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The Exploration of Scientific Studies on Vegetable Seed Coating from The Past to The Future

Sıtkı Ermiş[1,*], Akdoğan Kaan Can Tekbilek[2], Yasin Altay[3], Jemal Kassaw Abebe[4]

[1]Eskisehir Osmangazi University, Faculty of Agriculture, Department of Horticulture, Eskisehir, Türkiye

[2]Eskisehir Osmangazi University, Institute of Science, Eskişehir, Türkiye

[3]Eskisehir Osmangazi University, Faculty of Agriculture, Department of Animal Science, Eskisehir, Türkiye

[4]Mizan Tepi University, College of Agriculture and Natural Resource, Department of Horticulture, Mizan-Aman, Ethiopia

HIGHLIGHTS

- This study consists of data from a total of 631 scientific publications in scientific studies on vegetable seed coating between 1980 and 2024.
- More than 50% of the scientific studies in the field of vegetable seed coating have been carried out in India, USA and China respectively.
- The most commonly used keywords in scientific studies in the field of vegetable seed coating were; vegetable-oils, seed oil, performance, identification, vegetables, seed coat, coating, antioxidant activity and expression.

Abstract

Seed coating is a very hands-on technology that involves applications of external materials to seeds; this is done with great goals in mind, hence improved handling, protection to an extent, and, to certain small extents, germination and growth establishment. Despite its wide acceptability, the implementation of seed coating procedures has still got many challenges nowadays. This study, therefore, applies bibliometric analyses to deduce the trends and gaps between the seed coating research produced from 1980 up to 2024, particularly under the Web of Science database outlet. This work will integrate quantitative and qualitative methodologies regarding the analysis of publications, citations, affiliations, patents, grants, and data on other relevant indicators. The results showed that in the final years, there was an incredible rise in citations about this area, which, put differently, means continuously improving publishing and citation rates throughout the period. Publication data showed that India, the United States, and China represented important contributors to seed coating-related publications, as witnessed through both high publication outputs by its authors and numerous affiliation establishments. The present study comprehensively outlines the trends of research so that the researcher can identify the knowledge gap and assess developments to shape the future of research in seed coating. The results also provide insights for strategic guidance of future research and product development in the area.

Keywords: Bibliometric analysis; germination; seed; seed coating; vegetable

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Corresponding Author E-mail: ermis@ogu.edu.tr

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1. Introduction

Seeds are the fundamental components of agricultural production, with germination and emergence being pivotal and delicate phases in a crop's life cycle (Villalobos et al. 2016). Low-quality seeds and inadequate planting circumstances can directly or indirectly impede plants' growth, health, and yield, beginning at the seedling development stage. Besides, environmental stress factors that include biotic stresses related to pests and diseases and abiotic stresses such as drought, salinity, extreme temperatures have been discouraging the process of germination and seedling development. In fact, such environmental stresses may be the cause for drastic yield reductions in crops (Lamichhane et al. 2018).

High-quality seeds are crucial for the establishment of stands in both transplant production and direct seeding. Seed performance is optimized via modifications to provide maximum emergence in poor settings (Taylor 2020). In order to overcome these limitations, seed coating methods were developed to seed performance, as well as protect them against biotic and abiotic stressors. Seed coating is defined as the application of biological, chemical, or physical agents to the surface of seeds with the principal intention of increasing the rate of germination of the seeds, while accelerating the rate of emergence of the seedling and supporting the early growth of the plant. Coating technologies applied to the seeds can be used to improve accurate seed placement at sowing and as a delivery system for compounds and agents which protect and enhance both seed and plant performance (Afzal et al. 2020).

The technology of coating seeds has immensely enhanced over the years with different techniques being developed to meet specific agricultural needs. Major processes of seed coating techniques include pelleting, encrusting, film coating, and seed dressing (Taylor 2003). Pelleting is a process where materials like clays or polymers are used to create a smooth, rounded coating on the seed. This technique enhances handling and sowing of seeds while concurrently achieving accuracy in mechanical planting (Pedrini et al. 2020). Encrusting is a sort of pelleting, the original shape of the seed can be preserved with an added outer protective layer. This just slightly increases the size and weight of the seeds, whereby the seeds become suitable for higher sowing systems without compromising germination (Pedrini et al. 2018; Taylor 2020). Film coating is the new approach in which thin, smooth, and coloured film is applied to seeds. Film coating is little modification of the size and shape of the seed surface. The application of this technique helps the incorporation of pesticides, fungicides, and nutrients without harming the seed so that it may be well protected at its initial stage of development (Taylor and Harman 1990; Taylor et. al. 2001). Further, seed dressing is the simpler and effective way of dressing the seeds with the protecting agent from pests and diseases in use for many decades because of the availability of effective fungicides, its relatively low cost, and easiness of the treatment (Gullino et al. 2014).

