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*Review*

## **A bibliometric review of *Persea americana* Mill. (Lauraceae): A green gold in agroindustry**

**Rahimah Zakaria<sup>1,\*</sup>, Patricia Vit<sup>2</sup>, Adi Wijaya<sup>3</sup>, Asma Hayati Ahmad<sup>1</sup>, Zahiruddin Othman<sup>4</sup> and Bruno Mezzetti<sup>5</sup>**

<sup>1</sup> Department of Physiology, School of Medical Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Malaysia

<sup>2</sup> Food Science Department, Faculty of Pharmacy, Universidad de Los Andes, Merida 5101, Venezuela

<sup>3</sup> Department of Health Information Management, Universitas Indonesia Maju, Jakarta, Indonesia

<sup>4</sup> Department of Psychiatry, School of Medical Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Malaysia

<sup>5</sup> Department of Agricultural, Food and Environmental Sciences, Università Politecnica delle Marche, Ancona, Italy

\* **Correspondence:** Email: [rahimah@usm.my](mailto:rahimah@usm.my); Tel: +6097676156; Fax: +6097653370.

**Abstract:** Avocado's global acceptance has grown, resulting in expanding cultivation, agricultural development, and significant marketing efforts. Publicizing avocado also targets its by-products' nutritional and functional benefits. This is the first bibliometric analysis for avocado. It aims to provide a descriptive structure to identify collaborative patterns and emerging themes in avocado research. Based on the search string used in the article title, the study retrieved 2576 documents from the Scopus database for further analysis. For comparison, we separated the data into two study periods: 1916–2011 and 2012–2021. BibliometriX and VOSviewer software were used to examine the descriptive structure and collaborative patterns, as well as to create maps based on network data. When we compared the two study periods, we identified a changing pattern in descriptive structure, collaboration and research trends. Based on the identified emergent themes of the last decade, we propose that future research focuses on the functional and medicinal properties of avocado, postharvest management and its biological control, plant cultivars and diseases, and physicochemical properties of avocado and its by-products. Further bibliographic support revealed that, in addition to the fruit pulp, non-edible parts of *Persea americana* (bark, leaves, peel, seeds, and stem), and oil have remarkable concentrations of bioactive compounds with potential biological activity for health benefits.

**Keywords:** avocado; *Persea americana*; bibliometric analysis; BibliometriX; VOSviewer

## 1. Introduction

Avocado (*Persea americana* Mill.) is an evergreen tree of the Lauraceae family native to Mexico and Guatemala. Three avocado races (1. *Persea americana* var. *guatemalensis* Williams from Guatemala, 2. *Persea americana* var. *drymifolia* Blake from Mexico, and 3. *Persea americana* var. *americana* Mill. from Guatemala) [1] are the putative origin of the genus *Persea*, a germplasm with more than 150 species, almost half of which grow in tropical and subtropical America [2]. Mexico is the world's largest avocado producer, with an annual production of 2,184,663 tonnes [3]. This is followed by the Dominican Republic (644,306 tonnes), Peru (504,517 tonnes), Indonesia (410,094 tonnes), Colombia (326,666 tonnes) and Brazil (235,788 tonnes) [4].

The worldwide consumption of avocado has been increasing, causing agricultural expansion, and extensive marketing promoting relevant nutritional benefits of this traditional food. Because of their high global demand and lucrative business, avocados are also referred to as “green gold.” There is a sensory impact of the avocado flavor, but textural properties were driving fruit liking [5]. Keto diets with avocado stand for cognitive health [6,7], and mashed avocado fat replacement is proposed for nutritional benefits [8]. Mexican guacamole (a Spanish word derived from the Nahuatl's 'ahuacatl' avocado and 'mulli' sauce) is the iconic shiny green dip based on ripe avocado pulp, which is rich in proteins and oil. Fresh guacamole is popular in ethnic and vegetarian restaurants. Successful local brands of guacamole were developed for supermarkets.

Exploiting the phytochemical content of avocado by-products, including seeds and peel, will increase the value of the avocado industry and could result in the development of new products [9]. A recent review on the production, composition and applications of avocado focused on its by-products [10]: with applications on dietary inclusions proposed for goats [11] and pigs [12]. The antibacterial activity and toxicity were studied in four Brazilian cultivars [13]. Bioactive molecules were extracted by ultrasound from the avocado peel for food and nutraceutical applications [14]. Additionally, crop residues were burned for nutrient recovery [15].

It is also worth mentioning that the rising trend in avocado consumption over the past few decades has had detrimental effects on the environment and socioeconomic impacts in many countries [16]. In many parts of the world, where irrigated agriculture uses 70% of the world's water [17], overexploitation of freshwater resources has detrimental effects on food production and humanity [18]. In addition, illegal avocado farming causes increasing and uncontrolled deforestation in Mexico [19]. Deforestation promotes year-round warming in the tropics and summer warming in higher latitudes [20]. This climate change affects temperature, water resources, pests and pollination, which have direct impacts on crops, including avocado production [21].

The agro-industrial growth of avocado has caused a sharp rise in research on the fruit and its by-products. This review provides a structured bibliometric analysis that carefully examines the evolution and recent trends in avocado research during the last ten years (2012–2021), and were further compared to earlier years (1916–2011) using the Scopus database. This study aimed to establish a descriptive structure via content analysis for documents, authors, institutions, countries and journals, as well as to identify the collaboration patterns via co-authorship analysis of authors and countries. A keyword analysis was performed to identify major research themes and emerging trends in order to recommend

future avocado research utilizing data from the previous decade.

## 2. Materials and methods

### 2.1. Search Strategy

An exhaustive literature search was performed using the Scopus database, which is considered one of the most important and complete collections of scientific materials globally [22,23]. Our search was based on PRISMA guidelines [24], as shown in Figure 1. The search term avocado OR “*Persea americana*” has been used to search relevant articles related to research on avocado in the title of the article. All the searches and document retrieval were conducted on December 27, 2021. These documents were screened to exclude some documents based on our search criteria that include articles published in journals only in the English language (Figure 1). We have included only original articles, which are the primary source, and not included other document types such as review articles, books or book chapters, which are typically secondary sources.

The study of diverse organs of the avocado plant was further analyzed by adding them to the search string. Additional searches were done separately using wildcards as needed for each part of the plant (bark\*, fru\*, lea\*, peel, seed\*, stem), and oil. These were also done for bioactive (antimicrobial, antioxidant\*, nutr\*, cytotoxic, phenol\*, polyphenol\*), and sensory (sensor\* and volatil\*) properties.

