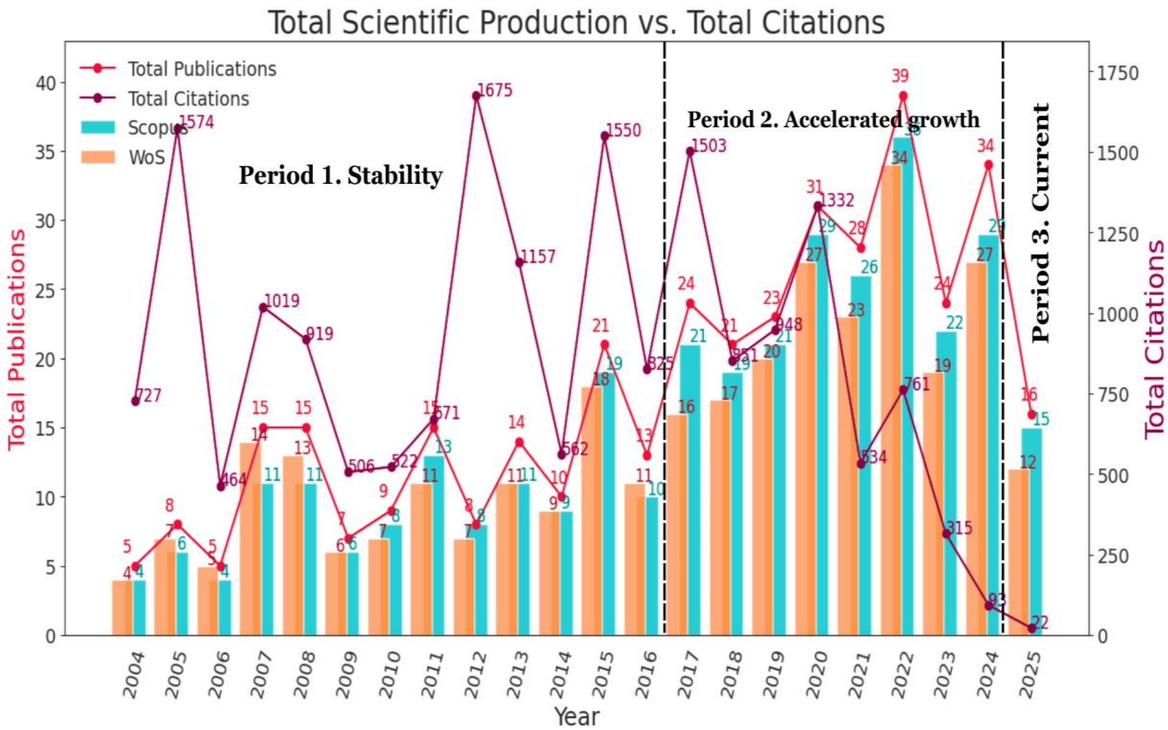

Figure 2: Total scientific article and citation (2004-2025)

Period 1. Stability (2004 - 2016)

During the first stage, the annual growth rate from 2004 to 2016 was 8.29%, with an average of between 5 and 15 publications per year and moderate fluctuations in citations. The highest peak occurred in 2012, with 1,675 citations, highlighting that some pioneering works began to make an impact in the scientific community. These studies include research on microwave drying [20], improvements in drying conditions [21], the effects of mango drying for its application in cosmetics [22], and the investigation that spurred interest in this topic regarding the characteristics of thin-film drying or refractance window technique [23]

Period 2. Accelerated growth (2017 - 2024)

Between 2017 and 2024, a significant growth rate of 5.10% was observed, indicating a sustained increase in the number of publications, peaking in 2022 with 39 articles. There was also a notable rise in the number of citations, with a peak of 1,503 in 2018, driven by the studies [24] and [25], which focused on uncontrolled solar drying and the evaluation of drying through the multi-flash conductive process.