Among seed coating technologies, multi-seed coating is one of the great recent innovations. It is a technology that involves coating several seeds in one pellet. Specific developments for small-seeded plants have been done with the intention of assuring regular dispersion during sowing and attaining better uniformity in seedling emergence. The multi-seed coating thus confers advantages under low germination rate conditions and in intercropping systems. In consideration of the foregoing, the concurrent improvement of seed performance and handling along with the early development of a plant makes those techniques vital for further advancement in modern agricultural practices. At the same time, despite such developments, there are a few bottlenecks regarding proper documentation and dissemination of knowledge on different seed coating methods.

Even though different researchers try to define and explain about seed coating, there were problems regarding to ways of publication time, which reference and organization used, number of citation and affiliation collected from different data base was not appropriately documented. Inclusive all information and available data to know performance rate knowledge about seed coating process. The information gathered from data base very important to show right direction and pattern about seed coating to researcher and reviewers. Gathering and collecting research out puts in seed coating and related fields are crucial to get more and detail information about number publication, citation and, affiliation.

Numerous systematic reviews in seed coating examine scientific literature to investigate research directions and trends. Bibliometric analysis is a method that quantitatively assesses scientific research using their bibliographies (Kaplan and Altay 2023). This method objectively evaluates scientific production, the efficacy of scientific investigations, collaboration networks, commonality in research domains, and the performance of authors and scientific institutions, among other factors (Çelik Ş 2020; Altay and Kaplan 2023). This quantitative methodology offers a substantial benefit in the objective assessment of scientific research, monitoring trends within the discipline, and facilitating strategic decision-making.

The negative features of bibliometric analysis, on the other hand, are insufficient scientific publications related to the area under investigation, the lack of any kind of data entry control within databases, and biased citation practices of scientific studies. Despite all such disadvantages, bibliometric analysis allows assessing historical progress of scientific studies, developing policies about their field, reinforcing interdisciplinary networks, and optimizing the use of resources for conducting scientific research (Onder and Tirink 2022; Kaplan and Altay 2023).

The main aim of the study is to indicate, by applying the method of bibliometric analysis-a quantitative method being increasingly applied in the field of science studies-historical development trends faced within scientific publications regarding the topic of seed coating. For that, this research critically presents studies on seed coating within a time frame from 1980 to 2024. The result of the presented study is bound to enable researchers to trace the past and ongoing research outputs and, thereafter, make full and informed decisions concerning seed coating based on the facts so identified. In this perspective, the ultimate goal is to have seed coating technologies advanced, including their potentials for sustainable agriculture.

2. Materials and Methods

2.1. Material

The material of this study consists of bibliometric data of 631 scientific studies obtained in a search with the help of the keywords "Seed Coating" and “Vegetable” conducted in the Web of Science database, which covers the periods between 1980 and 2024. The publication document content type distribution of the scientific studies on seed coating is presented as follows: Articles: 456; article book chapter: 15; article early access: 4; article proceedings paper: 5; Editorial material: 2; meeting abstracts: 3; Proceedings paper: 56; review: 88; and review book chapter: 2, totalling 631 publications. Among these, articles are the most frequent form of scientific publication. Reviews and proceedings papers are ranked next in the number of publications. In contrast, early access articles, book chapters, article proceedings papers, meeting abstracts, editorial materials, and review book chapters are much fewer compared to other types of publications.

2.2. Method

Great care was taken in selecting appropriate keywords and relevance of scientific publications to identify relevant studies on seed coating. After this step, data concerning the types of publications were extracted from these studies' bibliographies through the Web of Science database. The data were downloaded from the Web of Science database in plaintext format and processed using the “convert2pdf” function in R software (R Core Team 2024). After organizing the data, the dataset underwent comprehensive bibliometric analysis with the "bibliometrix" package in R software (Aria and Cuccurullo 2017).