### 2.2. Data analysis

For data analysis, a total of 2576 documents from the years 1916–2021 obtained from the search were downloaded in CSV format. The data were divided into two categories (study periods) based on the distribution of the publications: 1916 to 2011, and the last decade, 2012 to 2021. The purpose of this is to address the aforementioned aims by looking at the evolution of trends.

All of the documents were subjected to bibliometric analysis using R package Bibliometrix [25] and VOSviewer version 1.6.17 [26] to analyze, create and visualize bibliometric networks. All the software tools are free to download and use, and they are effective in performing the bibliometric analysis [27].

## 3. Results

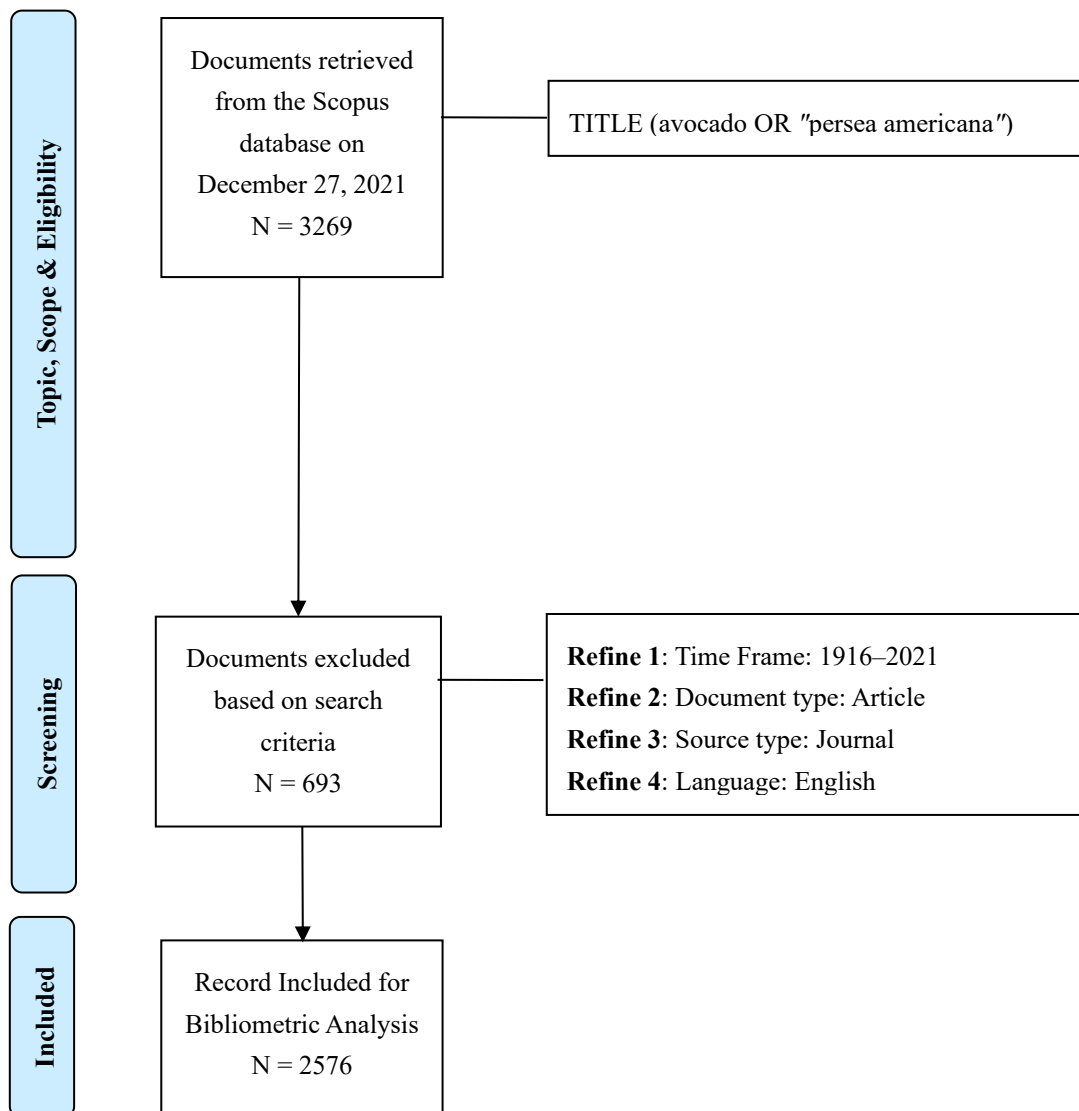
### 3.1. Annual publication trends

The annual publishing patterns of avocado research are depicted in Figure 2. The first document was published in 1916, and while there were initially few publications, the number gradually increased to two digits in the 1970s until 2015, and then to three digits starting from 2016 and onwards. In the last decade, there was an impressive growth in total publications on avocado, from 79 to 261.

