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Post-harvest fruit quality: A bibliometric analysis

Qualidade pós-colheita de frutas: Uma análise bibliométrica

Calidad poscosecha de frutas: Un análisis bibliométrico

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Abstract

This study presents a bibliometric analysis on postharvest fruit quality, aiming to identify trends, research gaps, and innovations within the field. Using bibliometric methods, 1,311 publications from 2010 and december of 2023 were selected based on specific criteria and analyzed through tools like VOSViewer and Bibliometrix to map collaborations, citations, and relevant keywords. The study highlights the growing importance of sustainable practices and technologies to ensure the longevity and quality of agricultural products. The analysis indicates that innovations such as edible coatings and natural antioxidants, along with the use of biosensors and artificial intelligence, hold significant potential for enhancing fruit conservation and reducing losses. Additionally, the findings underscore that international scientific collaboration—especially among emerging and developed countries, with China and Brazil leading in publications and partnerships—drives progress in the sector, strengthening food security and the sustainability of agricultural supply chains. The study further reveals that integrated strategies, such as climate-smart agriculture, are essential for reducing losses, bolstering food security, and promoting more sustainable supply chains. These findings not only contribute to guiding future research but also provide a basis for public policy on postharvest conservation, essential for addressing global challenges related to food waste and climate change.
Keywords: Bibliometrics; Food Preservation; Postharvest Technology; Postharvest Physiology.

Resumo

Este estudo apresenta uma análise bibliométrica sobre a qualidade pós-colheita de frutas, com o objetivo de identificar tendências, lacunas de pesquisa e inovações na área. Utilizando métodos bibliométricos, foram selecionadas 1.311 publicações entre 2010 e dezembro de 2023, com base em critérios específicos, e analisadas por meio de ferramentas como VOSviewer e Bibliometrix para mapear colaborações, citações e palavras-chave relevantes. O estudo destaca a crescente importância das práticas e tecnologias sustentáveis para garantir a longevidade e a qualidade dos produtos agrícolas. A análise indica que inovações, como revestimentos comestíveis e antioxidantes naturais, juntamente com o uso de biossensores e inteligência artificial, apresentam um grande potencial para aprimorar a conservação de frutas e reduzir perdas. Além disso, os resultados ressaltam que a colaboração científica internacional—especialmente entre países emergentes e desenvolvidos, com China e Brasil liderando em publicações e parcerias—impulsiona o avanço do setor, fortalecendo a segurança alimentar e a sustentabilidade das cadeias de suprimentos agrícolas. O estudo também

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revela que estratégias integradas, como a agricultura inteligente para o clima, são essenciais para minimizar perdas, fortalecer a segurança alimentar e promover cadeias de suprimentos mais sustentáveis. Essas descobertas não apenas contribuem para orientar pesquisas futuras, mas também fornecem subsídios para políticas públicas voltadas à conservação pós-colheita, essenciais para enfrentar desafios globais relacionados ao desperdício de alimentos e às mudanças climáticas.
Palavras-chave: Bibliometria; Conservação de Alimentos; Tecnologia Pós-Colheita; Fisiologia Pós-Colheita.

Resumen
Este estudio presenta un análisis bibliométrico sobre la calidad poscosecha de frutas, con el objetivo de identificar tendencias, brechas de investigación e innovaciones en el área. Mediante métodos bibliométricos, se seleccionaron 1.311 publicaciones entre 2010 y diciembre de 2023, con base en criterios específicos, y se analizaron con herramientas como VOSviewer y Bibliometrix para mapear colaboraciones, citas y palabras clave relevantes. El estudio destaca la creciente importancia de las prácticas y tecnologías sostenibles para garantizar la longevidad y la calidad de los productos agrícolas. El análisis indica que innovaciones como los recubrimientos comestibles y los antioxidantes naturales, junto con el uso de biosensores e inteligencia artificial, tienen un gran potencial para mejorar la conservación de frutas y reducir pérdidas. Además, los resultados resaltan que la colaboración científica internacional—especialmente entre países emergentes y desarrollados, con China y Brasil liderando en publicaciones y asociaciones—impulsa el progreso del sector, fortaleciendo la seguridad alimentaria y la sostenibilidad de las cadenas de suministro agrícolas. El estudio también revela que las estrategias integradas, como la agricultura climáticamente inteligente, son fundamentales para minimizar pérdidas, fortalecer la seguridad alimentaria y promover cadenas de suministro más sostenibles. Estos hallazgos no solo contribuyen a orientar futuras investigaciones, sino que también proporcionan una base para la formulación de políticas públicas sobre conservación poscosecha, esenciales para abordar los desafíos globales relacionados con el desperdicio de alimentos y el cambio climático.
Palabras clave: Bibliometría; Conservación de Alimentos; Tecnología Poscosecha; Fisiología Poscosecha.

1. Introduction

The preservation of post-harvest quality in fruits and vegetables is one of the greatest challenges faced by the agricultural supply chain. These products, which are highly nutritious, economically valuable, and beneficial to health (Bancal and Ray, 2023; Rizzo et al., 2023; Ali et al., 2011), are highly perishable and account for a significant portion of global food losses. It is estimated that 40% of fruits and vegetables are lost throughout the supply chain due to factors such as high humidity, accelerated respiration, physical damage during transportation and storage, water loss, cold damage, and microbial contamination (Singh et al., 2014; Yeshiwas & Tadele, 2021; Vinod et al., 2023). These losses not only result in significant economic impacts but also directly affect food security and environmental sustainability, exacerbating the waste of natural resources and greenhouse gas emissions. Reducing these losses is directly linked to several Sustainable Development Goals (ODSs), such as eradicating hunger (ODS 2), promoting sustainable consumption and production patterns (ODS 12), and mitigating climate change (ODS 13) (FAO, 2023).

Strategies to preserve post-harvest quality have focused on technologies and practices that slow down deterioration processes, ensuring longer shelf life and maintaining the sensory and nutritional properties of products. Solutions such as modified atmosphere packaging, edible coatings, evaporative cooling, and biocontrol have proven effective in reducing losses and waste, particularly in developing countries where smallholder farmers face financial and technological constraints (Baseadiya, et al., 2013; Makule et al., 2022). The implementation of affordable technologies is crucial to achieving ODS 1, which aims to eradicate poverty by increasing farmers' productivity and income through sustainable practices. In developed countries, challenges are more closely tied to retail and consumption, requiring improved logistics and increased consumer awareness (Gouda & Duarte-Sierra, 2024).

The advancement of post-harvest conservation practices directly connects research to the market, translating scientific innovations into practical solutions to enhance supply chain efficiency and meet global demands. In this context, bibliometrics has emerged as a strategic tool capable of measuring scientific output and identifying emerging trends in research fields. By analyzing the intersection of post-harvest quality, conservation technologies, and sustainability, bibliometrics not only maps scientific progress but also supports the formulation of public policies and the strategic allocation of investments. This approach is crucial for identifying knowledge gaps and fostering innovative solutions that drive positive economic, social, and environmental impacts, aligned with global sustainable development goals.

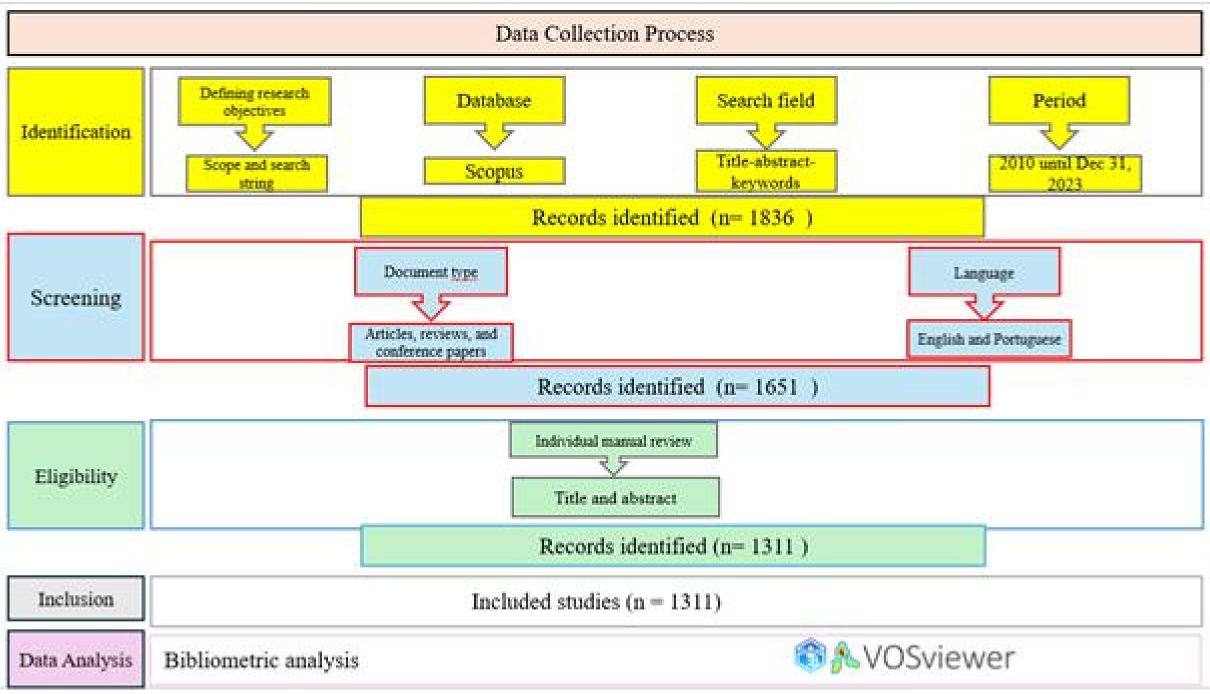
This study presents a bibliometric analysis on postharvest fruit quality, aiming to identify trends, research gaps, and innovations within the field. Specifically, the objectives were to: (1) identify the main publication trends in the field of post-harvest fruit quality, (2) map the most influential journals, researchers, and organizations in the area, (3) analyze the highest-impact publications and their contributions to advancing the field, and (4) identify thematic clusters and predominant research terms in the area.