3. Results

The curve in the following chart indicates that the number of publications each year, from 1980 to 2024, continuously shows an obvious uptrend in annual scientific research related to vegetable seed coating. The quantity has remained at a low level before 2000, with an average annual output below 10 papers; after 2001, the publication rate gradually went up and had an accelerated growth after 2011. The most productive period was from 2021 to 2024, where more than 60 articles were published in a year. Though slight ups and downs are present, the data indicate continuous growth in research outputs concerning seed coating technologies and, hence, increased interest in this topic by the scientific community, as presented in Figure 1.The curve in

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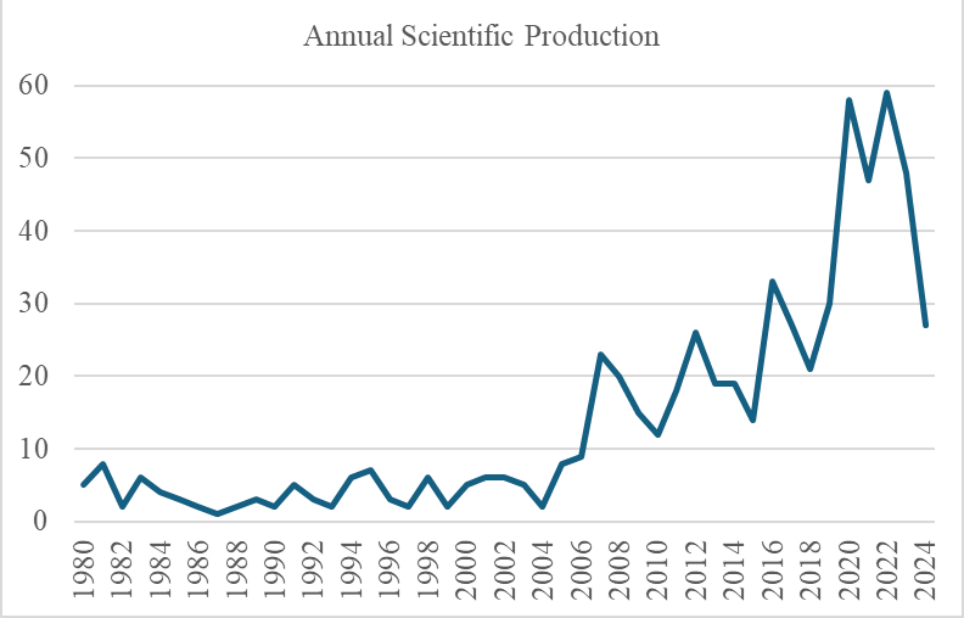

Figure 1. Trends in annual scientific publications on seed coating (1980-2024)

In addition to the growing number of publications, citation analysis represents an interesting indicator about the impact of scientific published works. The annual average citation counts from 1980 through 2024 deserves consideration with regard to the impact of research output on the scientific community. Figure 2 shows that citations increased rapidly, especially for works published after 2010. The annual average citation count is more than 10 for the period between 2014 and 2018, indicating that the works published within this period were highly cited. Therefore, from 2019 onward, the annual average cite counts decreased due to the relative freshness of the publications and hence fewer citations it would get. Another hypothesis could be that such studies beyond 2020 might have drawn on consequences of changed research dynamics in light of the COVID-19 pandemic.