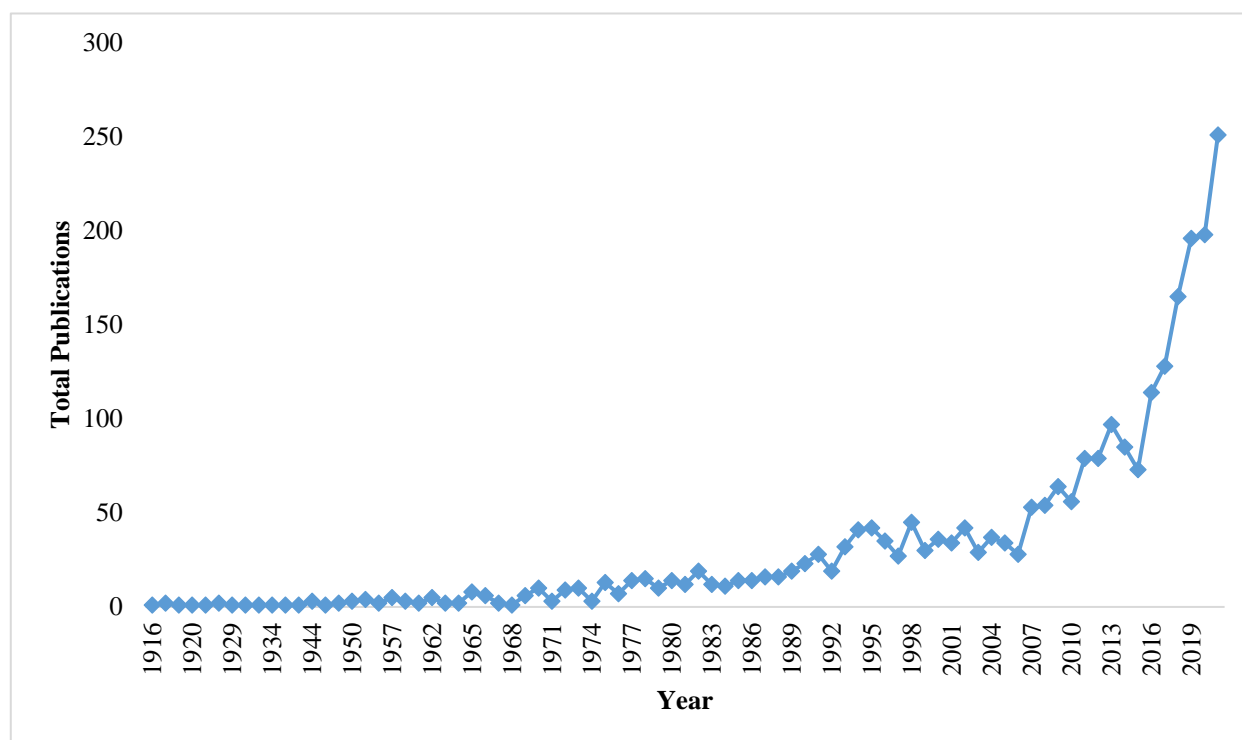
### 3.2. Main information of the retrieved document

The major information about the retrieved documents is presented in Table 1. The Scopus database yielded a total of 2576 documents published from 1916 to 2021. Between 2012 and 2021,

there were more documents published than between 1916 and 2011. Other data, such as the number of sources, keywords plus, and the author's keywords, were also higher in 2012–2021 than in 1916–2011. The number of authors, authors of multi-authored documents, authors per document, co-authors per document, and collaboration index were all greater in 2012–2021 than they were in 1916–2011, implying more collaboration. The average number of citations per document was fewer in 2012–2021 than in 1916–2011. This decrease may be attributable to the time frame, which led to more citations for earlier-published documents.



**Figure 1.** Search strategy based on PRISMA flow diagram [24].



**Figure 2.** Temporal evolution of scientific publications on *P. americana* research from 1916 to 2021.

**Table 1.** Main bibliometric information on *P. americana* during two publication periods (1916–2011 and 2012–2021).

| Description                          | Publication Period |           |
|--------------------------------------|--------------------|-----------|
|                                      | 1916–2011          | 2012–2021 |
| Documents                            | 1180               | 1386      |
| Sources (Journal)                    | 401                | 656       |
| Keywords Plus                        | 4527               | 7685      |
| Author's Keywords                    | 2194               | 3828      |
| Average citations per document       | 26.03              | 9.745     |
| Authors                              | 2506               | 4896      |
| Author appearances                   | 4079               | 7026      |
| Authors of single-authored documents | 80                 | 29        |
| Authors of multi-authored documents  | 2426               | 4867      |
| Single-authored documents            | 108                | 32        |
| Authors per document                 | 2.12               | 3.53      |
| Co-Authors per document              | 3.46               | 5.07      |
| Collaboration index                  | 2.26               | 3.59      |

### 3.3. Most prolific authors, co-authorship and collaboration patterns

Table 2 lists the topmost prolific authors in both periods. The topmost prolific in the first period (1916–2011) authors were Prusky D, an expert in postharvest from the Agricultural Research Organization of Israel (34 documents); Hoddle MS from the University of California, Riverside,

United States (26 documents); Lahav E from Regional Experiment Station, Acre, Israel (21 documents); Kobiler I from Agricultural Research Organization of Israel (20 documents); and Woolf AB from Plant & Food Research, New Zealand, Auckland, New Zealand (17 documents).

The most prolific authors in the first period have changed in the last decade (Table 2). Ramírez-Gil JG from Universidad Nacional de Colombia Medellin, Colombia, ranked first (19 documents), followed by Sivakumar D from Phytochemical Food Network Group, Pretoria, South Africa (18 documents); Arpaia ML from the University of California, Riverside, Department of Botany and Plant Sciences, Riverside, United States (16 documents); Carrillo D from Tropical Research & Education Center, Department of Entomology and Nematology, Homestead, United States (16 documents); and Pedreschi R from Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile (16 documents).