2. Methodology

The present study employed a bibliometric analysis methodology (Aria and Cuccurullo, 2017). Bibliometric review is a statistical technique used to quantitatively analyze the academic literature on a selected topic. This approach provides an overview of the existing literature and identifies the key contributions made by authors, countries, and research institutions. Furthermore, it offers a broader perspective on the research field examined and delivers a structured understanding of research patterns, thematic clusters, and structures within the field.

Next, Figure 1 is presented, which illustrates the process of collecting and selecting articles for bibliometric analysis.

Figure 1 - Flow diagram of the systematic review.



Source: Research data.

The following methodological steps, illustrated in Figure 1, were followed:

(a) Identification of the most frequently used keywords related to post-harvest quality and fruits. After reviewing various possible keywords used in previous scientific studies and systematic reviews, the following keywords were selected:

[TITLE-ABS-KEY "Postharvest quality" and TITLE-ABS-KEY "Fruit"]. These keywords were chosen to capture the main aspects related to the use of technologies applied to post-harvest fruit processes.

(b) Selection of the Database for the Research:
The Scopus database was chosen due to its extensive coverage of articles, citations, and key journals relevant to the analyzed topic.

(c) Definition of Selection Criteria for Analyzed Articles:
The selection criteria used to define the areas of analysis in the bibliometric study were based on the relevance and scope of the themes related to the study's objectives. The selected areas aimed to provide an interdisciplinary and comprehensive perspective on topics related to the post-harvest quality of fruits, drawing on the subject categories offered by the Scopus database. The following fields were included: Agricultural and Biological Sciences and Environmental Science: These were included as post-harvest quality is directly linked to agricultural production, plant physiology, and environmental impact. Biochemistry, Genetics, and Molecular Biology: These fields address biochemical and genetic processes affecting fruit quality, such as antioxidant synthesis and post-harvest metabolism. Engineering and Materials Science: Relevant for the development of technologies like coatings, packaging, and storage systems that extend fruit shelf life. Pharmacology, Toxicology, and Pharmaceutical Science: These areas relate to the health benefits of bioactive compounds in fruits and the safety of additives used in post-harvest processes. Chemistry and Computer Science: Reflecting the need to integrate chemical approaches, such as antioxidant compound analysis, with computational tools, such as modeling and big data analysis. Immunology and Microbiology: These fields address microbiological aspects that impact storage, such as fungal and bacterial growth.

The publication period was set between 2010 and December 2023 to capture the most recent and relevant trends in the field, enabling an analysis of technological, scientific, and industrial advancements over the last 13 years. This timeframe is sufficient to identify significant changes while remaining current to provide relevant insights for ongoing research and practices.

(d) Initial Filtering Process:
Data cleaning filters were applied, restricting document types to articles, reviews, and conference papers published in English and Portuguese, resulting in 1,651 documents.

(e) Final Review and Document Selection:
As an additional step, all extracted articles were reviewed to confirm their relevance and alignment with the study's focus. Only articles discussing post-harvest quality dimensions in fruits through a bibliometric approach were included. The final sample consisted of 1,311 documents.

The data were collected between August and September 2024. These data were stored and used for bibliometric analysis utilizing the VOSviewer and Bibliometrix software. Various analyses were conducted using VOSviewer and the biblioshiny package in Bibliometrix RStudio, including co-occurrence analysis, bibliographic coupling, network analysis, overlay visualization, collaboration and citation mapping, and thematic evolution analysis.

Additionally, based on the articles and information included in the dataset, the following indicators were determined:

(i) Number of articles published per year, per institution, per journal, per author, and per country;
(ii) Count of articles published by authors from a single country and multiple countries based on author affiliations;
(iii) Total number of citations per article and per journal.

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3. Results and Discussion

3.1 *Scientific production over time*

In total, 1,311 documents related to "post-harvest quality" and "fruits" were identified. These documents were categorized into 1,050 journal articles, 189 conference papers, and 72 reviews. The documents had an average of 21.46 citations per year, with an annual growth rate of 7.84 (Table 1).

Table 1 - Statistical summary of scientific production on fruit post-harvest quality from 2010 to 2023.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2010:2023
Sources (Journals, Books, etc)	258
Documents	1311
Annual Growth Rate %	7,84
Document Average Age	5,95
Average citations per doc	21,46
References	49783
DOCUMENT CONTENTS	
Keywords Plus (ID)	3261
Author's Keywords (DE)	2697
AUTHORS	
Authors	4214
Authors of single-authored docs	31
AUTHORS COLLABORATION	
Single-authored docs	34
Co-Authors per Doc	4,9
International co-authorships %	17,24
DOCUMENT TYPES	
article	1050
conference paper	189
review	72

Source: Research data.

Between 2010 and 2014, there were fluctuations in the number of articles published. However, after 2014, the total number of documents published per year increased exponentially, reaching over 160 documents by 2023 (Figure 2).

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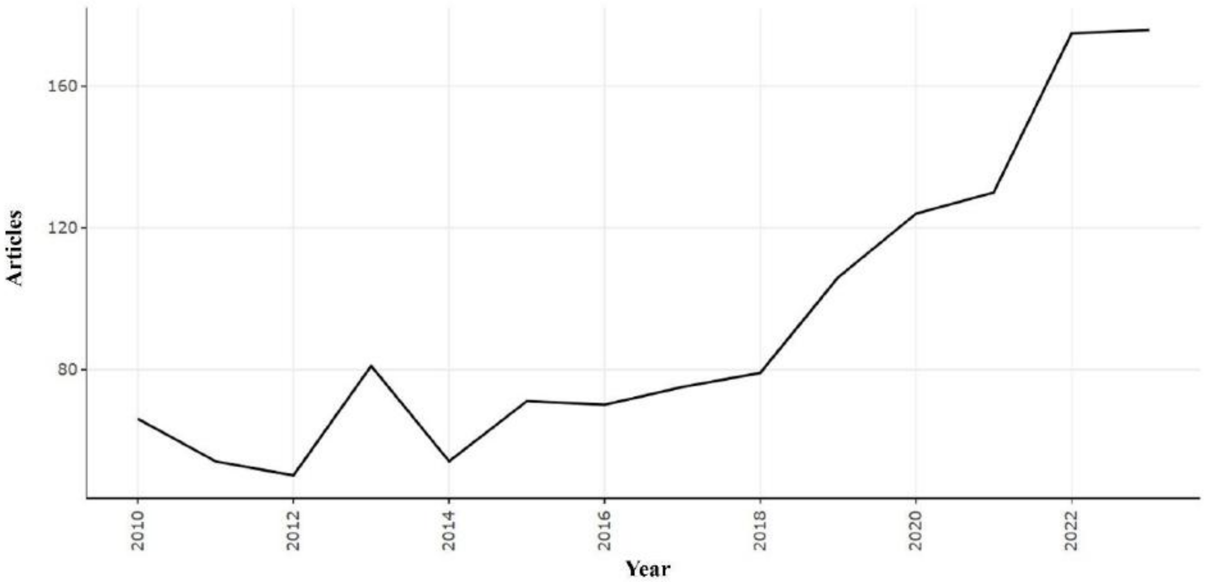
Figure 2 - Number of publications in the final dataset on fruit post-harvest quality using the Scopus database between 2010 and 2023.



Source: Research data.

3.2 *Main authors and institutions*

The Figure 3A illustrates author productivity over time, based on the number of articles published and citations received per year. The results revealed that the authors with the highest number of publications are affiliated with Chinese institutions (Figure 3B). Xuejin Li (Li, X.) and Jiangbo Li (Li, J.) stand out as the most prolific authors with significant citation impact in recent years, particularly in 2021 and 2022. These authors have maintained consistent publication activity over the years, with a notable increase in output from 2019 to 2022. In terms of impact, the dark circles indicate that some of these articles have received a considerable number of citations, especially for Li, X. in 2021 and 2022 (Figure 3A).