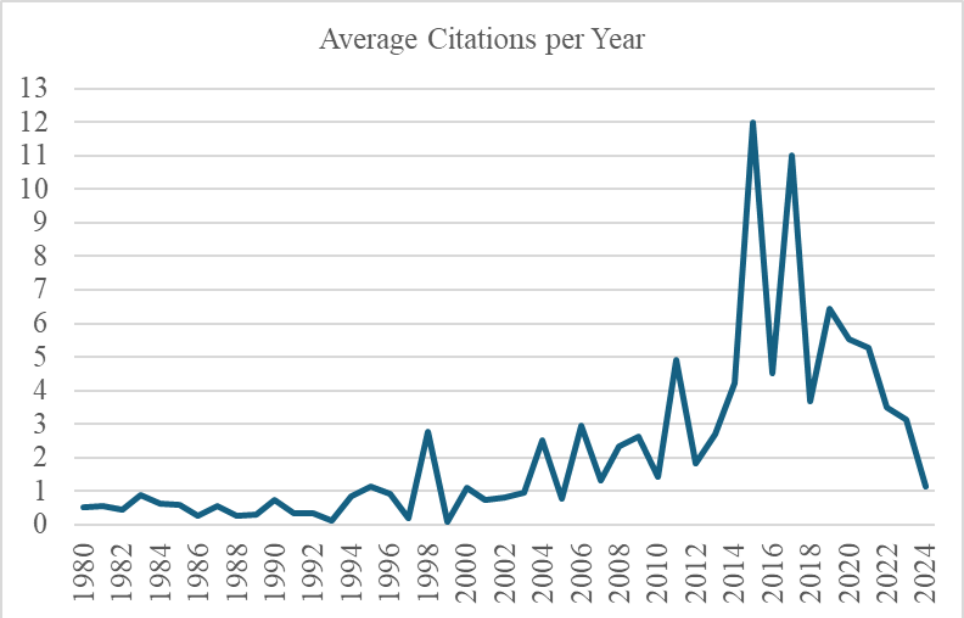

Figure 2. Yearly average citations for scientific publications on seed coating

The top 10 journals with the highest number of publications in the field of vegetable seed coating are shown in Figure 3.

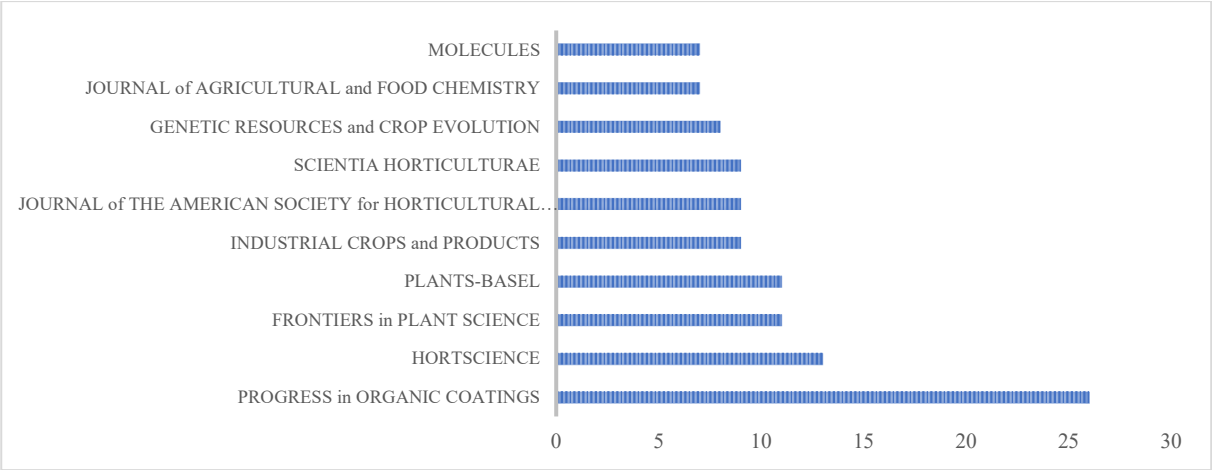

Figure 3. Journals with the highest number of scientific publications in the field of vegetable seed coating.

With a total of 26, the journal publishing most articles on vegetable seed coating is Progress in Organic Coatings, followed by Hortscience, with 13 articles; at 11 each are the journals of Frontiers in Plant Science and Plants-Basel, which come immediately after Progress in Organic Coating as the most publishing. Among the top 10 journals, the least published journals are *Journal of Agricultural and Food Chemistry* and *Molecules*, each with 7 articles. The 10 authors who have conducted the most scientific studies on vegetable seed coating are presented in Figure 4.

