A Bibliometric Analysis of Post-Harvest Research and Innovations in Tackling Grain Crisis using VOSviewer

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ABSTRACT

Grain security has been a significant concern over the decades since global food consumption is almost entirely grain-based, especially in developing countries. Food security can be achieved if grain security, as a prerequisite, is met. However, grain security for a country is not only a production issue but also a complex distribution problem, including postharvest issues. The problem of postharvest improvement in maintaining the quantity and quality of production can be solved through the application and development of research and innovation. This paper aims to systematically plot the output of scientific research on postharvest technology to overcome the grain crisis using a quantitative review technique called bibliometric analysis. Data was taken from the Scopus database and analyzed using VOSviewer software. Out of 2204, only 95 keywords from 314 articles met the threshold and were analyzed. The results show that the topic of storage (grain/food storage) received considerable attention from 2007 to 2021, featured in 70 articles with 396 total link strengths. Furthermore, one of the most cited research topics recently relates to using various scientific storage methods to reduce grain postharvest losses in developing countries, with 227 citations from 2017 to 2021. In general, researchers can use this study to examine trends and the direction of future research topics quantitatively.

Keywords: *grain security, good postharvest practice, hermetic storage, postharvest losses.*

1. INTRODUCTION

Grains are one of the most important staple crops in the world. The demand for grain has increased globally due to the rapid growth of the world's population, which contributes to an increased risk of hunger and food crises. Since the 2019 covid pandemic, the world has experienced a dramatic surge in the price of many staple food commodities. For example, in Burkina Faso, grain prices have increased throughout 2021 despite downward pressure from the harvest season. The price of maize increased by 39% from the previous year and has since risen further. Many other commodity prices rose sharply over this period: millet by 12% and sorghum by about 19% [1].

Restrictions on movement within the country to limit the spread of COVID-19 and closing borders due to conflicts in grain-producing areas have caused many countries that depend on their food supply from imports and low currency exchange rates to experience domestic food price inflation. With no grain reserves to withstand grain price shocks, the scale of the potential increase in grain prices in these countries will depend on the magnitude of the possible trade disruption and the time it takes for grain traders to find alternative grain sources. Thus, the grain crisis has become a global problem and has increased the world's attention to solving agricultural problems.

To meet this demand, most countries in the past few years have only issued policies that focus more on increasing food production, expanding agricultural land use, and controlling the population [2]. However, about a third of the food successfully produced globally is lost during postharvest operations, known as postharvest losses [3]. Postharvest losses are food initially available for human consumption but was not consumed because it disappeared or expired. Postharvest losses can occur during the supply chain from harvesting to consumption. The grain undergoes many treatments during the transfer of grain from the farmer to the consumer. If there is no appropriate handling and adequate processing facilities,

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it will trigger the risk of degradation by microorganisms, insects, and pests, thus impacting grain losses [2].

The loss of grains is the largest among other foodstuffs based on calorie content. On a global scale, 1.4 billion hectares of land produce food wastefully as it is eventually lost to postharvest operations [4]. Unfortunately, this issue has received less attention, indicated by the low research funding of less than 5% [5], even though investment costs in reducing postharvest losses are considered lower than increasing production to balance food demand.

Reducing grain loss is one of the most efficient ways to strengthen food security, fight hunger, conserve production resources, and improve farmer welfare. Technological intervention plays an essential role in resolving the issue of postharvest losses [6]. However, due to several constraints, appropriate postharvest technology has not been widely applied. These constraints include farmers' limited access to information about new postharvest technology options, factors causing damage, and best handling practices to reduce losses while saving resources, water, and energy. Thus, postharvest losses are currently still higher than they should be. Thus, through bibliographical analysis, this paper will examine some studies on postharvest technological interventions for grain published worldwide to describe the global output on the topic and define current research directions.

2. METHODOLOGY

Bibliometric analysis is a quantitative method to identify the direction and pattern of development and literature structure in a particular field based on the bibliometric data. The bibliometric data can include article attributes (i.e., publication, citation, contributor and publisher keywords) and their relationship. Thus, this technique is also commonly used to summarize the current state of the art of existing or emerging research topics.

2.1. Data collection

One of the critical stages in a bibliometric study is determining the proper database to extract data from the literature. The data for this study were collected from the Scopus database, as suggested by [7]. Scopus is used as a bibliometric resource in the study because it is considered by many researchers to be the largest database of citations and abstracts from peer-reviewed literature. Scopus is also one of the most massive and well-known databases in various research fields [8].