Period 3. Current (2025)

In 2025, a decline is observed in both the number of publications (16) and citations (22) [5], [26] which may reflect a transitional phase or a restructuring of the research focus. This interpretation takes into account that the year is still ongoing, and these figures may increase significantly as the year progresses. Nevertheless, when considering publications from previous years, a considerable upward trend can be noted—for instance, one of the 2025 publications has already received four citations [27].

Country Analysis

Table 2 presents the top 10 countries with the highest scientific output and impact (citations) related to mango drying, as well as the quality (quartile rankings) of their publications. The country with the highest production on this topic is India, accounting for 13.9% of the total output, closely followed by Brazil with 12.41%. Although India shows higher productivity (56 publications), Brazil registers a greater scientific impact in terms of citations, contributing 13.53%. Regarding quality, while there are some differences between the two countries, they are relatively minor; both have been published in Q1, Q2, and Q3 journals. However, China stands out as the country with the highest number of publications in top-tier journals (Q1 and Q2), without any publications in lower quartile journals (Q3 and Q4).

Table II. Scientific Production and Impact by Country.

Country	Production		Citation		Quartile			
	Count	%	Count	%	Q1	Q2	Q3	Q4
India	56	13.9	1485	12.46	12	19	13	2
Brazil	50	12.41	1612	13.53	15	25	1	0
China	26	6.45	926	7.77	17	7	0	0
Thailand	25	6.2	573	4.81	13	10	0	1
Mexico	21	5.21	751	6.3	7	7	1	0
Usa	21	5.21	1276	10.71	10	4	1	0
Colombia	15	3.72	445	3.73	5	1	0	2
France	14	3.47	428	3.59	8	3	1	2
Canada	13	3.23	309	2.59	6	7	0	0
Spain	12	2.98	530	4.45	7	2	0	0

One of the most recent studies conducted by researchers in India found that improved solar drying (ISD) can produce higher-quality dehydrated fruits and better preserve heat- and light-sensitive nutrients, after comparing five different drying methods—including open sun drying [12]. In Brazil, one of the latest investigations explored the pre-treatment of mango with isomaltulose using standard osmotic dehydration (OD) and pulsed vacuum osmotic dehydration (PVOD) prior to convective drying of mango slices. The application of isomaltulose combined with PVOD helped incorporate the desired sugar and enhance product stability, though at the cost of some nutrient losses, particularly ascorbic acid (vitamin C) and antioxidant activity [28].

In the case of China, the most recent publication on mango drying technologies introduced an innovative multifunctional gelatin-based hydrogel (Gel/G) used as a wrapping material to slow down fruit damage and extend shelf life. This approach helped stabilize key quality parameters of the fruit and delay its ripening process [29]. Similarly, researchers from Thailand developed a mango coating strategy. However, their study focused on a combined approach involving calcium chloride ($CaCl_2$) coating and specialized modified atmosphere packaging to preserve the quality of frozen ripe mango slices. By adjusting atmospheric conditions to low oxygen levels, they found that the most effective results were obtained with oxygen concentrations ranging between 0.96% and 3.23% [30].

An especially intriguing study from Mexico examined the effects of fat type (beef fat vs. vegetable oils) and dehydrated mango peel powder (MP) on beef hamburgers. The researchers prepared six different formulations—with and without mango peel powder—designated as follows: T1 (beef fat control), T2 (pre-emulsified avocado oil, no MP), T3 (pre-emulsified safflower oil, no MP), T4 (beef fat with 1% MP), T5 (pre-emulsified avocado oil with 1% MP), and T6 (pre-emulsified safflower oil with 1% MP). The aim was to assess how MP and fat type influenced the physicochemical properties of the hamburgers, from frozen storage to simulated digestion. The results showed that the addition of mango peel powder significantly reduced lipid oxidation during both freezing and in vitro digestion. This oxidative stability helped preserve the quality of the meat, resulting in a longer shelf life and improved nutritional profile due to the antioxidant properties of the mango peel. In summary, the study demonstrates that it is possible to produce healthier beef burgers with extended shelf life and oxidative stability by incorporating dehydrated mango-derived ingredients [30].