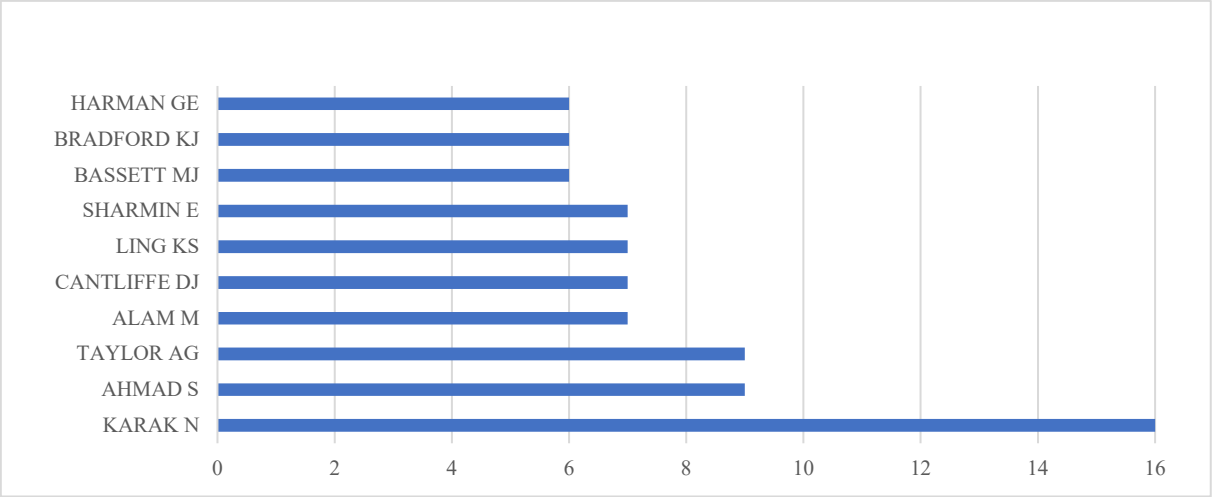

Figure 4. Journals with the highest number of scientific publications in the field of vegetable seed coating.

In 1980, Harman GE is recognized as the first author to publish a scientific paper on vegetable seed coating. Upon examining Figure 3, Karak N emerges as the leading author in the field, with 16 publications. Ahmad S and Taylor AG, with 9 publications each, are also significant contributors to the field. Among the top 10 authors with the most scientific publications, Harman GE, who conducted the first study on the topic, ranks last. The top 10 authors with the most citations for their scientific works are shown in Figure 5.

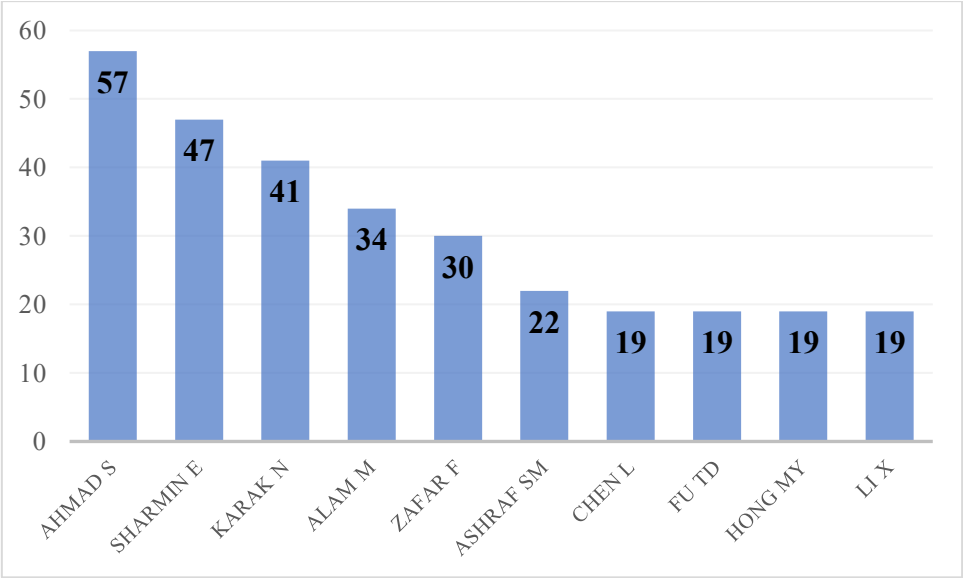

Figure 5. Authors with the most citations in the field of vegetable seed coating.

Upon examining Figure 4, Ahmad S stands out as the most cited author with 57 citations. Karak N, the author with the highest number of publications in the field of vegetable seed coating, ranks third with 41 citations. Among the top 10 authors with the most publications in the field, Sharmin E, with 7 articles, ranks seventh but stands out as the second most cited author with 47 citations. Harman GE, who conducted the first study on the topic, does not appear among the top 10 most cited authors. The distribution of corresponding authors' countries and the collaboration patterns between these countries in the field of vegetable seed coating are presented in Figure 6.