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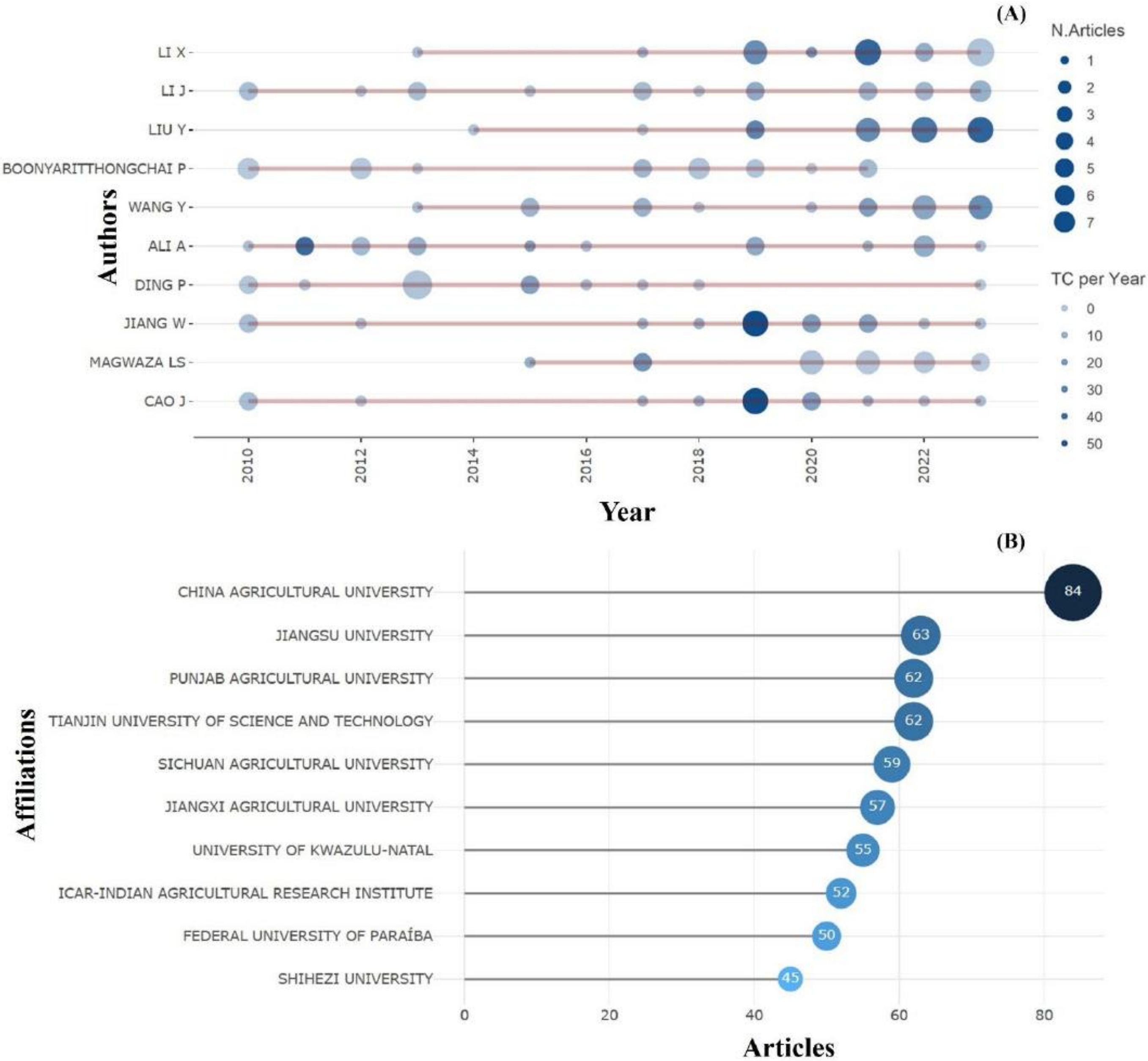
Figure 3 - Authors with the greatest scientific contributions in terms of number of articles and citations per year over time (A) and affiliated institutions with the greatest scientific contributions (B).



Source: Research data.

These findings are further reflected in Figure 3B, which highlights the predominance of Chinese institutions, with China Agricultural University ranking first (84 articles), followed by Jiangsu University (63 articles), Sichuan Agricultural University (59 articles), and Shihezi University (45 articles). This suggests that China has made substantial investments in agricultural research, aligning with its strategy to enhance food security, improve agricultural efficiency, and promote innovations in post-harvest technologies.

The results also highlight the presence of significant Indian universities, such as Punjab Agricultural University and the ICAR - Indian Agricultural Research Institute, underscoring India as another developing country with a strong focus on agricultural innovation, particularly in the area of post-harvest quality preservation for fruits. This emphasis can be attributed to the country's need to reduce food waste and improve distribution chains in a nation with a large population.

Notably, African universities, such as the University of KwaZulu-Natal in South Africa, and the Brazilian institution Federal University of Paraíba also feature in the analysis. This is significant as it reflects Africa's engagement in agricultural research. In African countries, post-harvest innovations are critical for reducing losses and ensuring food security, particularly in rural areas with limited infrastructure. Similarly, Brazil, as one of the world's largest agricultural producers, has a direct interest in advancing post-harvest technologies to maintain its international competitiveness and address challenges such as preserving agricultural products in remote regions.

3.3 *Analysis of journals and sources*

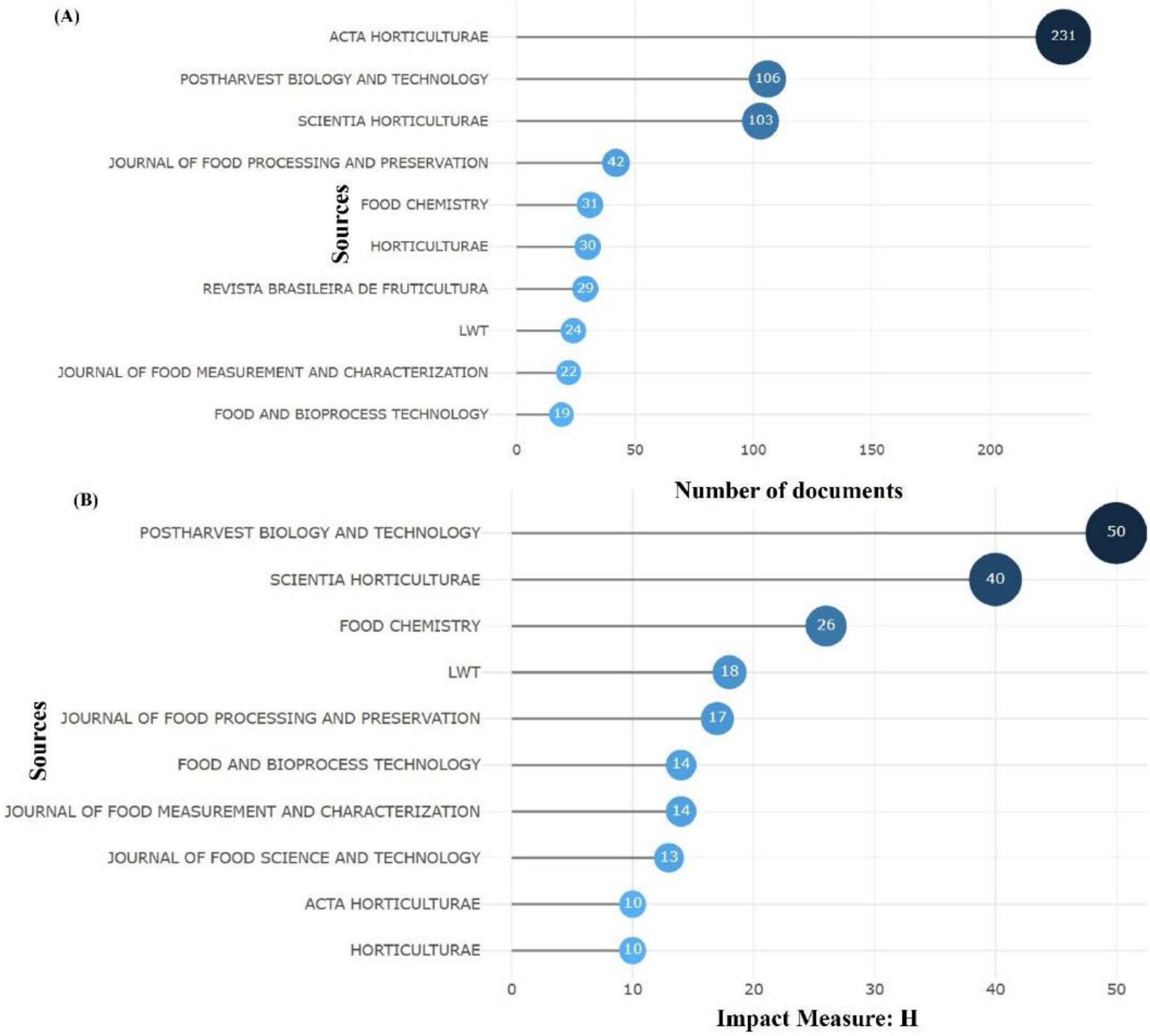
The journal Acta Horticulturae published the highest number of documents (231, Figure 4A) but has a relatively lower citation impact, with an H-index of 11 (Figure 4B). This may indicate that, despite its high volume of publications, the journal generates fewer citations or focuses on topics of lower impact, potentially emphasizing more practical or regional issues. On the other hand, Postharvest Biology and Technology combines a moderate number of publications (100) with the highest citation impact (H=50, Figure 4), suggesting that its articles are widely cited and influential within the scientific community.

The prominence of journals like Postharvest Biology and Technology and Scientia Horticulturae underscores the strong relevance of postharvest biology and technology research, where innovations are vital for reducing food losses and maintaining the quality of agricultural products. The high ranking of postharvest-focused journals in terms of H-index reflects the growing importance of this field, not only in terms of publication volume but also in scientific impact.

Journals such as Food Chemistry and LWT also exhibit significant impact (Figure 4B), highlighting the interdisciplinary nature of postharvest research. This field bridges biological and chemical aspects, food processing, and associated technologies. Additionally, the inclusion of the Brazilian journal Revista Brasileira de Fruticultura demonstrates the importance of regional studies and fruit production research in the global scientific landscape, particularly in fruit-producing countries like Brazil.