**Table 2.** Top authors of *P. americana* research during two publication periods (1916–2011 and 2012–2021).

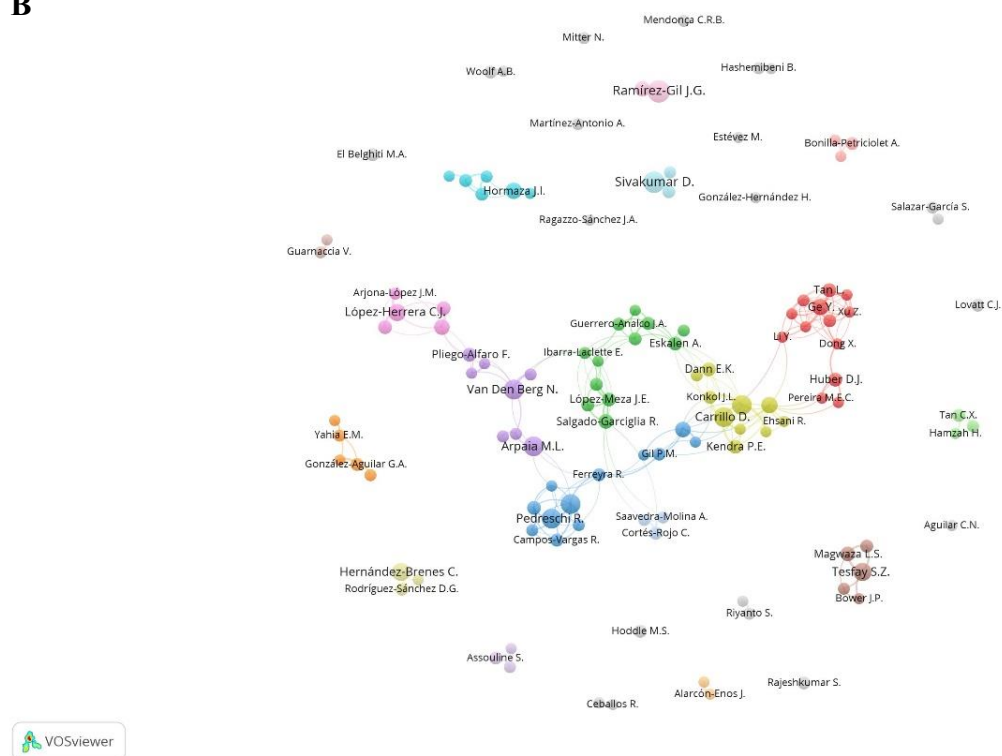
| Ranking | Publication Period           |                 |                                  |                 |
|---------|------------------------------|-----------------|----------------------------------|-----------------|
|         | 1916–2011                    |                 | 2012–2021                        |                 |
|         | Author<br>(Country)          | NP <sup>1</sup> | Author<br>(Country)              | NP <sup>1</sup> |
| 1       | Prusky D<br>(Israel)         | 34              | Ramírez-Gil JG<br>(Colombia)     | 19              |
| 2       | Hoddle MS (United<br>States) | 26              | Sivakumar D<br>(South Africa)    | 18              |
| 3       | Lahav E<br>(Israel)          | 21              | Arpaia ML<br>(United States)     | 16              |
| 4       | Kobiler I<br>(Israel)        | 20              | Carrillo D<br>(United States)    | 16              |
| 5       | Woolf AB<br>(New Zealand)    | 17              | Pedreschi R<br>(Chile)           | 16              |
| 6       | Sedgley M<br>(Australia)     | 17              | Ploetz RC<br>(United States)     | 16              |
| 7       | Whiley AW<br>(Australia)     | 16              | van den Berg N (South<br>Africa) | 16              |
| 8       | Pliego-Alfaro F<br>(Israel)  | 16              | Defilippi BG<br>(Chile)          | 15              |
| 9       | Neeman I<br>(Israel)         | 15              | Hernández-Brenes C<br>(Mexico)   | 13              |
| 10      | Gazit S<br>(Israel)          | 14              | Tesfay SZ<br>(South Africa)      | 13              |

<sup>1</sup>NP number of publications.

The co-authorship network between authors was mapped in order to investigate the connections between authors of publications or those with whom they have collaborated. The color indicates a cluster of authors that are strongly connected by co-authorship links. Figure 3A shows co-authorship links between authors who published at least five documents between 1916 and 2011. A total of 110 out of 2507 authors met the requirement, resulting in 30 different node colors. Figure 3B shows co-



B



**Figure 3.** Map of authors with collaborative links in the field of *P. Americana* research A between 1916 and 2011, and B between 2012 and 2021.

### 3.4. Most productive countries and collaborative patterns

The United States dominated, with 378 documents, followed by Israel (182), Australia (130), Mexico (89), and Spain (88) in 1916–2011. In the recent decade, the most productive countries in the earlier era have shifted (Table 3). Mexico dominated, with 260 documents, followed by the United States (239), Brazil (128), Spain (128), and South Africa (105) (Table 3).

The co-authorship network between countries was mapped in order to investigate the connections between countries of publications or those with whom they have collaborated. Color indicates a cluster of countries that are strongly connected by co-authorship links. Figure 4A shows co-authorship links between countries that published a minimum of five documents, and Figure 4A shows between 1916 and 2011, while Figure 4B was for the last decade (2012–2021). Between 1916 and 2011, 29 out of 68 countries met the criterion, resulting in ten different node colors (Figure 4A). Mexico is grouped together with Germany, Colombia, and Cuba in cluster 1 (red), while the United States, Chile, India, and Greece are in cluster 2 (green). France, Nigeria, Belgium, and Italy are in cluster 3 (blue); Spain, Venezuela, and the Netherlands are in cluster 4 (yellow); New Zealand, Japan, and South Korea are in cluster 5 (purple); Israel and Ghana are in cluster 7 (orange); Australia and South Africa are in cluster 8 (brown); and the United Kingdom and Sri Lanka in cluster 9 (pink).

Between 2012 and 2021, a total of 48 out of 92 countries met the threshold, resulting in seven different node colors (Figure 4B). The countries in cluster 1 (red) to rank in the top ten most productive countries worldwide are India and China. Brazil, which is the third most productive country, is in



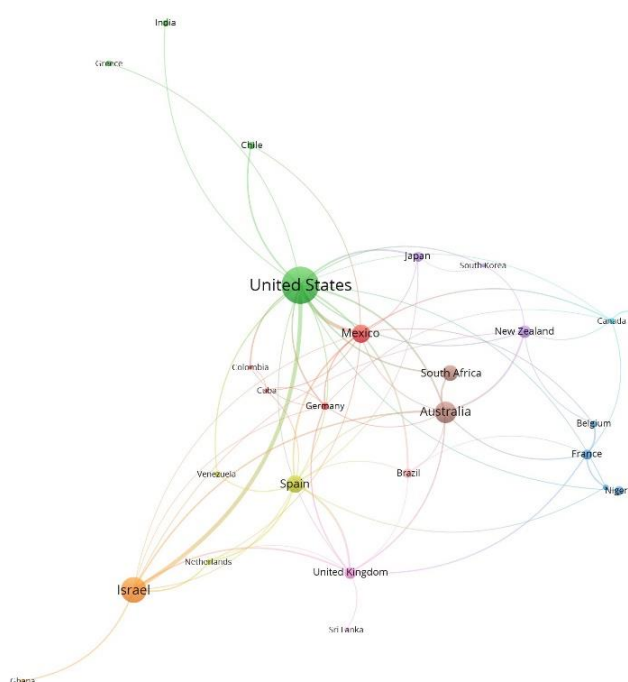
cluster 2 (green) alongside Germany, Sweden, Kenya, Tanzania, Denmark, and Norway. While cluster 3 (blue) includes Mexico, Italy, the United Kingdom, the Netherlands, Greece, Cuba, and Russia, cluster 4 (yellow) includes Spain, Chile, Portugal, Ecuador, Peru, and Poland. The United States, Colombia, Canada, Iran, Morocco, and Argentina are in cluster 5 (purple); Australia, Israel, New Zealand, Belgium, and Sri Lanka are in cluster 6 (turquoise); and cluster 7 (orange) includes South Africa, France, Nigeria, Cameroon, and Pakistan.