Our research focuses on all research on postharvest interventions in grain commodities from early 2007 to late 2021 in peer-reviewed journals, especially in the fields of agricultural and biological science and engineering. This year's selection was based on the consideration that in 2007 there was a world food price crisis [9]. The search process was carried out in June 2022. Therefore, we decided to exclude the 2022 article because every retrieval from that period would risk including incomplete bibliometric data. Our analysis did not include grey literature, conference proceedings, or book/book chapters. For filter processing, articles written in languages other than English are excluded.

2.2. Search strategy

On the Scopus Website (http://scopus.com/), using the combination of search parameters in the document search field, the search query string is obtained as follows: (TITLE-ABS-KEY (postharvest* OR post-harvest*)) AND (TITLE-ABS-KEY (technology OR treatment OR procedure OR method OR innovat* OR control* OR process* OR handl*)) AND (TITLE-ABS-KEY (crisis OR loss OR security OR shortage OR wast*)) AND (TITLE-ABS-KEY (grain OR cereal)) AND NOT (TITLE (feed OR fruit OR fertilizer)) AND NOT (KEY (feed OR fruit OR fertilizer)) AND (LIMIT-TO (LANGUAGE , "english")) AND (LIMIT-TO (SUBJAREA , "agri") OR LIMIT-TO (SUBJAREA , "engi")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")).

As shown in the strings, "postharvest", "technology", "crisis", and "grain", along with similar terms, are the main keywords of interest. However, because the grain crisis also occurred in using grain as a feed ingredient, the term feed was excluded from the search data. In addition, the terms fruit and fertilizer are also excluded because they are often associated with research on non-grain materials and are carried out in the pre-harvest phase, respectively. The reason for removing these terms is to filter out all unnecessary keywords that may be included in the data analysis, which may distract from the purpose of the study scope. In the context of this research, the bibliometric analysis only focuses on global research outputs related to postharvest technological innovations to overcome the grain crisis as a food ingredient. Exactly 314 publications were retrieved from the Scopus database. Each publication includes the following information: document title, author, country of author, year of publication, author's keywords, research area, the title of the source, and the number of citations. All data is downloaded in ".csv" format (Microsoft Excel).

2.3. Bibliometric analysis

This study adopted three effective techniques: performance analysis, science mapping, and network mapping. Performance analysis is a descriptive method for evaluating publications and citation-related metrics (e.g., evaluation of the total number of publications and citations, h-index). Meanwhile, science mapping (or bibliometric mapping) analyses the influence and strength of relationships among different article attributes as indicated by item co-occurrence weights and total link strength. Furthermore, the results of bibliometric mapping can be improved through network analysis.

In the current study, the performance analysis is supported by data taken from Scopus consisting of total publications, number of publications per year active, and total annual citations, which can be easily determined through frequency, and impact factors, as well as h-index. The h-index is equivalent to the maximum number of *i* articles cited in a set of *n* calculated publication years with at least *i* citations [10]. In this study, these parameters are calculated with the help of an analytical tool embedded in the Scopus system.

Science and network mapping was performed using pre-extracted files from data sources and free software called VOSviewer (version 1.6.18). In addition, the bibliometric mapping in this study is limited to keywords and co-authorship analysis. Meanwhile, network mapping is done through clustering and visualization. Vosviewer, which has an attractive graphical user interface, makes it easier to identify clusters in the map to derive themes from them. In network visualization, items are represented by labels and circles. The item's weight determines the size of the item's label and circle. The higher the item weight, the larger the item's label and circle size. In addition, the existence of colour coding indicates the popularity and similarity of the research.

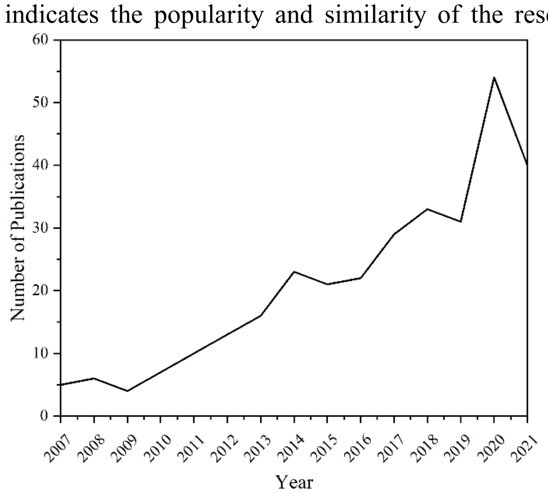

Figure 1 Annual publication growth of bibliometric papers from 2007 to 2021.