These findings emphasize the importance of considering both the volume of publications and citation impact when assessing the scientific relevance of a source. Journals that combine a high number of publications with a strong H-index, such as Postharvest Biology and Technology, are particularly influential in the postharvest research field. The field's interdisciplinary nature, integrating areas such as biology, chemistry, and food processing, is crucial for scientific and technological advancements that can directly impact food security and agricultural efficiency.

Figure 4 - Distribution of documents and impact measures of academic sources in postharvest research. Number of documents published in the main sources (A) and impact measure H of the sources (B).



Source: Research data.

The H-index of a scientific journal is influenced by various factors, including whether its articles are open or closed access. In this context, this can impact the number of citations. Open-access journals tend to have greater reach and visibility, as their content is freely available to the scientific community and the general public, without the need for subscriptions or additional costs. This increases the likelihood of their articles being read, shared, and cited in other publications. On the other hand, closed-access journals, such as Acta Horticulturae, may present significant barriers to access, as they require subscriptions or individual payments per article. These limitations reduce the dissemination of their content and, consequently, the likelihood of being cited in other research.

3.4 *Keywords and focus areas*

Figure 5 shows that the most recent research focuses on post-harvest quality, with an emphasis on coating technologies, the use of antioxidants, and preservation methods such as food additives and enzymatic activity control. These results indicate an evolution in research over the years, with a growing focus on more innovative and sustainable methods to enhance the durability and quality of fruits after harvest. This figure also reveals emerging and future research directions.

Five thematic clusters are presented. Cluster 1 (green) represents research domains associated with post-harvest quality and fruit preservation, highlighting the importance of technologies aimed at maintaining post-harvest quality, such as the use of edible coatings, antioxidants, and food additives. The primary focus is on preserving the visual, sensory, and nutritional quality of fruits, with studies investigating the effectiveness of these treatments in extending the shelf life of fruits.

Cluster 2 (red) includes aspects of fungal control and quality studies, relating to research that investigates methods to maintain post-harvest food quality, with a focus on fungal control. The research includes the use of antifungal agents and the study of chemical compounds to prevent the growth of microorganisms that cause spoilage. This cluster also addresses food microbiology and chemistry. This is more evident in Cluster 3 (yellow), which is composed of the physicochemical properties of fruits and post-harvest handling, such as the impact of handling and storage on post-harvest quality. The use of essential oils to preserve fruits is also a prominent theme, reflecting an interest in natural methods to extend the shelf life of fruits.

Cluster 4 (blue) emphasizes the biochemical aspects of post-harvest preservation, including the role of phenolic compounds, cryopreservation (storage at very low temperatures), and the regulation of enzyme activity, such as superoxide dismutase, which has antioxidant functions. The research here focuses on strategies to maintain quality and increase the longevity of fruits. Finally, Cluster 5 (light blue) highlights the role of bioactive compounds such as flavonoids and antioxidant enzymes in protecting fruits against oxidative stress during the post-harvest period. Studies also focus on markers of deterioration, such as malondialdehyde, and the role of peroxidases in the response to aging.

All clusters are closely interconnected, and from these tightly linked clusters, we can recognize that current research on the post-harvest quality of fruits is multidisciplinary, encompassing areas such as food chemistry, microbiology, biochemistry, and new preservation technologies like essential oils and cryopreservation. The primary focus is on preserving fruit quality, controlling deterioration, and extending shelf life using a combination of natural agents, edible coatings, and storage environment control.

By analyzing the temporal evolution of topics (Figure 5B), it is observed that terms such as "fungi," "harvesting," and "physicochemical property" reflect earlier efforts to understand the basic processes affecting fruit quality after harvest, such as fungal activity and changes in physicochemical properties during storage. Meanwhile, transitional terms like "enzyme activity," "phenol derivative," and "ethanol" indicate an expansion of research to include chemical and biochemical aspects. This transition also reflects a deeper integration of studies on antioxidants and phenolic compounds, which are important for extending the shelf life of fruits. Among the most recent topics, "shelf life," "cryopreservation," "coatings," and "food additives" stand out, emerging prominently from 2020 onward. This analysis reveals a clear evolution in research, shifting from an initial emphasis on basic characteristics and microbiological challenges to more applied and technological approaches, such as the use of coatings and preservation methods. This shift reflects the needs of the agricultural and food sectors, which seek practical solutions to improve quality and reduce post-harvest losses.

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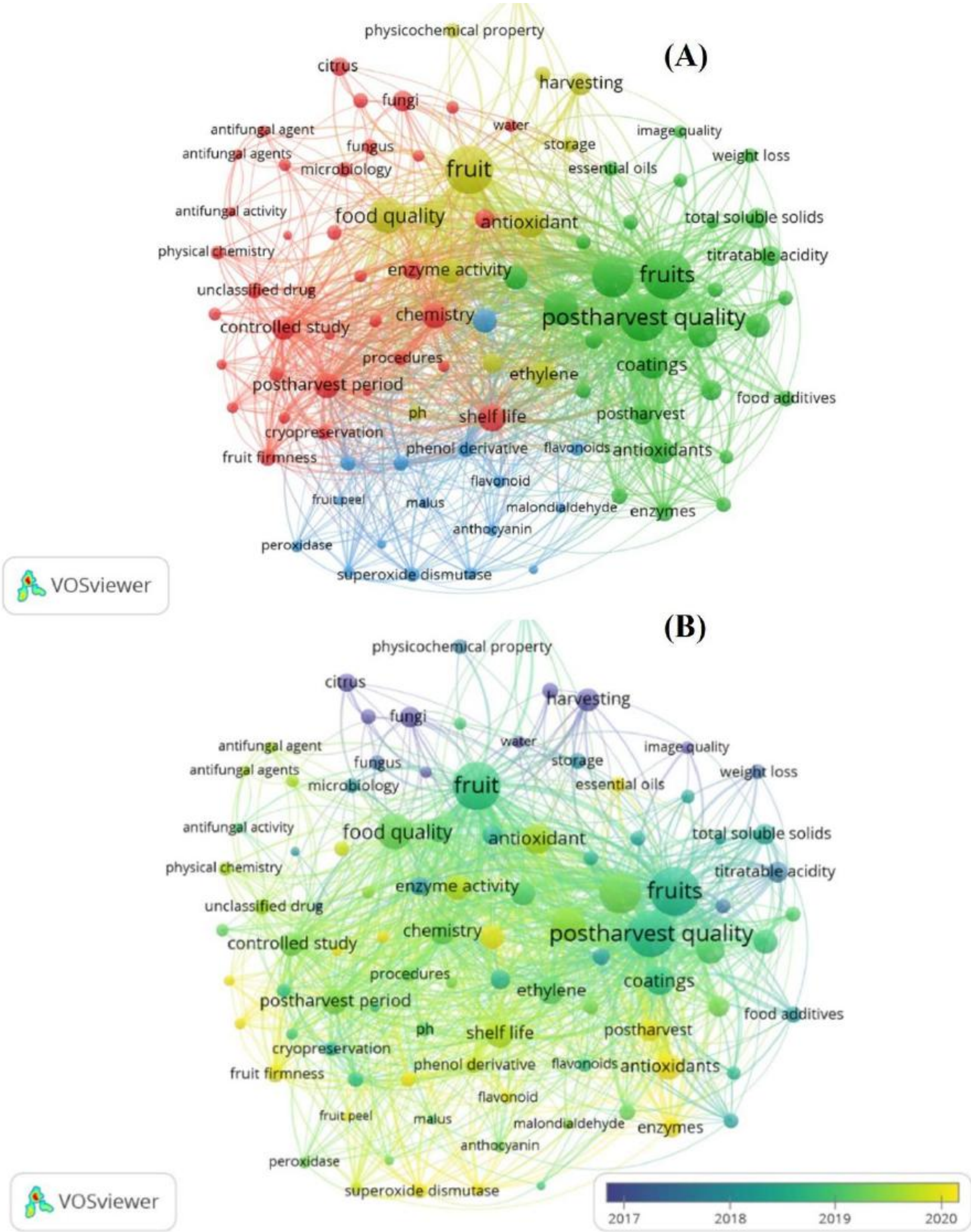
Figure 5 - Overlay visualization map displaying the main keywords in post-harvest quality of fruits from 2010 to 2023 in the Scopus database. (A) Each node represents a keyword, and the size of the node indicates the frequency of the keyword. A larger node signifies a higher occurrence of the keyword. The connection between two keywords indicates the number of times they co-occur. (B) The color scale shows the average publication year of each keyword across all publications containing the keyword.



Source: Research data.

3.5 *Co-authorship networks and collaborations*

When analyzing Figure 6A, China's leadership is evident not only in the volume of publications (SCP) but also in international collaborations (MCP). This data indicates that the country is establishing itself as a global scientific powerhouse, exporting knowledge and collaborating with various nations. It also reflects China's substantial investment in research, particularly in fields such as agriculture and sustainability.