**Table 3.** Top countries of *P. americana* research during two publication periods (1916–2011 and 2012–2021).

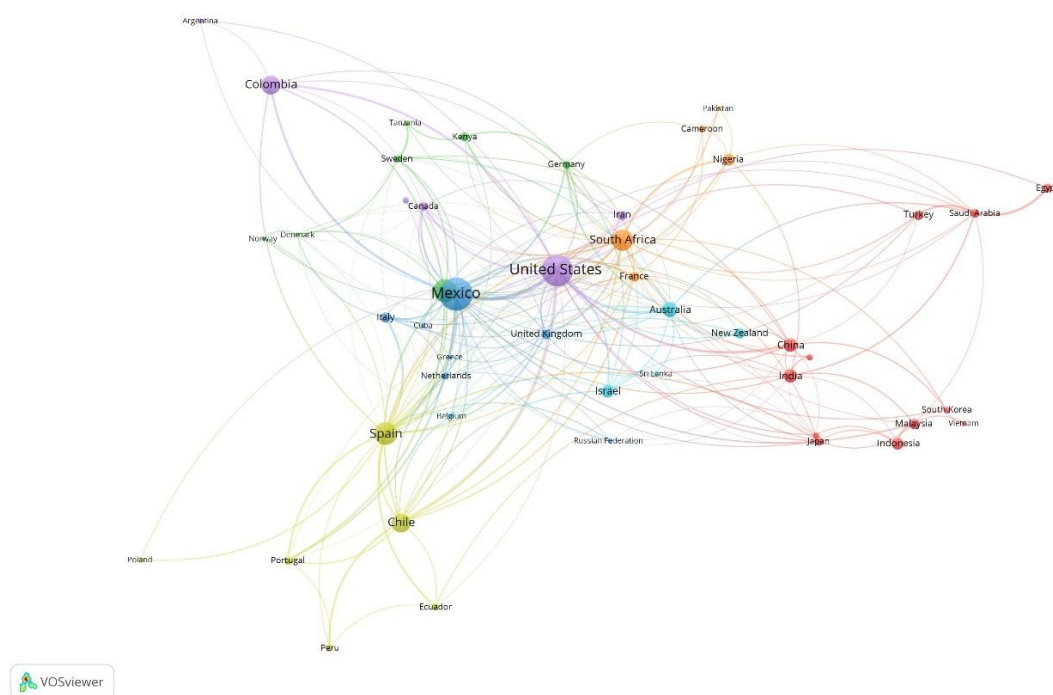
| Ranking | 1916–2011      |                 | 2012–2021     |                 |
|---------|----------------|-----------------|---------------|-----------------|
|         | Country        | NP <sup>1</sup> | Country       | NP <sup>1</sup> |
| 1       | United States  | 378             | Mexico        | 260             |
| 2       | Israel         | 182             | United States | 239             |
| 3       | Australia      | 130             | Brazil        | 128             |
| 4       | Mexico         | 89              | Spain         | 128             |
| 5       | Spain          | 88              | South Africa  | 105             |
| 6       | South Africa   | 68              | Colombia      | 86              |
| 7       | New Zealand    | 43              | Chile         | 85              |
| 8       | United Kingdom | 41              | Australia     | 55              |
| 9       | France         | 30              | India         | 45              |
| 10      | Japan          | 29              | China         | 42              |

<sup>1</sup>NP number of publications.

A



B



**Figure 4.** Map of countries with collaborative links in the field of *P. americana* research A between 1916 and 2011, and B between 2012 and 2021 (minimum cluster size: 5).

Most productive countries are linked together. For example, in Figure 4A the United States excels at international collaboration, with a total link strength of 79, followed by Israel (37), Mexico (32), Australia (24), and Spain (22). With a total link strength of 102, the United States continues to be one of the best performers in international collaboration, alongside Mexico (78) (Figure 4B). This is followed by Spain (64), Chile (41), and South Africa (37) in the last decade.

### 3.5. Journals' distributions of avocado research

Table 4 lists the top 10 most relevant sources for avocado publications from 1916 through 2021, as well as from 2012 to 2021. With 47 documents published between 1916 and 2011 and 43 documents released in the last ten years, the *Scientia Horticulturae* ranked first in both study durations. This was followed by *Postharvest Biology and Technology* with 40 documents published between 1916 and 2011, and 29 documents in the last 10 years. From 1916 to 2011, certain sources, such as *Food Chemistry* and *Plos One*, did not make the top 10, but were ranked third and fourth in the last decade.

### 3.6. Co-occurrence of author keywords analysis

Figure 5 shows the co-occurrence of author keywords in avocado literature, Figure 5A from 1916 to 2011 and Figure 5B from 2012 to 2021. These keywords can be divided into four major clusters. The red cluster is the largest and is concerned with biological control and plant disease (Figure 5A) but later shifts to functional food and medicinal use (Figure 5B). The green cluster is the second largest.

It focused on physicochemical properties (1916–2011), but later shifted to postharvest management (2012–2021). The blue cluster is mostly concerned with functional food and medicinal use (1916–2011) but later shifted to biological control and plant disease in the past 10 years (2012–2021). Meanwhile, the yellow cluster concentrates on postharvest management (1916–2011) but later shifted to physicochemical properties in the past 10 years (2012–2021). The shifts imply that the role of avocado as a functional food and in medicinal use is becoming more popular, followed by postharvest management, biological control and plant disease, and its physicochemical properties.

**Table 4.** Top 20 most relevant sources for *P. americana* research during two publication periods (1916–2011 and 2012–2021).

| Ranking | 1916–2011   |                 | 2012–2021                          |                 |
|---------|---|-----------------|------------------------------------|-----------------|
|         | Source  | NP <sup>1</sup> | Source                             | NP <sup>1</sup> |
| 1       | Scientia Horticulturae                                    | 47              | Scientia Horticulturae             | 43              |
| 2       | Postharvest Biology and Technology                        | 40              | Postharvest Biology and Technology | 29              |
| 3       | Journal of the American Society for Horticultural Science | 35              | Food Chemistry                     | 22              |
| 4       | Journal of Food Science                                   | 30              | PloS One                           | 18              |
| 5       | Journal of Agricultural and Food Chemistry                | 29              | Plant Disease                      | 17              |
| 6       | Plant Physiology  | 24              | Crop Protection                    | 14              |
| 7       | Journal of Phytopathology                                 | 21              | Journal of Economic Entomology     | 14              |
| 8       | Hortscience   | 20              | Plants                             | 13              |
| 9       | Physiologia Plantarum                                     | 20              | Florida Entomologist               | 12              |
| 10      | Phytochemistry  | 20              | Molecules                          | 12              |

<sup>1</sup>NP number of publications.