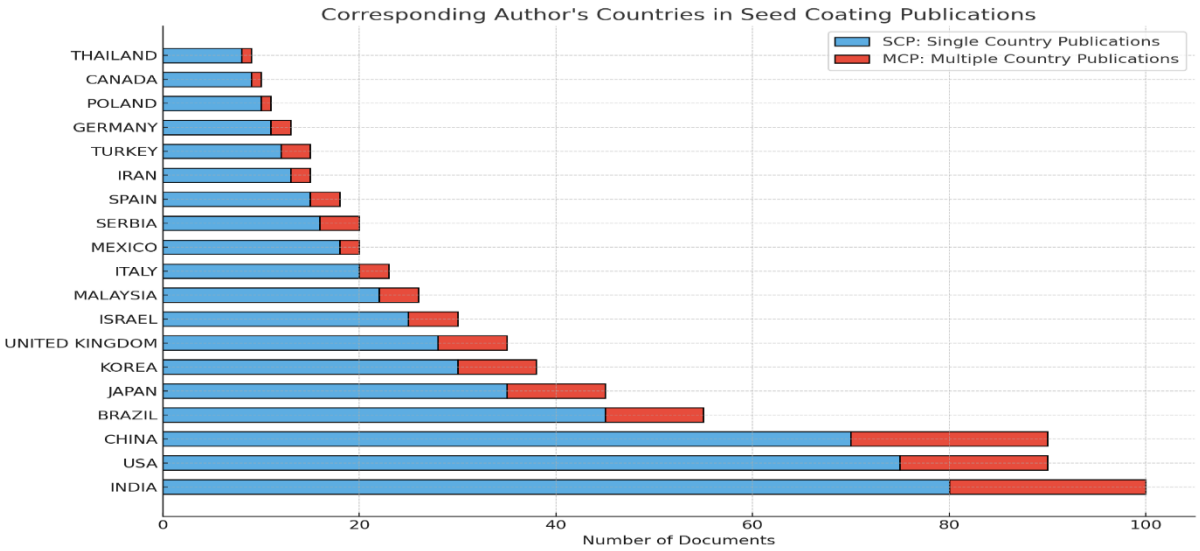

Figure 6. Distribution of authors with scientific publications on vegetable seed coating by country.

In terms of countries with corresponding authors of scientific publications on vegetable seed coating, India is the country with the most publications, with 109 articles (MCP: 17, SCP: 92). After India, USA with 102 articles, MCP: 15, SCP: 87, China with 87 articles, MCP: 21, SCP: 66 and Brazil with 29 articles, MCP: 5, SCP: 24 are the leading countries that have the highest number of scientific studies in this area. China has the highest internationally collaborative publications with 21 joint articles. Türkiye has 10 scientific papers on vegetable seed coating, of which 0 is at the level of MCP and 10 is on the level of SCP. It is worth mentioning that Türkiye is the only one among the top 20 countries with the largest number of publications in this field and does not have an internationally collaborative publication. This suggests a relatively more inward-looking nature for

research in vegetable seed coating. Figure 7 shows the ranking of the first 10 countries that publish scientific studies on vegetable seed coating.

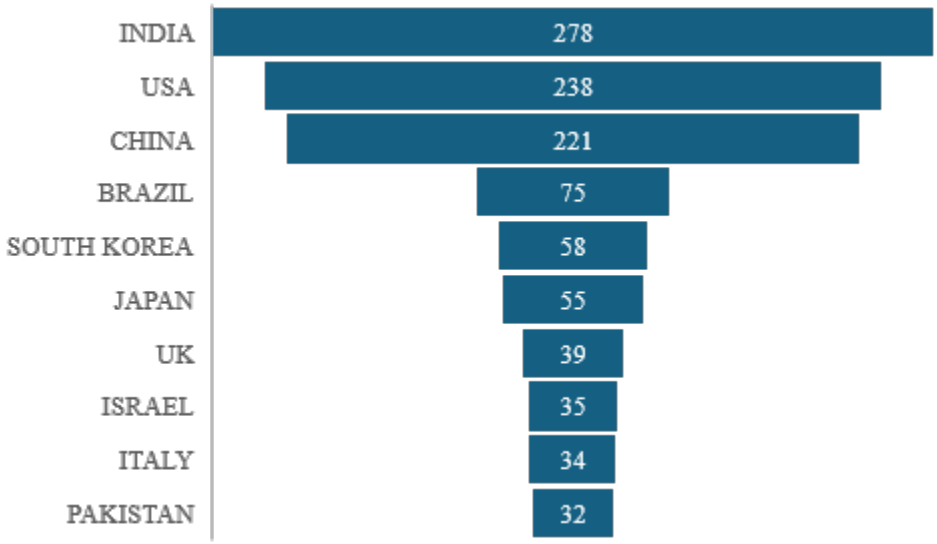

Figure 7. Top 10 countries by number of publications on vegetable seed coating

It places India in the lead with 278 scientific studies, followed by the USA with 238, China with 211, and Brazil with 75 scientific publications. Pakistan is ranked at the tail among the top ten countries, with a total of 32 studies. With 24, Türkiye doesn't make the Top 10. Considering scientific studies in number, the Asian and American continents are shown to be the leaders on vegetable seed coating studies. European countries conduct fewer vegetable seed coating studies compared to Asian and American countries. This cannot be overemphasized in European countries for any better approach to this aspect driven by a general lack in scientific studies regarding vegetable seed coatings. The 10 most important keywords in scientific studies on vegetable seed coating are shown in Figure 8.