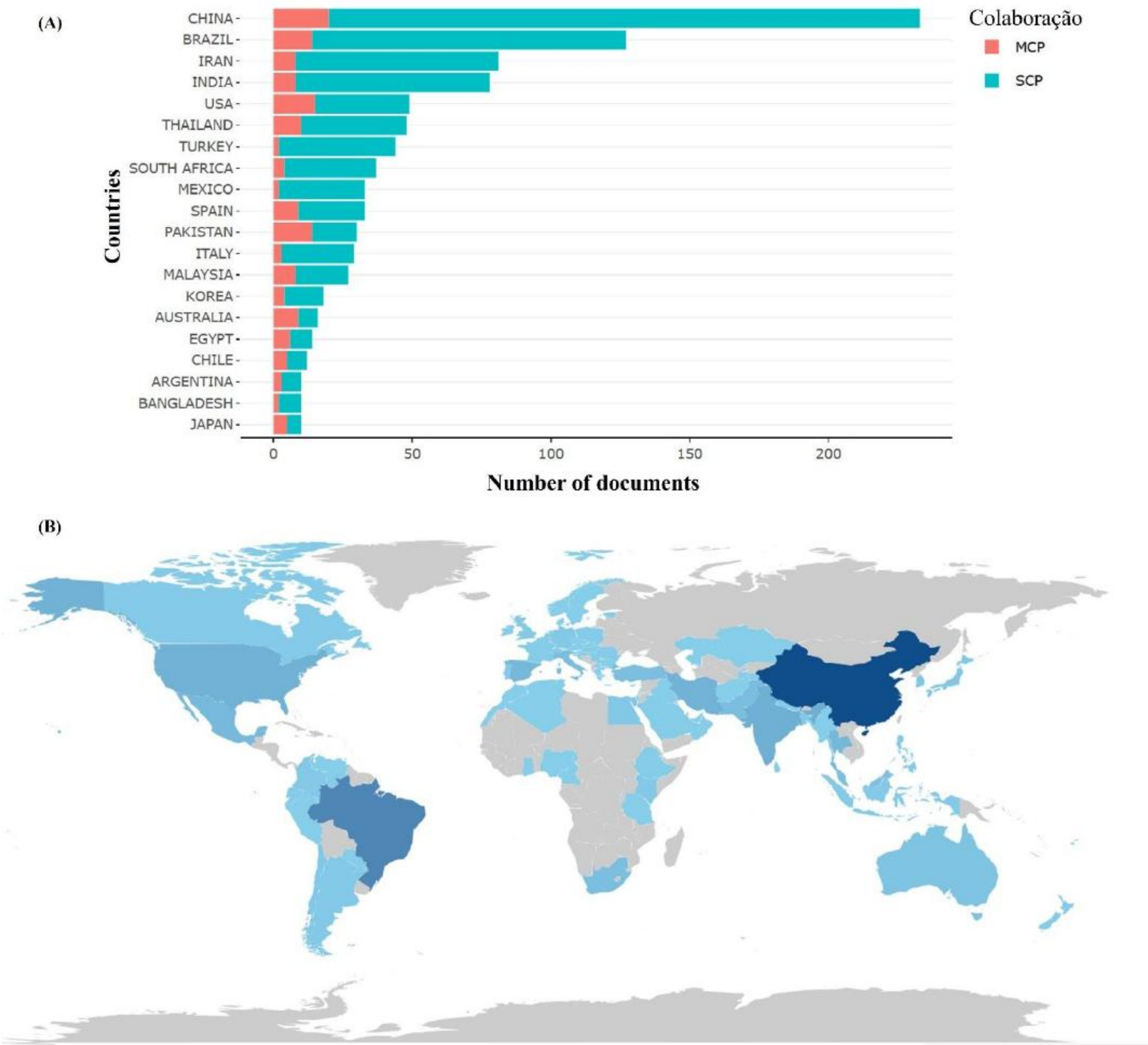
Of particular interest is Brazil's prominence as a regional scientific hub (Figure 6B), with a significant number of publications, primarily conducted locally. This highlights the strength of Brazilian research institutions and their relevance in Latin America. However, the country's lower participation in international collaborations suggests that fostering more global partnerships could further enhance the impact of its scientific output.

On the other hand, countries with a high proportion of MCP publications, such as Argentina, Spain, Pakistan, Malaysia, and Japan, suggest that these nations have prioritized or relied on international collaborations to boost their scientific productivity. Such collaborations are essential for scientific advancement in specific fields, facilitating knowledge exchange and the use of shared infrastructure.

Interestingly, countries like Iran, India, Thailand, and South Africa are emerging as scientific research hubs. While they still engage in fewer international collaborations than more developed nations, they are strengthening their national and regional scientific capacities. Increasing the number of international partnerships could further contribute to sustainable scientific development in these countries.

The findings reported here highlight an inequality in scientific production in the field of post-harvest fruit quality, with research concentrated in certain regions while large parts of Africa, Central America, and some areas of Asia exhibit low output. This reflects economic and infrastructure challenges that hinder scientific research development. These countries could benefit from international cooperation programs and funding initiatives to strengthen their research systems.

Figure 6 - Global collaboration, including countries with a minimum of five documents: (A) a network visualization map of countries based on bibliographic coupling analysis of documents retrieved on research publications by authors from a single country (SCP) and publications resulting from international collaborations involving researchers from multiple countries (MCP) in the Scopus database (2010–2023); and (B) a scientific production map in the field of post-harvest fruit quality, highlighting countries with higher production (in darker shades of blue) and those with lower production (in lighter shades).



Source: Research data.

3.6 ***Global space-time distribution and collaboration networks***

Global collaboration in research on this topic encompassed 39 countries, although publication and collaboration frequencies varied (Figure 7). China and Brazil are at the center of the network, with a high number of international collaborations. This indicates that they are not only leaders in national scientific production but also key facilitators of international partnerships. This may reflect strategic policies aimed at fostering scientific cooperation, particularly in critical areas such as agriculture and sustainability.

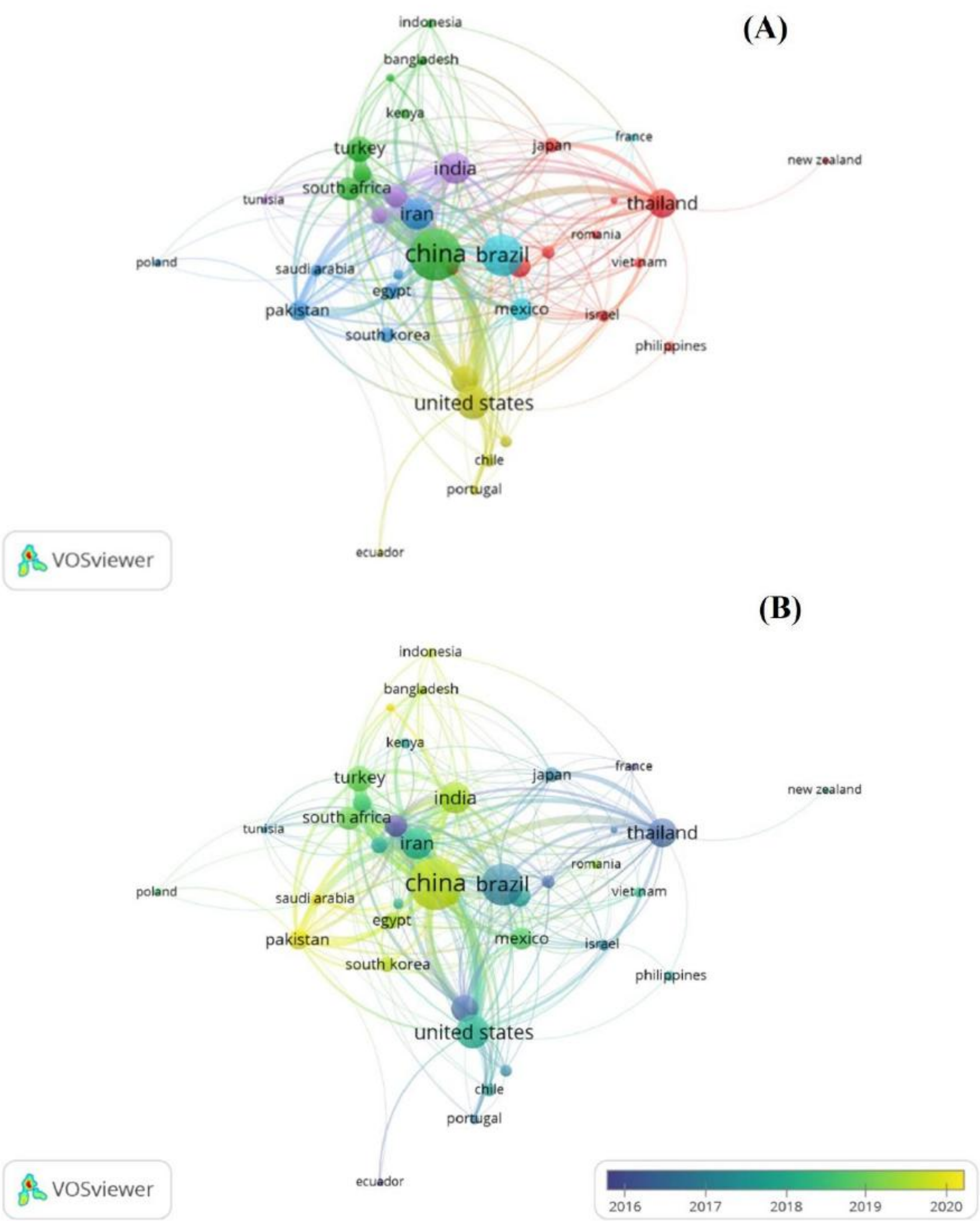
Countries such as Iran, India, Turkey, South Africa, and Thailand have strong connections with other nations in Asia, Latin America, and Africa, suggesting a rise in scientific collaborations in developing regions. This trend may be linked to the growing need to address global challenges, such as food security and climate change, which have a more direct impact on these countries.