### 3.7. Bibliographic search on parts of the avocado plant, oil, bioactive and sensory topics

The size of the node is proportional to the number of keyword frequencies in Figure 5. The highest frequency was *Persea americana*, also known as avocado, for both periods. Other high-frequency author keywords were lauraceae, ripening, ethylene, and fruit. These keywords, however, have been less common in recent years. They have been replaced by other high-frequency author keywords like antioxidant, avocado oil, fatty acid, biological control, and avocado seed. The shift in the distribution of high-frequency author keywords suggests that different parts of the plant and its bioactive properties were among the recent research hotspots. We, therefore, proceeded with a further bibliographic search focused on different parts of the plant, including bark, fruit, leaves, peel, seeds, and stem, as well as avocado oil. In addition to the pulp of the fruit, the seed, leaf, and peel are also gaining research interest, as seen in Table 5 for the number of articles published (NP) in the last decade. The NP results are given for each subject area retrieved in the Scopus database. Some studies investigated more than one organ and were also conducted in a wider subject area. Therefore, the additions were not relevant for a total account but to perceive and compare the trends of the research on bark, fruit, leaf, peel, pulp, seeds, stem, and oil of *Persea americana*.



**Table 5.** Subject areas on parts of the plant and oil of the *P. americana* research conducted in the last decade.

| Subject areas                                | Avocado parts of the plant and oil product <sup>1</sup> |                |              |              |              |               |              |              |
|--|---|----------------|--------------|--------------|--------------|---------------|--------------|--------------|
|  | Bark<br>(6)   | Fruit<br>(192) | Leaf<br>(84) | Peel<br>(43) | Pulp<br>(38) | Seed<br>(146) | Stem<br>(23) | Oil<br>(183) |
| Agricultural and biological sciences         | 1   | 150            | 42           | 22           | 20           | 53            | 13           | 98           |
| Biochemistry, genetics and molecular biology | 3   | 42             | 24           | 12           | 7            | 32            | 4            | 35           |
| Chemistry                                    | 1   | 28             | 8            | 17           | 13           | 39            | 1            | 56           |
| Environmental science                        | -   | 16             | 10           | 5            | -            | 16            | -            | 15           |
| Medicine                                     | -   | 11             | 17           | 4            | 4            | 15            | 3            | 19           |
| Chemical engineering                         | -   | 14             | 7            | 9            | 8            | 17            | -            | 34           |
| Engineering                                  | -   | 11             | 3            | 4            | 3            | 16            | -            | 20           |
| Pharmacology, toxicology and pharmaceuticals | 2   | 10             | 20           | 7            | 4            | 23            | 4            | 15           |
| Immunology and microbiology                  | 2   | 5              | -            | 3            | 3            | -             | 2            | 10           |
| Social sciences                              | -   | -              | -            | -            | -            | -             | -            | -            |
| Earth and planetary science                  | -   | -              | 4            | -            | -            | -             | -            | -            |
| Energy                                       | -   | -              | 3            | 3            | -            | -             | -            | -            |
| Multidisciplinary                            | 1   | 6              | -            | -            | -            | -             | 1            | -            |
| Dentistry                                    | -   | -              | -            | -            | -            | -             | 1            | -            |
| Material science                             | -   | -              | -            | -            | -            | 10            | -            | 11           |
| Physics and astronomy                        | -   | -              | -            | -            | 3            | 7             | -            | -            |
| Nursing                                      | -   | -              | -            | -            | -            | -             | -            | 1            |

<sup>1</sup>The number of publications is in parentheses.

Accordingly, in Table 6, a set of bioactive and sensory topics were organized for the subject areas of study. Most of the contributions to avocado research in the last decade were done in Agricultural and biological science; Biochemistry, genetics and molecular biology; and Chemistry. They were followed by subject areas in Environmental science, Medicine, Chemical engineering, Engineering, and Pharmacology, toxicology and pharmaceuticals.

Research topics with parts of the plants and oil were represented by 17 of Scopus's subject areas in Table 5. Fruit, oil, seed, and leaves were the most frequent words used in the titles, especially in Agricultural and biological sciences; Chemistry; Biochemistry, genetics and molecular biology; and Pharmacology, toxicology and pharmaceuticals; up to one publication with the word nutritional in the title was of the Nursing subject area. The Medicine subject area had more oil, leaf, seed, and fruit words used in the titles. Bioactive and sensory research topics were represented by 18 of Scopus's subject areas in Table 6. Antioxidants, phenolics, nutritional, and volatiles were the most frequent words used in the titles, especially in Agricultural and biological sciences; Chemistry; Biochemistry,

genetics and molecular biology; and Pharmacology, toxicology and pharmaceuticals. Up to one publication with the word nutritional in the title was of the Business, management and accounting subject area.