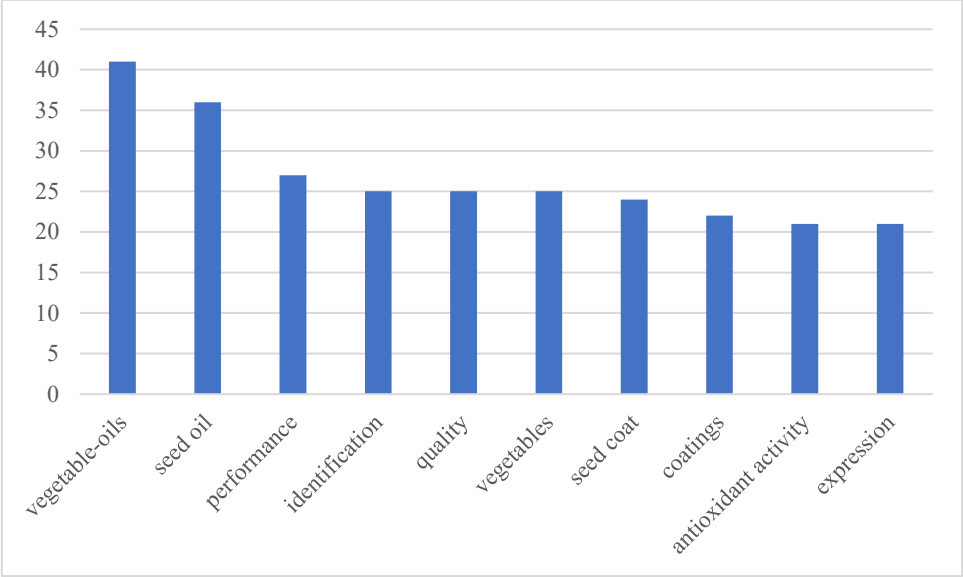

Figure 8. The most important keywords in scientific studies on vegetable seed coating.

Scientific studies on vegetable seed coating have focused on certain key terms. Among these studies, "vegetable-oils" (41) is the most frequently used keyword. Other commonly used keywords include "seed oil" (36), "performance" (27), "identification" (25), "quality" (25), "vegetables" (25), and "seed coat" (24). The other keywords are less frequently used, examples being "antioxidant activity", which occurs 21 times, and "expression" also occurring 21 times. From the keywords, it would appear that research into this area involves

the application of seed oils as coating materials for the enhancement of germination rates, the selection of appropriate materials to use as coating agents for seeds, the assessment and evaluation of seed quality and shelf life, and the prevention of diseases in vegetable seeds using coating agents that have antioxidant properties. Figure 9 shows the word cloud created from these keywords.

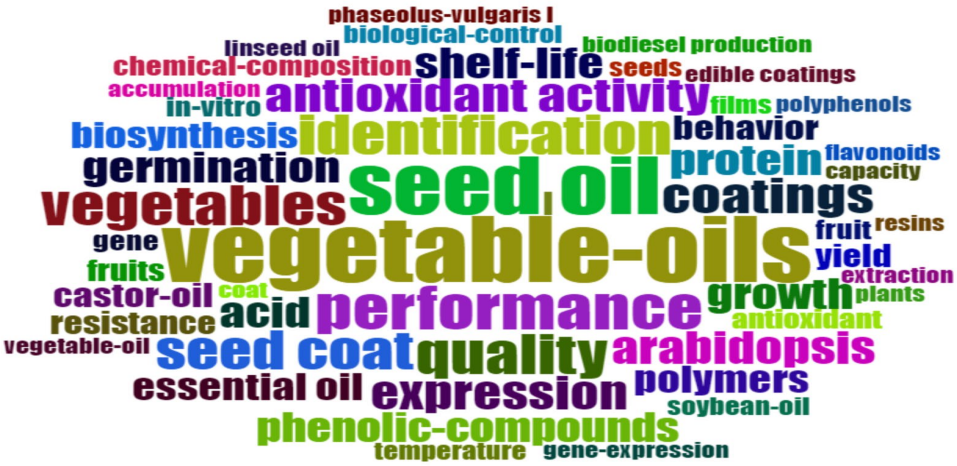

Figure 9. Word cloud generated from the most common keywords in the field of vegetable seed coating.