The position of the United States in the graph appears somewhat peripheral compared to other central clusters. This may indicate that the country has prioritized scientific collaborations within a more limited network or focused on traditional partners. Such a trend could have implications for the future of global science as other nations emerge as strategic collaboration hubs.

Many of the clusters reflect regional collaborations, such as the group led by Thailand and Japan in Asia or Iran, India, and Turkey in Central Asia. This suggests that scientific collaborations often occur within regional contexts, possibly facilitated by economic and geopolitical agreements. However, countries like Brazil and China have managed to transcend these regional boundaries, establishing themselves os globais hubs.

Figure 7B reveals that collaborations among major countries, particularly China, Brazil, and India, are recent and increasing. This may be linked to recent investments in research and development, shifts in science and technology policies, or emerging global challenges that require more intensive international cooperation, such as climate change and food security.

Figure 7 - Countries with at least 5 articles and more than 10 collaborations (A) network visualization analysis (B) chronological overlap visualization analysis.



Source: Research data.

3.7 *Emerging topics and trends*

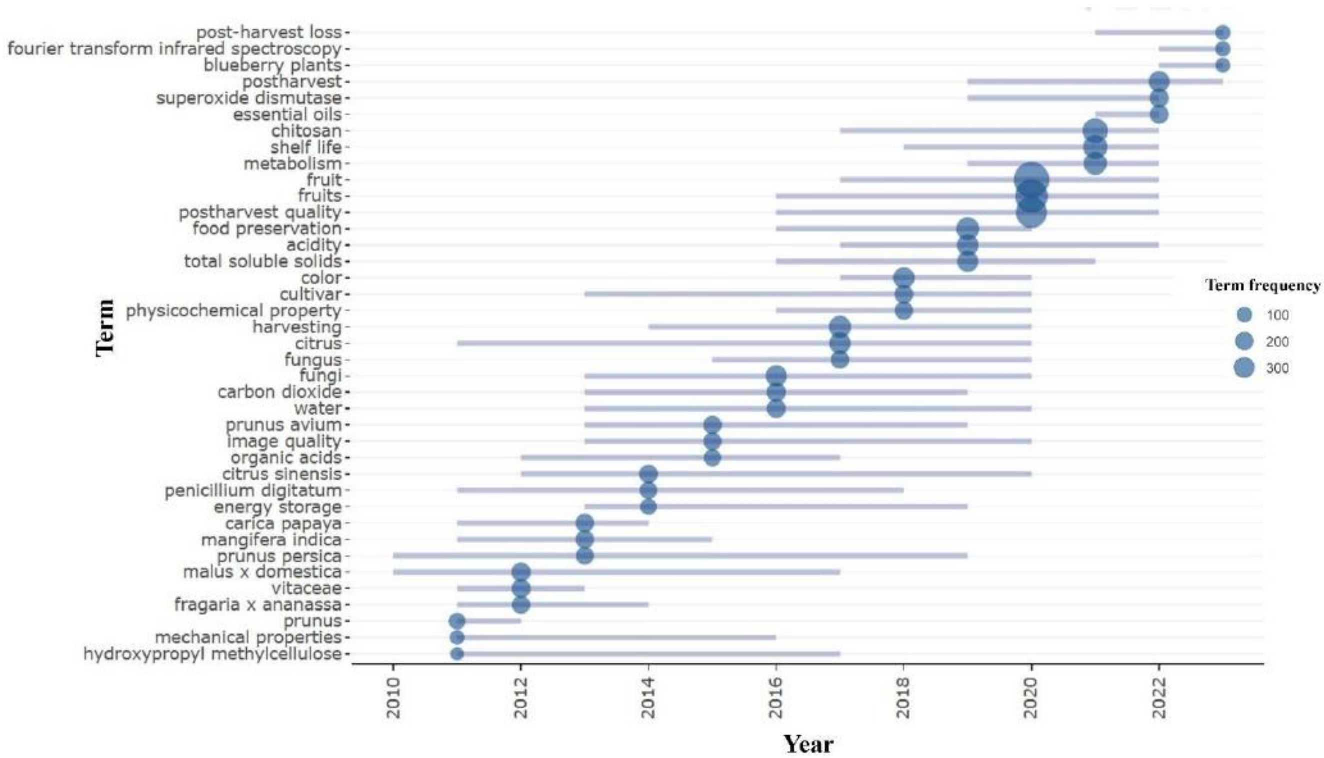
An analysis of Figure 8 reveals that terms such as superoxide dismutase, essential oils, and shelf life began to emerge and gain greater visibility around 2015–2016. More recent terms, such as fungi, physicochemical properties, and post-harvest quality, have been prominent in recent years, indicating a growing trend in these areas. Frequently appearing terms such as fruits, post-harvest quality, and food preservation suggest that these are central areas of interest for research and development.

Terms like acidity and total soluble solids also appear with high frequency, reinforcing their crucial role in post-harvest quality studies, particularly in relation to flavor and consumer acceptability. These physicochemical properties are critical for consumer acceptance, as they directly impact the taste and appearance of products. The frequent occurrence of these terms indicates a continued focus on maintaining sensory quality during storage.

On the other hand, topics such as essential oils, metabolism, and citrus fruits are well-established, as they appear consistently over time. Meanwhile, more technical topics, such as Fourier-transform infrared spectroscopy and hydroxypropyl methylcellulose, though less frequent, emerge in specific years, suggesting advanced technological innovations for monitoring and predicting post-harvest product quality. These advancements enable rapid detection of quality changes, facilitating more effective interventions.

Also from the analysis of Figure 8 and the discussion of Figure 5, it was possible to list the main trends and emerging themes in post-harvest as described in Table 2.

Figure 8 - Analysis of emerging topics in the context of post-harvest quality, based on the frequency and year of appearance of these terms in publications or studies.



Source: Research data.

Table 2 - Emerging themes involving technologies used in fruit preservation and their main results.

Technology	Authors	Journal of publication	Main results observed
Antioxidants	Arabia et al., 2024; Ghifari et al., 2023, Morelli et al., 2023	Postharvest Biology and Technology	Ascorbic acid (AsA) regulates ripening by modulating the cellular redox state, controlling reactive oxygen species (ROS), and effectively preventing damage such as sunburn, internal browning, and superficial scald. Studies have highlighted that maintaining endogenous AsA levels in controlled environments significantly reduces chilling injuries in fruits such as peaches, pears, and bananas.
Edible Coatings	Falguera et al., 2011; Wang et al., 2023; Kocira et al., 2021	Trends in Food Science & Technology	Polysaccharide-based coatings (e.g., chitosan, pectin, cellulose), lipids (natural waxes), and proteins (zein, casein) form barriers against water and oxygen loss while also exhibiting antibacterial properties. Applications on strawberries and apples have demonstrated reduced weight loss and preserved texture and color for up to 14 days of storage.
Essential Oils	Esmaeili et al., 2021; Gonçalves et al., 2021, Seshadri et al., 2020	Journal of Food Measurement and Characterization	Essential oils, such as thyme and oregano, inhibit pathogens like *Botrytis cinerea* and *Colletotrichum* spp., delaying deterioration and extending shelf life. Studies on papayas and strawberries have shown firmness preservation and a reduction in senescence by over 30%.
Food Additives	Ramos-Villarroel et al., 2015; Meneses-Espinosa et al., 2023;	Food Research International	Organic acids, including lactic, citric, and ascorbic acids, lower pH levels and inhibit microbial growth. Applications on fresh-cut fruits, such as melons and pineapples, have maintained sensory quality for up to 10 days.
Enzymatic Activity	Navina et al., 2023; Moon et al., 2020; Khalid et al., 2022	International Journal of Food Properties	Physical techniques such as refrigeration and irradiation have reduced the activity of polyphenol oxidase (PPO), delaying enzymatic browning in apples and potatoes. The use of natural antioxidants and plant extracts has also been effective in preserving color and flavor.
Cryopreservation	Jha et al., 2024; Bonat et al., 2015; Meneses-Espinosa et al., 2023	Applied Food Research	Cryopreservation through supercooling and cryogenic freezing has prevented ice crystal formation in high-water-content fruits, such as mangoes and pineapples, maintaining texture and color for over six months.
Ethylene Control	Pongprasert et al., 2018; Alonso-Salinas et al., 2023; Büchele et al., 2023	Postharvest Biology and Technology	1-MCP has reduced ethylene activity in climacteric fruits, maintaining apple firmness for up to 90 days. Modified atmosphere packaging has decreased ethylene production, preserving the sensory quality of bananas and tomatoes.

Source: Research data

3.8 Top 20 most cited articles globally

An analysis of Table 3 reveals that the most globally cited articles focus on natural, low-toxicity alternatives, such as the use of *Aloe vera* and essential oils. This reflects consumer demand for sustainable solutions and alternatives to conventional chemical products, aligning with the growing preference for healthier foods with fewer pesticide residues.

Typically, the use of coatings such as chitosan, *Aloe vera*, gum arabic, and alginate is combined with other antimicrobial or antioxidant compounds. These coatings help extend the shelf life of fruits by maintaining their physical quality, reducing water loss, and inhibiting the growth of pathogenic microorganisms.

Table 3 - Top 20 highly cited articles in the field of post-harvest fruit quality research.