**Table 6.** Subject areas on the bioactive and sensory research topics in *P. americana* conducted in the last decade.

| Subject areas                                | Bioactive and sensory research topics <sup>1</sup> |                      |                       |                     |                   |                      |                 |                   |
|--|--|----------------------|-----------------------|---------------------|-------------------|----------------------|-----------------|-------------------|
|  | Anti-microbial<br>(16)                             | Anti-oxidant<br>(62) | Cyto-toxicity<br>(10) | Nutritional<br>(34) | Phenolics<br>(43) | Poly-phenols<br>(12) | Sensory<br>(15) | Volatiles<br>(22) |
| Agricultural and biological sciences         | 6  | 29                   | 4                     | 7                   | 25                | 7                    | 10              | 17                |
| Biochemistry, genetics and molecular biology | 5  | 17                   | 7                     |                     | 7                 | 3                    | 3               | 7                 |
| Chemistry                                    | 4  | 18                   | 2                     | 3                   | 10                | 3                    | 2               | 3                 |
| Environmental science                        | 2  | 5                    | 2                     | 4                   | 6                 | 3                    | 1               | -                 |
| Medicine                                     | 2  | 8                    | 1                     | 5                   | 1                 | 1                    | 1               | -                 |
| Chemical engineering                         | 2  | 10                   | -                     | 2                   | 8                 | -                    | 1               | -                 |
| Engineering                                  | 3  | 3                    | -                     | -                   | 6                 | -                    | 3               | -                 |
| Pharmacology, toxicology and pharmaceuticals | -  | 15                   | 3                     | -                   | 7                 | -                    | 2               | -                 |
| Immunology and microbiology                  | -  | -                    | -                     | -                   | -                 | 2                    | -               | 2                 |
| Social Sciences                              | -  | -                    | -                     | -                   | -                 | 2                    | -               | -                 |
| Earth and planetary science                  | -  | -                    | -                     | 2                   | 3                 | -                    | -               | -                 |
| Energy                                       | -  | -                    | -                     | -                   | 2                 | 1                    | -               | -                 |
| Multidisciplinary                            | -  | -                    | -                     | -                   | -                 | -                    | -               | 1                 |
| Computer science                             | -  | -                    | -                     | 1                   | 2                 | -                    | -               | -                 |
| Material science                             | 1  | 3                    | -                     | -                   | -                 | -                    | 2               | 1                 |
| Physics and astronomy                        | 1  | 3                    | -                     | -                   | -                 | -                    | 2               | -                 |
| Nursing                                      | -  | -                    | -                     | 6                   | -                 | -                    | -               | 2                 |
| Business, management and accounting          | -  | -                    | -                     | 1                   | -                 | -                    | -               | -                 |

<sup>1</sup>The number of publications is in parentheses.

#### 4. Discussion

Due to the recent strong agroindustrial momentum in this research field, we conducted a bibliometric analysis to examine the evolution of *P. americana* research publishing patterns over the last ten years (2012–2021) and compared them to earlier years (1916–2011). The evolution of avocado research was divided into three stages based on annual publication trends analysis: 1. From 1916 to

1977, when the number of publications was small and fluctuated; 2. From 1977 to 2006, when the number of publications increased steadily; and 3. From 2006 to present, when the number of publications increased exponentially. The observed publication trends could be linked to avocado production. For instance, the year 2015 was well-known as the year of avocado shortage, which coincided with a reduction in publications.

Between 1916 and 2011 (95 years) 2506 authors produced 1180 documents, with 80 authors contributing single-authored documents and 2426 authors contributing multi-authored documents, averaging 2.12 authors per document. However, more documents (1386) were published, with only 32 single-authored documents and multi-authored documents almost duplicated (up to 4896). Authors of multi-authored publications increased to 3.53 per document, implying increased collaboration from 3.46 to 5.07 co-authors per document in the last decade (See Table 1). The co-authorship network maps in both study periods revealed that most of the prolific authors were found to be grouped together in the same cluster, and their clusters were linked to one another, indicating cross-border links or international collaborations.

When comparing the two study periods, the most productive countries had changed. The United States (especially California and Florida), Israel, and South Africa were the primary avocado exporters in the early years, accounting for 90 per cent of global exports, with Israel accounting for the vast majority [29]. A similar discovery was made, in which the United States and Mexico continue to be the best performers in international collaboration, whereas Israel was left out of the top ten most productive countries for the period 2012–2021. These observations corresponded to the fact that the United States is the world's greatest avocado importer, while Mexico is the world's major avocado provider [30].

The top two most productive sources for both study periods were *Scientia Horticulturae* and *Postharvest Biology and Technology*, according to our data. *Scientia Horticulturae* is an international journal that publishes horticulture crop research. Meanwhile, *Postharvest Biology and Technology* is an international journal that publishes only postharvest biological and technological research. These findings suggest that the majority of avocado research focused on horticulture crops and postharvest biology and technology. *PloS One* and *Food Chemistry* were two new additions to the top 10 sources for the period 2012–2021. *PloS One* covers primary research from any discipline within science and medicine, whereas *Food Chemistry* publishes papers related to advancements in the chemistry and biochemistry of foods or the analytical methods/approach used. These findings could indicate that studies into the chemical, nutritional, and therapeutic aspects of avocados have increased in the previous decade (2012–2021) [31–33]. These changes correspond to the shifts in the themes seen in Figure 5.

We used co-occurrence keyword analysis to identify themes based on the highest co-occurrence. A significant change was observed in the distribution of high-frequency author keywords when comparing between two study periods in some of the clusters. These may imply that current hot research topics are related to physicochemical properties of avocado and its by-products, functional and medicinal properties, postharvest management, and biological control, as well as plant cultivar and diseases. The subsequent discussion will focus on these topics.

#### *4.1. Physicochemical properties of avocado and its by-products*

Biometrical parameters (weight, length, size), ripening indicators (firmness, dry matter, color),

pH, free acidity, total soluble solids, and nutrient composition (six sugars, seven organic acids, nine fatty acids, eleven carotenoids, five chlorophylls, three phytosterols, one phytostanol, two tocopherols and several phenolics) were compared in Hass and Hass avocado types [34]. Despite the similar appearances of Hass and Hass types, some Hass types had better phytochemical and nutrient composition than Hass fruit [34]. UV light radiation, antioxidant solution, and modified procedures could be used to maintain the physicochemical qualities and microbiological content of Hass avocado pulp, providing an alternative for increasing crop value and lowering post-harvest losses [35]. Vis/NIR hyperspectral imaging is becoming popular for non-destructive and rapid determination of nutritional concentrations of Hass avocado fruit [36], although it is not a regulatory method. Perhaps this is a technological transition, but only time will reveal it.

Monetizing avocado waste for nutritional and environmental benefits is a research goal to identify nutraceutical profiles available to the business sector [37]. Vinha et al. [37] analyzed ascorbic acid, vitamin E, carotenoids, flavonoids, polyphenols, and radical-scavenging activity of pulp, peel and seeds, in addition to proximate analysis (ash, moisture, proteins, and fat), and acidity. They found that, except for vitamin E, bioactive compounds were more concentrated in peel and seeds than the avocado pulp, and they suggested that the non-edible portions of the fruit have potential use in the food and dermo-cosmetic industry. In addition to the edible pulp, research on other parts of the plant and the avocado oil is given in Table 5, where bark, fruit, leaf, peel, pulp, seed, and oil were the leading words in the titles. The three major subject areas were 1. Agricultural and biological sciences, 2. Chemistry, and 3. Biochemistry, genetics and molecular biology.