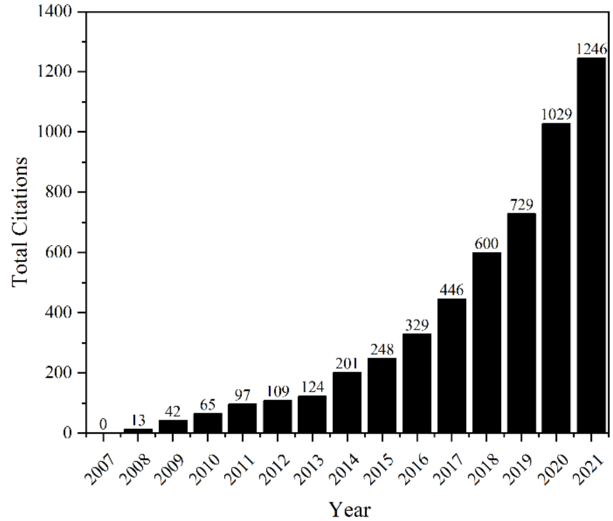

Figure 2 Annual total citations trend of the bibliometric articles.

3. RESULTS AND DISCUSSION

3.1. Publication output and growth trend

Performance analysis was conducted early to test publications obtained from Scopus before the bibliometric data was mapped. This method can evaluate publication performance in terms of publication output by author, affiliated institution, country, and growth trend over the years. This study presents the number of publications per year, the total citations per year, the h-index, the most cited articles, and the most relevant articles.

The annual frequency of publication of scientific articles can be an indicator of publication performance in certain fields. Figure 1 describes the annual publication rate of articles from 2007 to 2021 for a total of 314 publications. The least number of publications (n=5) was recorded in 2007. The data peaked in 2020 with 54 publications, and of these articles were the most published in the Journal of Stored Products Research and the Journal of Food Processing and Preservation.

The number of publications is irrelevant if other studies do not cite the article. Thus, the total number of annual citations received by articles is also evaluated. In Figure 2, it can be seen that there is an increasing trend in the total number of citations per year, from only 13 in 2008 to 1246 in 2021. The total number of annual citations experienced a significant spike in 2020 along with the outbreak of the Covid 19 pandemic around the world, and the issue of the food crisis is getting hotter.

The productivity and impact of a collection of search results articles can be displayed using an h-graph, as shown in Figure 3. The horizontal axis indicates the order of documents based on the number of citations from the largest to the smallest. In contrast, the vertical axis indicates the number of citations for each article. The 45-degree linear line depicts the relationship of the number of citations equivalent to the number of articles. When the curve for the number of document citations intersects with the 45-degree line, the h-index value of this collection of articles can be determined, which is marked by a star.

The h-index, in the case of this study, is used as a numerical indicator that shows the influence and productivity of the collection of articles on search query results on Scopus. Based on the data, the h-index for the collection of articles is 33, which means that 33 of the 314 articles have been cited at least 33 times.

Furthermore, the most cited articles from the document collection are shown in Table 1. The results show that the article by Magan and Aldred [11] on strategies to minimize mycotoxins in the food chain was the most cited, with 394 total citations. However, when a

Table 1. Most cited article on postharvest handling of grains.

	Document Title	Authors	Publication Year	Journal Title	Impact Factor	Journal h-index	Total Citations	Average Citation
1	Post-harvest control strategies: Minimizing mycotoxins in the food chain	Magan N., Aldred D.	2007	International Journal of Food Microbiology	5.277	199	394	28.1
2	Biorational approaches to managing stored-product insects	Phillips T.W., Throne J.E.	2010	Annual Review of Entomology	19.686	209	371	33.7
3	Mycotoxin problem in Africa: Current status, implications to food safety and health and possible management strategies	Wagacha J.M., Muthomi J.W.	2008	International Journal of Food Microbiology	5.277	199	343	26.4
4	Postharvest losses and waste in developed and less developed countries: Opportunities to improve resource use	Hodges R.J., Buzby J.C., Bennett B.	2011	Journal of Agricultural Science	1.476	78	328	32.8
5	Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries	Kumar D., Kalita P.	2017	Foods	5.561	53	227	56.8
6	Detection techniques for stored-product insects in grain	Neethirajan S., Karunakaran C., Jayas D.S.	2007	Food Control	5.548	135	190	13.6
7	The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries	Tefera T., Kanampiu F., De Groote H.	2011	Crop Protection	2.571	108	145	14.5
8	Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania	Abass A.B., Ndunguru G., Mamiro P.	2014	Journal of Stored Products Research	2.643	82	123	17.6
9	Cereal fungal infection, mycotoxins, and lactic acid bacteria mediated bioprotection: From crop farming to cereal products	Oliveira P.M., Zannini E., Arendt E.K.	2014	Food Microbiology	5.516	128	110	15.7
10	Effectiveness of hermetic systems in controlling maize storage pests in Kenya	De Groote H., Kimenju S.C., Likhayo P.	2013	Journal of Stored Products Research	2.643	82	92	11.5