Title	Authors	Journal	TC	TC/ano
Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage	Ali et al., 2011	Food Chemistry	365	26,07
Antimicrobial edible films and coatings for fresh and minimally processed fruits and vegetables: A review	Valencia-Chamorro et al., 2011	Critical Reviews in Food Science and Nutrition	254	18,14
Postharvest quality of apple predicted by NIR-spectroscopy: Study of the effect of biological variability on spectra and model performance	Bobelyn et al., 2010	Postharvest Biology and Technology	254	16,93
Effect of chitosan and alginate based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava (*Psidium guajava* L.)	Nair et al., 2018	Food Chemistry	249	35,57
Effect of chitosan–*Aloe vera* coating on postharvest quality of blueberry (*Vaccinium corymbosum*) fruit	Vieira et al., 2016	Postharvest Biology and Technology	249	27,67
The fruit cuticle as a modulator of postharvest quality	Lara et al., 2014	Postharvest Biology and Technology	236	21,45
Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review	Moretti et al., 2010	Food Research International	236	15,73
Effects of carboxymethyl cellulose and chitosan bilayer edible coating on postharvest quality of citrus fruit	Arnon et al., 2014	Postharvest Biology and Technology	204	18,55
Postharvest application of gum arabic and essential oils for controlling anthracnose and quality of banana and papaya during cold storage	Maqbool et al., 2011	Postharvest Biology and Technology	198	14,14
Effect of chitosan and chitosan-nanoparticles on post harvest quality of banana fruits	Lustriane et al. 2018	Journal of Plant Biotechnology	191	27,29
Effect of gum arabic coating combined with calcium chloride on physico-chemical and qualitative properties of mango (*Mangifera indica* L.) fruit during low temperature storage	Khaliq et al., 2015	Scientia Horticulturae	167	16,70
Effect of molecular weights of chitosan coating on postharvest quality and physicochemical characteristics of mango fruit	Jongsri et al., 2016	LWT	158	1,56
Effects of chitosan/nano-silica on postharvest quality and antioxidant capacity of loquat fruit during cold storage	Song et al., 2016	Postharvest Biology and Technology	153	17,00
Effects of cuticular wax on the postharvest quality of blueberry fruit	Chu et al., 2018	Food Chemistry	144	20,57
Inhibitory effect of salicylic acid and *Aloe vera* gel edible coating on microbial load and chilling injury of orange fruit	Rasouli et al., 2019	Scientia Horticulturae	142	23,67
Hyperspectral near-infrared imaging for the detection of physical damages of pear	Lee et al., 2014	Journal of Food Engineering	141	12,82
Early detection of mechanical damage in mango using NIR hyperspectral images and machine learning	Rivera et al., 2014	Biosystems Engineering	140	12,73
The effect of alginate-based edible coatings enriched with essential oils constituents on *Arbutus unedo* L. fresh fruit storage	Guerreiro et al., 2015	Postharvest Biology and Technology	139	13,90
A starch edible surface coating delays banana fruit ripening	Thakur et al., 2019	LWT	135	22,50
Application of biocomposite edible coatings based on pea starch and guar gum on quality, storability and shelf life of ‘Valencia’ oranges	Saberi et al. 2018	Postharvest Biology and Technology	133	19,00

TC - Total citations. Source: Research data.

Other highlights from Table 3 includes the works of Valencia-Chamorro et al., 2011 and Ali et al., 2011, which demonstrate that edible coatings influence physicochemical characteristics such as texture, color, and firmness—qualities that are essential for consumer acceptance. From a postharvest quality perspective, focusing on physicochemical attributes is crucial, as characteristics like texture and color are the primary indicators of freshness perceived by consumers. Maintaining these traits helps extend shelf life and reduce waste.

With 254 and 140 citations, respectively, the studies by Bobelyn et al., 2010 and Rivera et al., 2014 focus on advanced technologies such as NIR spectroscopy and hyperspectral imaging, which enable non-destructive quality assessments of fruits. These methods allow the detection of physical damage or early deterioration without compromising the product. The introduction of such technologies can enhance the efficiency of postharvest quality control, reduce losses, and ensure higher-quality products reach the market.

Finally, the work of Moretti et al., 2010, with 236 citations, explores the impact of climate change on the postharvest quality of fruits and vegetables. Rising temperatures and changes in precipitation patterns are expected to create greater challenges in maintaining postharvest quality, as these factors influence ripening and susceptibility to diseases. This perspective highlights the need for new technologies and strategies for mitigation and adaptation to address challenges posed by climate change. Such technologies include the development of more efficient storage and preservation methods to minimize the adverse effects of temperature and humidity fluctuations. Additionally, climate-adapted postharvest management strategies, such as using more resilient cultivars and disease control techniques that are less reliant on chemical products, are essential to maintaining product quality throughout the supply chain.

4. Conclusion

The bibliometric analysis encompassed 1,311 publications from 2010 to December 2023, highlighting the most frequent terms associated with fruit postharvest, such as "postharvest quality," "edible coatings," "antioxidants," and "shelf life." These topics reflect the growing focus on sustainable technologies aimed at extending fruit durability while preserving sensory and nutritional attributes.

Among the most cited journals with the highest publication volumes, Postharvest Biology and Technology and Scientia Horticulturae stood out. These journals combine a significant number of published articles with high impact factors, underscoring their relevance in disseminating innovative and applied research in the field of postharvest conservation.

In terms of the most researched areas, the primary focus lies in agricultural and biological sciences, with strong integration across disciplines such as chemistry, biotechnology, and food technology. Recent advancements have centered on the development of methods and technologies for fruit preservation, emphasizing edible coatings, natural antioxidants, and microbial control. These advancements directly contribute to reducing postharvest losses and increasing the sustainability of agricultural supply chains.

The most impactful articles were published in high-citation journals, including Food Chemistry and Critical Reviews in Food Science and Nutrition. These studies highlighted technological innovations such as the use of biosensors and essential oils, reflecting a demand for practical and cost-effective solutions to address global challenges like food security and climate change.

Lastly, this analysis emphasized the critical role of international collaborations, led by countries like China and Brazil, in advancing the field. Despite significant progress, challenges remain regarding the implementation of these technologies in developing countries, underscoring the need for public policies and accessible solutions for small-scale farmers. Future studies should explore integrated strategies that align sustainability, technological innovation, and socio-economic impacts, promoting a more resilient and efficient food supply chain.

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References

Ali, A., Chin, L. H., Ibrahim, M. H., Mahmud, T. M. M., Yusof, Y. A., & Ghaffar, M. A. (2011). Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage. *Food Chemistry, 124*(2), 620–626. https://doi.org/10.1016/j.foodchem.2010.06.085.

Alonso-Salinas, R., Mendoza-Torres, D., González-Aguilar, G. A., Pacheco-Aguilar, R., & Martínez-Téllez, M. A. (2023). Effect of potassium permanganate, ultraviolet radiation and titanium oxide as ethylene scavengers on preservation of postharvest quality and sensory attributes of broccoli stored with tomatoes. *Foods, 12*(12), 2418. https://doi.org/10.3390/foods12122418.

Arabia, A., Munné-Bosch, S., & Muñoz, P. (2024). Ascorbic acid as a master redox regulator of fruit ripening. *Postharvest Biology and Technology, 207*, 112614. https://doi.org/10.1016/j.postharvbio.2023.112614.

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007.

Arnon, H., Granit, R., Porat, R., & Poverenov, E. (2014). Effects of carboxymethyl cellulose and chitosan bilayer edible coating on postharvest quality of citrus fruit. *Postharvest Biology and Technology, 87*, 21–26. https://doi.org/10.1016/j.postharvbio.2013.08.007.

Bancal, V., & Ray, R. C. (2023). *Fruits and vegetable wastes: Valorization to bioproducts and platform chemicals*. Springer. https://doi.org/10.1007/978-981-16-9528-5.

Baswal, A. K., & Ramezanian, A. (2020). 1-Methylcyclopropene potentials in maintaining the postharvest quality of fruits, vegetables, and ornamentals: A review. *Journal of Food Processing and Preservation, 45*(1), e15129. https://doi.org/10.1111/jfpp.15129.

Bobbelyn, E., Hertog, M. L. A. T. M., & Nicolai, B. M. (2010). Postharvest quality of apple predicted by NIR-spectroscopy: Study of the effect of biological variability on spectra and model performance. *Postharvest Biology and Technology, 55*(3), 133–143. https://doi.org/10.1016/j.postharvbio.2009.09.006.

Bonat, C. G., Ghanem, A., & Su-Ling, B. M. (2015). Influence of freezing process and frozen storage on the quality of fruits and fruit products. *Food Reviews International, 32*(3), 280–304. https://doi.org/10.1080/87559129.2015.1075212.

Büchele, F., Hassenberg, K., Geyer, M., Herppich, W. B., & Blanke, M. (2023). Dynamic control of atmosphere and temperature based on fruit CO_2 production: Practical application in apple storage and effects on metabolism, quality, and volatile profiles. *Food and Bioprocess Technology, 16*(11), 2497–2510. https://doi.org/10.1007/s11947-023-03079-0.

Chu, W., Gao, H., Fang, X., & Zheng, Y. (2018). Effects of cuticular wax on the postharvest quality of blueberry fruit. *Food Chemistry, 239*, 68–74. https://doi.org/10.1016/j.foodchem.2017.06.024.