#### *4.2. Functional and medicinal properties*

There is a growing interest in avocado and its by-products as natural sources of nutrients and functional qualities, possibly explaining the shift in theme [37,38]. Avocado is included in the functional food review of superfoods with health benefits [39,40], and the seed is in prospective nutritional and bioactive sources from Indonesia [41]. Diverse technologies have been studied in the research of functional properties and applications of avocado fruit, such as nanoemulsions of peels [42], microwave assisted extraction of peel [43], formulation of non-dairy ice cream [44], the addition of low methoxyl pectin to peel and seed extracts for enhancing their lipid digestibility, and polyphenol bioaccessibility [45].

Avocado pulp and oil are both excellent sources of bioactive polyphenols and antioxidants, and both are being actively studied [9,31,46–49]. The nutritional quality of avocado pulp and social interventions have been of interest. The nutritional status of families self-identified with Mexican heritage was studied in California, and a high allotment of avocados significantly reduced self-reported energy intake by 29% kcal/family/day and improved the nutritional quality of families [50]. Functional agents in the treatment of cardiometabolic risk factors were studied in traditional Mexican foods [51]. Avocado consumption was also related to anthropometric measures in Australia [52]. The medicinal properties of avocado include usage of its water-insoluble fiber in treating obesity [53], as bioactive antimicrobials [54], in maintaining blood glucose levels, and also as skin care [55]. Its pulp and seed have anti-cancer properties [56], while the seed extracts have anti-inflammatory and anti-ulcer activities [57]. A nanoemulsion containing avocado peel extract has been shown to possess anti-cholesterol and antioxidant properties against cardiovascular-related diseases [58], as well as having antiproliferative [38] and anticancer potential [42].



### 4.3. Postharvest management and biological control

Adequate orchard management practices, harvesting practices, packing processes, postharvest treatments, temperature management, transportation and storage conditions, and ripening at destination, all play a role in maintaining avocado fruit quality along the supply chain [59]. Genetic and environmental factors determine the spectra of nutrients in avocado fruit, aimed to select nutritionally enriched cultivars for the supply chain of farmers and consumers. Molecular markers, genomics, and new breeding techniques (NBTs) are used to improve nutritional traits [60]. High heritability of traits is needed to predict successful marker-assisted selection. Diverse heritable traits such as flavor, size, and hard skin –building on sensory, convenient, and protective transport preferences– were crucial for the predominant “Hass” market trade in California and worldwide expansion [5]. The “Fuerte” from Atlixco, Mexico, was overtaken by the flavor, size and hard skin of “Hass” in California and worldwide [5]. Looking at nutritional traits, the contents of carotenoids,  $\beta$ -sitosterol, and  $\alpha$ -tocopherol (the most biologically active form of vitamin E) are heritable nutritional traits in ripe avocado fruit [61].

The growing understanding of plant beneficial bacteria has sparked interest in biological control, which has risen in recent years in response to public concerns about the use of chemicals in the environment. This highlights the need to find alternatives to the chemicals used for disease control [62,63]. Recent developments such as composite plant transformation, single nucleotide polymorphism (SNP) analysis, genomics, and transcriptomics will supplement existing molecular, histological, and biochemical test research and help to better understand avocado defensive mechanisms against avocado diseases [64]. In addition, the high genetic diversity found in the studied avocado germplasm suggests that it could be a rich source of variable alleles for improving the crop's genetics and is valuable for future breeding [65,66].

### 4.4. Plant cultivars and diseases

The agroindustry needs to conduct constant research on the interactive nutritional status of the avocado plant cultivars and the action of the environment on their physiology. These studies include irrigation and nutrient management [67], nutrient losses [68] and best nutrient concentration [69], fertilization timing [70,71], leaf sampling [72], salt stress [73], soil moisture [74], nutrient removal [75], and soil-less and protected growing system [76]. The soil quality has an impact on the elemental uptake of the avocado plant [77].

Detection of avocado laurel wilt pathology arises after nutritional stress, urging modern controls like remote sensing [78–80]. Pest control and disease management are needed because avocado diseases continue to be a major impediment to the growth of the avocado agribusiness industry, which is dominated by Latin American nations. Plant cultivars and diseases have become increasingly relevant in the previous decade (2012–2021). The most relevant postharvest disease and disorders were anthracnose, stem-end rot, chilling injury, and lenticel damage [81]. In today's agricultural production scenario, new technologies such as geographic information systems (GIS) and mobile phone applications have been implemented, and can be well integrated into the avocado production chain [82]. These systems may improve information management for effective decision-making, resource optimization, implementation of better agronomical practices, task programming, and disease management sustainability, among other activities that may optimize crop management [83–85].

#### 4.5. Study limitations

This bibliometric study has several limitations. First, the information provided is restricted to the Scopus database. Despite being one of the most important and complete collections of scientific materials globally [22,23], we still lack some scientific literature on avocados. Second, this analysis only included publications written in English, which unavoidably left out some important recent studies on avocados published in other languages. Third, the data we used for our analysis was up to December 27, 2021, and new research is being released almost daily. Fourth, if the authors had not included our study inclusion descriptors in the article titles, we might have omitted some avocado-related publications. Fifth, the quality of each study may not be accurately reflected by the number of citations used to measure the influence of the research.

### 5. Conclusions

This is the first study to provide a bibliometric analysis of avocado research trends in the last 105 years, from 1916 to 2021. A comparative map was presented for two study periods, 1916 to 2011 and the final decade, 2012 to 2021. Two main areas of food science and technology were dissected for a rigorous analysis of corresponding topics in Scopus subject areas: 1. Avocado parts and oil products, and 2. Bioactive and sensory research topics. The dominance of avocado research in agricultural and biological sciences was evident, with limited or absent studies in social sciences. We propose that future research topics will focus on the functional and medicinal properties of avocado, postharvest management and its biological control, plant cultivars and diseases, and physicochemical properties of avocado and its by-products based on the identified emerging themes of the last decade. This study contributes to the literature by providing scholars and practitioners with useful insights on avocado research for future research directions.

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### Conflict of interest

All authors declare no conflict of interest in this paper.

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