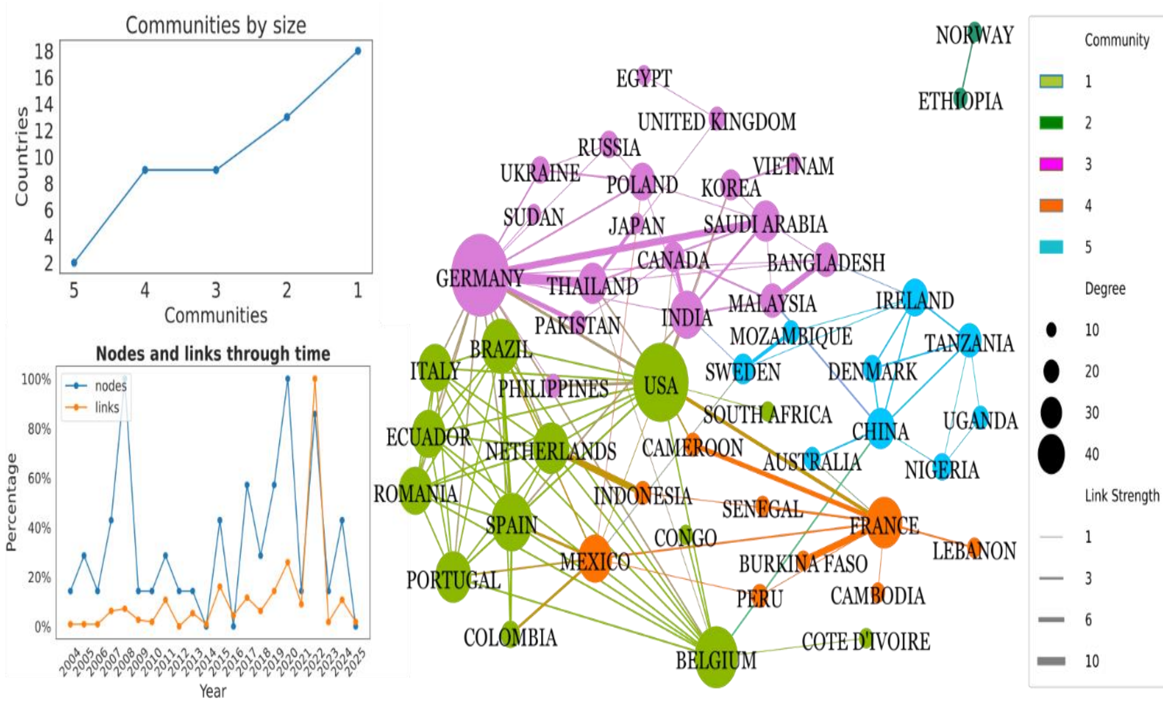

Figure 3. Global collaborative country network of drying technologies for mangos.

However, the analysis of international scientific collaboration networks (Figure 3) identifies five distinct communities or clusters of countries that have published on mango drying and the various associated technologies. The first community, connected solely by Ethiopia and Norway, shows no collaboration with other countries. In contrast, the second community (purple), composed of 18 countries and led by Germany, demonstrates strong internal collaboration, including a notable connection between Thailand and Saudi Arabia. The third community (blue) exhibits modest collaboration among nine countries.

The fourth community (light green) reveals extensive interconnections, not only among its member countries but also with countries from other communities, a pattern that is similarly observed in the fifth community (orange), led by France. A particularly interesting finding is that the top 10 countries in terms of scientific output and impact are dispersed across all communities. Remarkably, although Germany does not appear among the top 10 countries in Table 2, it emerges as the most connected country across all communities in Figure 3.

Furthermore, the node and link graphs over time show that while 2021 witnessed a surge in collaborative links, the number of newly participating countries remained relatively stable. In recent years, however, the trend has reversed: the number of collaborative links has declined significantly, while the number of new countries entering the field has increased.