Esmaeili, Y., Alizadeh, M., Barzegar, M., & Sahari, M. A. (2021). Essential oils as natural antimicrobial agents in postharvest treatments of fruits and vegetables: A review. *Journal of Food Measurement and Characterization, 16*(1), 507–522. https://doi.org/10.1007/s11694-021-01178-0.

Falguera, V., Quintero, J. P., Jiménez, A., Muñoz, J. A., & Ibarz, A. (2011). Edible films and coatings: Structures, active functions and trends in their use. *Trends in Food Science & Technology, 22*(6), 292–303. https://doi.org/10.1016/j.tifs.2011.02.004.

Food and Agriculture Organization of the United Nations (FAO). (2023). *Food security and nutrition around the world.* Retrieved November 4, 2024, from https://www.fao.org/3/cc3017en/online/state-food-security-and-nutrition-2023/food-security-nutrition-indicators.html.

Gonçalves, D. da C., et al. (2021). Recent advances and future perspective of essential oils in control *Colletotrichum* spp.: A sustainable alternative in postharvest treatment of fruits. *Food Research International, 150*, 110758. https://doi.org/10.1016/j.foodres.2021.110758.

Gouda, M. H. B., & Duarte-Sierra, A. (2024). An overview of low-cost approaches for the postharvest storage of fruits and vegetables for smallholders, retailers, and consumers. *Horticulturae, 10*(8), 803. https://doi.org/10.3390/horticulturae10080803.

Ghifari, A. S., Saha, S., & Murcha, M. W. (2023). The biogenesis and regulation of the plant oxidative phosphorylation system. *Plant Physiology, 192*(2), 728–747. https://doi.org/10.1093/plphys/kiad108.

Guerreiro, A. C., et al. (2015). The effect of alginate-based edible coatings enriched with essential oils constituents on *Arbutus unedo* L. fresh fruit storage. *Postharvest Biology and Technology, 100*(1), 226–233. https://doi.org/10.1016/j.postharvbio.2014.09.002.

Jha, P. K., et al. (2024). Can cryogenic freezing preserve the quality of fruit matrices during long-term storage compared to the mechanical method? *Applied Food Research, 4*(1), 100374. https://doi.org/10.1016/j.afres.2023.100374.

Jongsri, P., et al. (2016). Effect of molecular weights of chitosan coating on postharvest quality and physicochemical characteristics of mango fruit. *LWT, 73*(1), 28–36. https://doi.org/10.1016/j.lwt.2016.05.038.

Khalid, M. A., et al. (2022). Edible coatings for enhancing safety and quality attributes of fresh produce: A comprehensive review. *International Journal of Food Properties, 25*(1), 1817–1847. https://doi.org/10.1080/10942912.2022.2107005.

Khaliq, G., et al. (2015). Effect of gum arabic coating combined with calcium chloride on physico-chemical and qualitative properties of mango (*Mangifera indica* L.) fruit during low temperature storage. *Scientia Horticulturae, 190*(1), 187–194. https://doi.org/10.1016/j.scienta.2015.04.020.

Kocira, A., et al. (2021). Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality: A review. *Agronomy, 11*(5), 813. https://doi.org/10.3390/agronomy11050813.

Lara, I., Belge, B., & Goulao, L. F. (2014). The fruit cuticle as a modulator of postharvest quality. *Postharvest Biology and Technology, 87*(1), 103–112. https://doi.org/10.1016/j.postharvbio.2013.08.012.

Lee, W. H., et al. (2014). Hyperspectral near-infrared imaging for the detection of physical damages of pear. *Journal of Food Engineering, 130*(1), 1–7. https://doi.org/10.1016/j.jfoodeng.2013.12.032.

Lustriane, C., et al. (2018). Effect of chitosan and chitosan-nanoparticles on postharvest quality of banana fruits. *Journal of Plant Biotechnology, 45*(1), 36–44. https://doi.org/10.5010/jpb.2018.45.1.036.

Makule, E., Dimoso, N., & Tassou, S. A. (2022). Precooling and cold storage methods for fruits and vegetables in Sub-Saharan Africa – A review. *Horticulturae, 8*(9), 776. https://doi.org/10.3390/horticulturae8090776.

Maqbool, M., et al. (2011). Postharvest application of gum arabic and essential oils for controlling anthracnose and quality of banana and papaya during cold storage. *Postharvest Biology and Technology, 62*(1), 71–76. https://doi.org/10.1016/j.postharvbio.2011.04.002.

Meneses-Espinosa, E., et al. (2023). Advantages and disadvantages of using emerging technologies to increase postharvest life of fruits and vegetables. *Food Reviews International, 40*(5), 1348–1373. https://doi.org/10.1080/87559129.2023.2212061.

Moon, K. M., et al. (2020). Recent trends in controlling the enzymatic browning of fruit and vegetable products. *Molecules, 25*(12), 2754. https://doi.org/10.3390/molecules25122754.

Morelli, L., et al. (2023). Novel insights into the contribution of plastoglobules and reactive oxygen species to chromoplast differentiation. *New Phytologist, 237*(5), 1696–1710. https://doi.org/10.1111/nph.18585.

Moretti, C. L., et al. (2010). Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review. *Food Research International, 43*(7), 1824–1832. https://doi.org/10.1016/j.foodres.2009.10.013.

Nair, M. S., Saxena, A., & Kaur, C. (2018). Effect of chitosan and alginate-based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava (*Psidium guajava* L.). *Food Chemistry, 240*(1), 245–252.

Navina, B., et al. (2023). Insights into recent innovations in anti-browning strategies for fruit and vegetable preservation. *Trends in Food Science & Technology, 139*(1), 104128. https://doi.org/10.1016/j.tifs.2023.104128.

Pongprasert, N., Srilaong, V., & Kaewsukseang, S. (2018). 1-MCP micro-bubbles delaying postharvest ripening of "Khai" banana. *Acta Horticulturae, 1213*, 245–250. https://doi.org/10.17660/ActaHortic.2018.1213.34.

Ramos-Villarroel, A. Y., Martín-Belloso, O., & Soliva-Fortuny, R. (2015). Combined effects of malic acid dip and pulsed light treatments on the inactivation of *Listeria innocua* and *Escherichia coli* on fresh-cut produce. *Food Control, 52*, 112–118. https://doi.org/10.1016/j.foodcont.2014.12.020.

Rasouli, M., Koushesh Saba, M., & Ramezanian, A. (2019). Inhibitory effect of salicylic acid and Aloe vera gel edible coating on microbial load and chilling injury of orange fruit. *Scientia Horticulturae, 247*, 27–34. https://doi.org/10.1016/j.scienta.2018.12.004.

Rivera, N. V., et al. (2014). Early detection of mechanical damage in mango using NIR hyperspectral images and machine learning. *Biosystems Engineering, 122*(1), 91–98. https://doi.org/10.1016/j.biosystemseng.2014.03.009.

Rizzo, M., et al. (2023). Fruit ripeness classification: A survey. *Artificial Intelligence in Agriculture, 7*(1), 44–57. https://doi.org/10.1016/j.aiia.2023.02.004.
Saberi, B., et al. (2018). Application of biocomposite edible coatings based on pea starch and guar gum on quality, storability and shelf life of 'Valencia' oranges. *Postharvest Biology and Technology, 137*, 9–20. https://doi.org/10.1016/j.postharvbio.2017.11.003.

Seshadri, V. D., et al. (2020). Essential oils of *Cinnamomum loureirii* and *Evolvulus alsinoides* protect guava fruits from spoilage bacteria, fungi and insect (*Pseudococcus longispinus*). *Industrial Crops and Products, 154*, 112629. https://doi.org/10.1016/j.indcrop.2020.112629.

Singh, V., et al. (2014). Postharvest technology of fruits and vegetables: An overview. *Journal of Postharvest Technology, 2*(2), 124–135.

Song, H., et al. (2016). Effects of chitosan/nano-silica on postharvest quality and antioxidant capacity of loquat fruit during cold storage. *Postharvest Biology and Technology, 119*, 41–48. https://doi.org/10.1016/j.postharvbio.2016.04.015.

Thakur, R., et al. (2019). A starch edible surface coating delays banana fruit ripening. *LWT, 100*, 341–347. https://doi.org/10.1016/j.lwt.2018.10.055.

Valencia-Chamorro, S. A., et al. (2011). Antimicrobial edible films and coatings for fresh and minimally processed fruits and vegetables: A review. *Critical Reviews in Food Science and Nutrition, 51*(9), 872–900. https://doi.org/10.1080/10408398.2010.485705.

Vieira, J. M., et al. (2016). Effect of chitosan – Aloe vera coating on postharvest quality of blueberry (*Vaccinium corymbosum*) fruit. *Postharvest Biology and Technology, 116*, 88–97. https://doi.org/10.1016/j.postharvbio.2016.01.011.

Vinod, B. R., et al. (2023). Recent advances in physical treatments of papaya fruit for postharvest quality retention: A review. *Efood, 4*(2), 1–18. https://doi.org/10.1002/efd2.79.

Wang, X., et al. (2023). Biological control efficacy of *Bacillus licheniformis* HG03 against soft rot disease of postharvest peach. *Food Control, 145,* 109402. https://doi.org/10.1016/j.foodcont.2022.109402.

Yeshiwas, Y., & Tadele, E. (2021). An investigation into major causes for postharvest losses of horticultural crops and their handling practice in Debre Markos, North-Western Ethiopia. *Advances in Agriculture, 2021*, 1985303. https://doi.org/10.1155/2021/1985303.