comparative analysis was conducted on the average number of citations per year for the top ten articles, it was found that the articles on mycotoxins were still inferior to other articles on efforts to reduce postharvest losses during storage. For a span of only 5 years, from 2017 to 2021, the postharvest storage method article by Kumar and Kalita [2] could produce 227 citations or 56.8 citations per year. In contrast, it took 15 years for mycotoxin articles to produce 394 citations. This study shows strong performance as a review article based on the number of citations. The performance of the journal in which this article was published may also be a determining factor. The article was published in the journal Foods, which has a good impact factor of 5,561 and an h-index of 53, even though it was only launched in 2012.

There is growing interest in finding out grain storage techniques that are resistant to postharvest pests and diseases, cost-effective, practical to use, and without sacrificing food quality and safety. In addition to securing the amount of food supply reserves within a certain period, especially for seasonally produced grains, grain storage is also carried out to maintain the quality of the grain before it is ready for consumption and further processing. However, some studies report the maximum loss in this operation [12]. The losses can be in the form of grain deterioration due to respiration from the grain itself, insects, and microorganisms. Most of the loss occurred in grain stored in traditional buildings, which were unsuitable for preventing insect infestation and fungal growth. In maize, for example, losses are estimated to reach 59.48% after storage in traditional buildings [13]. At the same time, metal silos were found to be effective in several studies. However, its high initial cost was a major barrier to its adoption, especially at the smallholder level [14]. Appropriate and effective postharvest storage technology interventions will help reduce losses and improve farmers' quality of life.

For the interest of this research, the review conducted by Kumar and Kalita [2] will indeed be useful for many postharvest researchers because the world is leaning more towards increasing food production to overcome the grain crisis. The study offers insight into pre-storage and storage techniques based on various factors, enabling the reader to assess different effective loss suppression mechanisms for grains. Kumar and Kalita [2] effectively describe the postharvest handling process of grain and compare them with each other. As also supported by Asghar et al. [15], the best method for storing cereal grains for a long time is airtight storage which can suppress the growth of insects and fungi, called hermetic storage. This method creates an auto-modified atmosphere of high carbon dioxide levels using a sealed waterproof bag or structure.

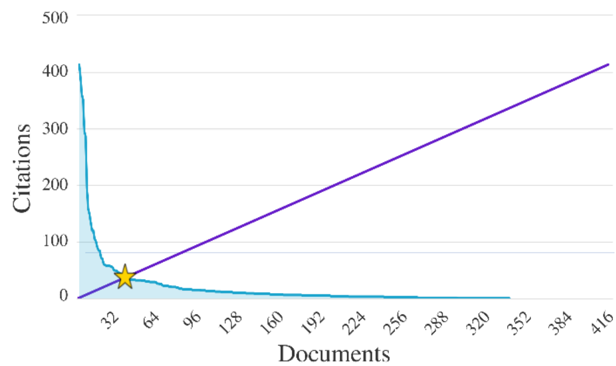

Figure 3 h-graph of the document collection.

Various hermetic storage options, such as plastic silos, supergrain bags, grain safe bags, and Purdue improved cowpea storage (PICS) bags, have been developed and promoted recently. Njoroge [16] found that maize storage for 6 months using PICS bags only resulted in weight loss of 0-2%, much smaller than those using woven polypropylene bags which reached 36.3-47.7%. Simply put, the PICS bag is a type of storage bag consisting of a double-layer thick (80um) high-density polyethylene (HDPE) bag wrapped in a woven nylon bag. These bags have become a practical and cost-effective storage technology and have become popular in several countries. However, one of the main challenges in hermetic bags is that the grain to be stored should have gone through drying to prevent mold and rotting. In addition, although hermetic bags have been tested to protect grains from insect damage, they are not a good barrier against rodent attacks. Thus, it is suggested by Kumar and Kalita [2] that the future direction of this research interest is based not only on providing appropriate and affordable storage technology but also on applying better agricultural practices. This effort will be able to significantly reduce losses and improve food security, as well as improve the welfare of farmers.