Journal Analysis

The analysis of scientific journals enabled the identification of the main platforms for disseminating research related to mango and its dehydration methods. Table 3 presents the ten journals with the highest output on dehydrated mango. Notably, six of these journals are ranked in the top quartile (Q1), while the remaining four are in Q2. The two journals with the highest number of publications are Journal of Food Engineering and Drying Technology, with h-index values of 228 and 117, respectively. These journals belong to Q1 and Q2 quartiles, indicating a high level of editorial quality and international visibility.

However, *Food Chemistry* stands out with the highest h-index (348) and a SCImago Journal Rank (SJR) of 1.952, making it the most influential journal in the set. It is followed by *LWT - Food Science and Technology* (h-index of 187) and *Journal of Food Science* (h-index of 189), both also classified in Q1. A noteworthy case is *LWT - Food Science and Technology*, which, although it does not report publications in Web of Science for the period analyzed, has 16 indexed documents in Scopus. Despite this limitation in database coverage, *LWT* demonstrates a high impact (SJR = 1.480) and a considerable h-index (187), as previously mentioned, justifying its Q1 classification. This suggests that although its visibility is more aligned with the Scopus database, its academic relevance remains significant.

Table III. Scientific Production and Impact by Country.

Journal	SN	WoS	Scopus	Total	SJR	H- Index	Quartile
Journal Of Food Engineering	02608774	23	24	27	1.159	228	Q1
Drying Technology	07373937	25	26	27	0.668	117	Q2
Journal Of Food Processing And Preservation	01458892	19	19	20	0.573	71	Q2
Lwt	00236438	0	16	16	1.480	187	Q1
International Journal Of Food Science And Technology	09505423	13	13	13	0.723	127	Q1
Journal Of Food Process Engineering	01458876	12	12	12	0.621	66	Q2
Journal Of Food Science And Technology	00221155	0	12	12	0.716	120	Q2
Food Chemistry	03088146	10	10	10	1.952	348	Q1
Journal Of Food Science	00221147	7	8	9	0.798	189	Q1
Foods	23048158	8	8	8	1.021	123	Q1

The Journal of Food Engineering has recently published studies on various methods for dehydrating mango pulp [31]. This study identified an optimal size for dehydrating mango pulp through freeze-drying processes. Drying Technology has published the same number of articles, although more recent. For instance, the latest research on mango in this journal presents an experiment involving the preparation of jam from mango pulp using different dehydration methods. In the first method, a higher amount of air was used, resulting in pulp with a greater proportion of nutrients. In the second method, air was removed, producing a crispier pulp with a more pleasant taste but reduced nutritional content [32].