The relationships between the keywords used in scientific studies on vegetable seed coating are shown in Figure 10.

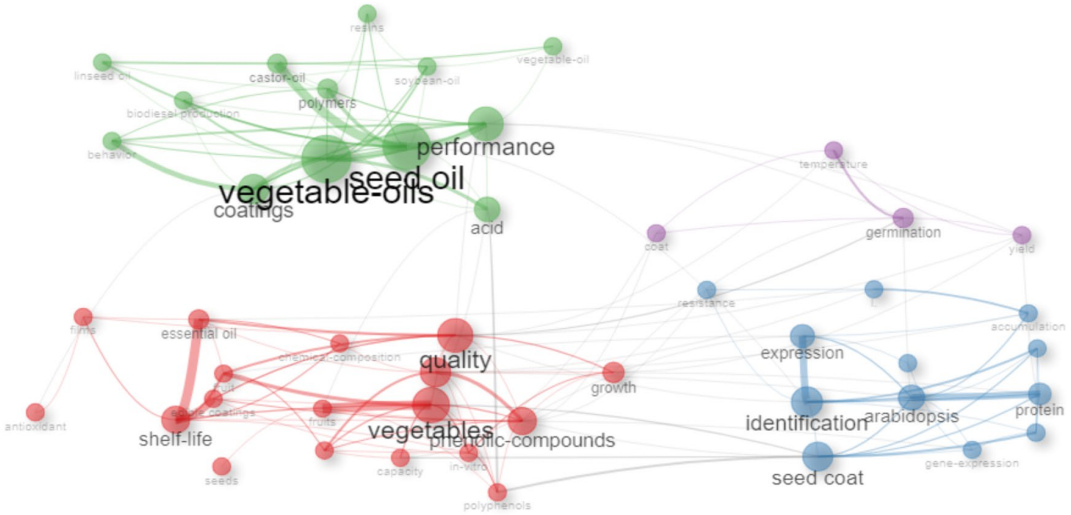

Figure 10. Relationships between keywords in scientific studies on vegetable seed coating.

Upon examining Figure 9, the keywords are organized into four groups, each represented by a different color. The first group is centered around the keywords "vegetable-oils" and "seed oil," which show a strong

connection with the other terms in the group. The majority fall into this cluster probably due to studies focusing on the use of seed oils as coating materials. The second cluster combines words such as "vegetables" and "quality," showing some relationship between the studies of growth, coating, capacity, and chemical composition. The third cluster contains the words "germination," "temperature," "yield," and "coat," which represent studies on the influence of temperature on germination, the impact of germination on yield, and the improvement in the rate of seed germination. The fourth cluster, represented in blue, includes the words "identification," "expression," and "seed coat," which are related to each other. This association may relate to the studies of proper selection of the materials used in coating seeds and their processing for quality control.

4. Conclusions

The study presents a wide bibliometric analysis of vegetable seed coating research produced within the period of 1980-2024, hence highlighting advances, trends, and gaps in this important area of research. The results of the present study have evidenced the continuous rise in scientific publications, especially in the last decade, reflecting growing interest in seed coating technologies as basic tools to improve agricultural productivity and sustainability. This reflects more the importance of the area to handle issues concerning germination, development of seedlings, management of pests and diseases, and increasing crop yield in a changing environment; as can be seen in the increased number of publications and citation rates.

Despite these advances, standardized methodology, interdisciplinary collaboration, and the search for innovative materials for seed coating remain a number of the key challenges facing the area. Future studies will be directed toward the improvement of performance and scalability of the coatings by incorporating advanced technologies, such as nanomaterials and bio-based polymers. Besides, filling up the gaps in data sharing will add more strength to the foundation of this field.

The present study, while achieving remarkable successes in the field of seed coating, has tried to enhance the contribution of our country, which has a relatively modest share in the global research landscape, and raise awareness about the importance of seed coating technologies. Closing existing gaps and developing much more collaboration will go a long way in helping the contribution of seed coating technologies toward the achievement of betterment in sustainable agriculture, improving global food security, and answering the challenges brought forward by the changing climate.

Author Contributions: Conceptualization: S.E and Y.A.; methodology, S.E and Y.A, analysis of data, production of figures: S.E. Y.A. and A.K.C.T; writing, review, and editing: S.E., Y.A., A.K.C.T and J.K.A.; supervision of research, structuring the paper, writing the original draft, and draft preparation: S.E. and Y.A. All authors have read and agreed to the published version of the manuscript.

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