3.2. Mapping analysis on bibliometric data

The bibliometric data were analyzed in co-occurrence mapping and co-authorship mapping. Co-occurrence refers to the relationship between keywords, while co-authorship relates to the interaction of authors, contributing countries, or affiliations to develop the research field.

In co-occurrence mapping, all keywords are used as a unit of analysis with a full counting method and combining synonyms and their plurals. This study also establishes some limitations in the analysis. For example, a minimum of five (5) keyword occurrences is set as a limiting factor. So, out of 2,204 keywords from 314 articles, only 95 keywords met the threshold.

Table 2 Most highly co-occuring keywords.

	Keywords	Links	Total Link Strenght	Occurrences
1	Storage	88	396	70
2	Maize	83	357	64
3	Postharvest Losses	73	197	51
4	Postharvest	59	140	45
5	Hexapoda	71	272	42
6	Food Security	68	167	29
	Grain	57	151	29
7	Fungi	68	188	25
8	Animal	71	182	22
9	Coleoptera	44	128	21
	Harvesting	59	135	21
	Wheat	63	129	21
10	Moisture	42	94	19
	Mycotoxin	54	123	19

Each keyword is analyzed using software that can calculate links, total link strength, and co-occurrence of keywords with other keywords. Link means a concurrent connection between two keywords. According to the VOSviewer manual, each link has a strength, represented by a positive numeric score. The higher this score, the stronger the link. Total link strength shows the number of publications where two keywords appear together. Also, occurrences represent the number of articles where the keyword can be found. As shown in Table (2), the keywords with the highest co-occurrence are shown. Storage, maize, postharvest losses, postharvest, and hexapods were among the keywords that appeared most frequently, along with their occurrence weights (total link strength) being 70(403), 64(361), 51(198), 45(141), and 42(275), respectively.

The occurrence of keywords is also illustrated through network visualization. Visualizing networks has received attention from researchers. It has become a powerful method for identifying hidden topics from large data sets. As seen in Figure (4), the 95 keywords were able to form 5 clusters: cluster 1 (red), cluster 2 (green), cluster 3 (blue), cluster 4 (yellow), and cluster 5 (purple). Then, the keywords in each cluster were examined to determine the main topics brought by each cluster. The size of the circle represents the occurrence of keywords. The larger a circle, the more a keyword is selected in the considered documents. At the same time, the distance between items and lines shows the relationship between keywords.

Cluster 1. The first cluster is generally associated with efforts to suppress losses during grain storage by conditioning the grain before storage and regulating