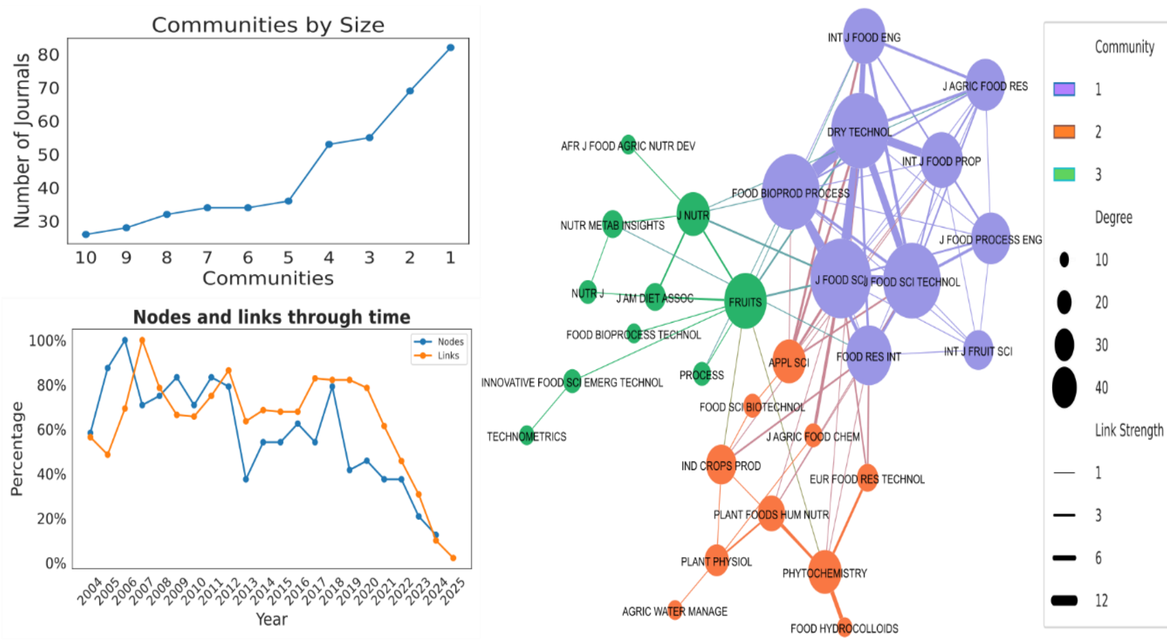

Figure 4. Citation network analysis of drying technologies for mangos.

On the other hand, the citation network analysis (Figure 4) reveals the thematic clustering of journals into three main communities. The purple community consists of journals that focus on thermal drying, mathematical modeling, and energy efficiency, led by Drying Technology, Journal of Food Engineering, and LWT. The green community centers on nutritional and antioxidant evaluation, with Food Chemistry as the main node. Finally, the orange community comprises publications dedicated to technological and food innovation topics, such as Innovative Food Science and Emerging Technologies and Journal of Food Process Engineering [33].

Moreover, the temporal evolution graphs reveal a steady increase in scientific output since the year 2000, with a notable surge over the past decade. This trend suggests a growing interest in developing drying technologies that enhance quality and extend the shelf life of mango, considering its economic and nutritional significance. These findings support the conclusion that the highest-impact journals not only concentrate the largest volume of publications but also serve as key nodes of thematic interconnection among scientific communities.

Author Analysis

The analysis of scientific collaboration networks enables the identification of researchers' networking strategies. Additionally, it allows for the assessment of the relevance of individual researchers based on both their publication output and the impact of their work. Table 4 presents the ten most prolific authors in the field of mango dehydration. The findings show that Dr. Carle leads with the highest number of publications (9), citations (463), and h-index (8). This study highlights the interdisciplinary and applied focus that characterizes several of the most influential authors in the network. For instance, their research addresses technological processes aimed at valorizing industrial mango peel residues through blanching and intermittent microwave-convective drying, to produce functional coproducts [34].

Although Professor Sagar ranks second with the same number of publications as Dr. Carle, his citation count is comparatively lower (123). However, he stands out for his high score on the Collaborative Diversity Index (CDI), with a value of 0.71, indicating collaboration with a wide range of researchers, likely from different institutions, countries, or disciplines. This suggests that his collaboration strategy emphasizes diversity rather than necessarily high visibility in terms of citation impact.

This line of research is complemented by related works, such as the study on the physicochemical properties and drying kinetics of osmotically dehydrated tropical fruits under various drying conditions [35]. That research also explores combined drying techniques to optimize the quality and utilization of fruits such as mango, reflecting a shared orientation toward sustainable and value-added solutions within the agro-industrial sector.

A noteworthy case is that of Professor Neidhart, who, despite having only seven publications, holds the second-highest citation count (373). He also exhibits a high Effective Size value (46.58) and a low constraint value (0.08), indicating that his collaboration network consists of individuals who do not collaborate with each other, thereby granting him access to diverse and non-redundant information. This open network structure may explain the high visibility and impact of his work.

Regarding social network variables, Effective Size reflects the level of collaboration among authors. High values indicate that the researcher is connected with co-authors who are not directly linked to one another, which provides access to unique ideas and perspectives. For instance, Dr. Carle has an exceptionally high Effective Size (104.29), establishing himself as a key node within his academic network. In contrast, Professor Dissa has the lowest value (1.0), which suggests that the individuals she collaborates with also tend to collaborate among themselves. This is confirmed by her constraint value of 0.93, indicating a highly interconnected and internally collaborative group of co-authors. In terms of the Scientific Collaboration Index (CDI), Professor Sagar shows a value of 0.71, reflecting his engagement with a diverse range of collaborators across his publications.

The analysis also highlights other authors such as Ferrari, Chakraborty, Hubinger, and Germer, who, despite having a moderate output ranging from six to eight articles, exhibit mixed network configurations. For example, Ferrari and Hubinger have relatively high Effective Size values (18.65 and 28.0, respectively) and low constraint levels (0.16 and 0.1), suggesting that their collaborations grant them some access to new sources of knowledge. However, their citation impact remains lower than that of the field’s leading authors.

Table IV. Top 10 Most Outstanding Authors in Drying Technologies for Mangos.

Author	Papers Total	Total Citations	H-Index	Effective_Size	Constraint	CDI
Carle R	9	463	8	104.29	0.04	0.15
Sagar V	9	123	7	4.6	0.3	0.71
Ferrari C	8	89	5	18.65	0.16	0.19
Nguyen T	8	33	2	10.0	0.21	0.14
Chakraborty R	7	136	6	21.38	0.14	0.18
Neidhart S	7	373	7	46.58	0.08	0.13
Desmorieux H	6	254	4	16.91	0.16	0.16
Dissa A	6	254	4	1.0	0.93	0.33
Germer S	6	72	4	15.9	0.18	0.2
Hubinger M	6	201	6	28.0	0.1	0.2

Figure 5 illustrates the scientific collaboration network of the personal networks of the most productive authors. The analysis reveals six components emerging from this network. The largest component is led by Professors Carle and Neidhart, who also share a common geographic location. Both researchers are affiliated with the Institute of Food Science and Biotechnology at Hohenheim University in Germany. A notable example of their international collaboration on mango-related research is the article [36], which examines the co-extraction of arabinogalactan and pectin from mango by-products, highlighting the technological and sustainable potential of these investigations.

Another prominent component involves researchers Hubinger, Germer, and Ferrari. Although relatively smaller in size compared to the previously mentioned component, it is significant, particularly considering that only two main authors lead it. An example of collaborative work between Germer and Ferrari is the article [37], which investigates the stability of drum-dried mango peels, evaluating how moisture, temperature, and the use of additives influence their physical properties and shelf life.

Overall, these findings demonstrate that metrics from scientific collaboration and social network analysis not only complement traditional measures of academic impact, but also provide a richer perspective on the collaboration strategies adopted by researchers. Those with more open and diverse networks tend to have greater access to innovative knowledge and, potentially, higher visibility and impact in their publications.

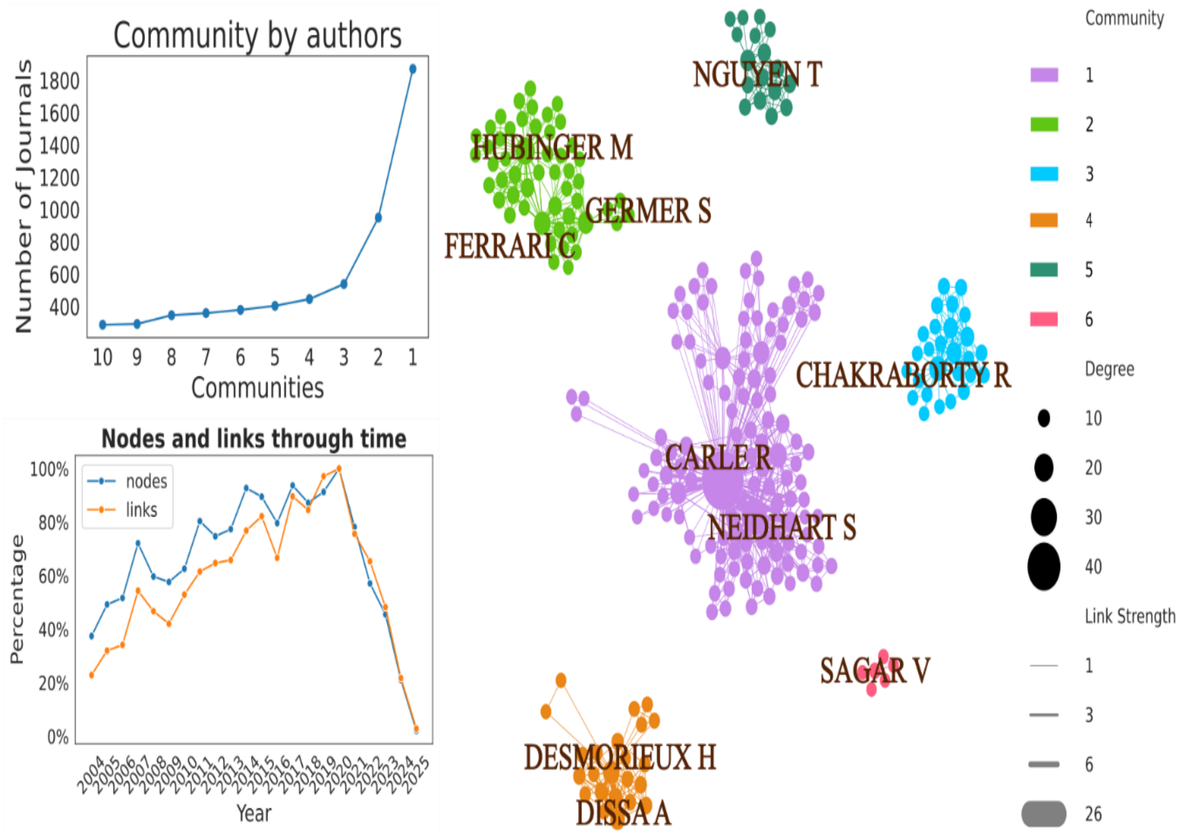

Figure 5. Leading author community in writing about drying technologies for mangos

Conclusions

This centralized review aimed to identify the scientific output, analyze the countries with the greatest academic impact, the leading journals, and the scientific collaboration network among authors in the field of mango drying technologies. To achieve this, two separate searches were conducted in the WoS and Scopus databases. These datasets were subsequently merged using advanced data mining and web scraping algorithms, resulting in a consolidated corpus of 404 publications.

The analysis reveals that the field of mango drying technologies has experienced sustained growth over the past 21 years, with an average annual growth rate of 10.06%. Among the most productive countries, India leads in publication volume, accounting for 13.9% of the total articles (56), followed by Brazil with 12.41%. However, Brazil surpasses India in scientific impact, with the highest percentage of citations (13.53%), indicating greater influence within the academic community.

China stands out for publishing exclusively in high-ranking journals (Q1 and Q2), with no records in Q3 or Q4 quartiles, reflecting a clear emphasis on editorial quality. Regarding scientific journals, the most prominent in terms of publication output are the Journal of Food

Engineering and Drying Technology, with h-indices of 228 and 117, respectively. Both belong to the Q1 and Q2 quartiles. At the individual level, Dr. Reinhold Carle ranks as the leading researcher in the field, with 9 publications, 463 citations, and an h-index of 8, consolidating his position as the most influential academic figure in this domain.

One of the main challenges identified in scientometric studies is the integration of databases with heterogeneous structures, such as Scopus and WoS. Although this review successfully overcame that technical barrier, it is recommended that more robust algorithms be developed, capable of enriching the analysis by incorporating complementary sources, such as OpenAlex. Furthermore, while this study adopts a rigorous quantitative approach, it is advisable to complement these findings with qualitative research to explore, in greater depth, the emerging trends, research gaps, and innovation opportunities in mango drying technologies.

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