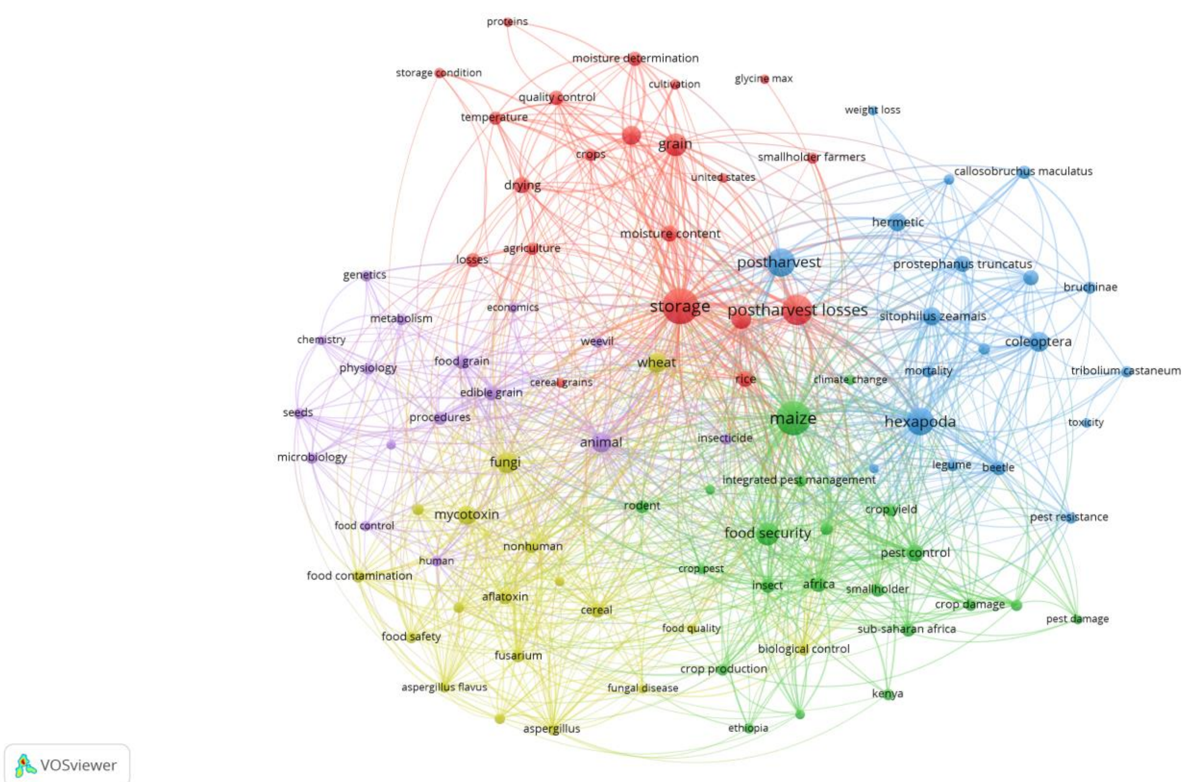

Figure 4 Co-occurrence map of the keywords.

storage conditions. Storage, postharvest losses, and grain are the keywords with the highest co-occurrence, with scores of 70, 51, and 29, respectively. In other words, for example, a co-occurrence weight of 70 means the keyword "storage" appears in 70 articles out of 314 articles, or 22% of the total publications in the analysis.

Based on closer network visualization in VOSviewer, storage was more strongly linked with 4 keywords: maize, postharvest losses, Hexapoda, and grain. This keyword set can be considered a hot topic in grain storage research. Individually, these keywords were found in 64, 51, 42, and 29, respectively.

Storage can be successful if it can maintain the quality and quantity of grain stored during the shelf life, whose length depends on various factors. The shelf life of grains is greatly influenced by storage conditions, such as moisture content and temperature. At humidity over 70% and a temperature of 20-40 ˚C, the potential for grain damage can increase. Preventing damage, especially from mold growth, can be pursued by setting the general humidity below 70% [17]. In addition, another effort that can be made is to minimize the temperature difference between the inside and outside of the storage building, which has the potential to cause moisture accumulation at certain points due to temperature fluctuations.

Furthermore, the shelf life of grains can be extended by drying the grains before storage to about 13%. According to Abedin et al. [17], rice only has a shelf life of a few weeks if stored at a moisture content of 16% or higher. The practices of cleaning and drying the grain before storage may result in lower losses by margins of 4.5% and 7.9%, respectively, because they help reduce mold and pest incidence in stored grain lots [18].

Cluster 2. The second cluster focuses more on pest control efforts to improve food security, especially in Africa. Maize, food security, and pest control were the keywords with the highest co-occurrence weights at 64, 29, and 16, respectively. Maize is more related to keyword storage (co-occurrence weight = 70) and hexapods (co-occurrence weight = 42). Thus, it can be explained in these results that the increased interest in maize research is also closely related to storage problems due to hexapod attacks.

Currently, it is found that insects are the most threatening pest in most of Africa, as they can cause widespread damage in a short period. For example, storage losses for maize in Kenya are 17.6%, with perceived weight losses due to insects, rodents, molds, spillages, birds, and moisture being 7.2%, 2.0%, 5.7%, 0.5%, 0.1%, and 3.4%, respectively [18]. The weight loss of maize due to insect infestation during 6 months of storage in Togo using traditional buildings was estimated by [19] to reach 0.2-11.8%. At the field storage level, more than 30% of the weight loss in maize is caused by this type of pest. According to Mwangi et al. [18], storing maize for less than 2 months, drying grains before storage, cleaning grain before storage and applying pesticides in the first month of storage or after the purchase was associated with lower losses.

Cluster 3. The top 3 keywords are postharvest, hexapoda, and coleoptera, with co-occurrence frequencies of 45, 42, and 21, respectively. By examining the keywords associated with this cluster, it can be observed that the topic concentration lies in various insects that can cause weight loss during postharvest operations.

Insect pests are considered the largest and most important cause of grain loss. Traditionally in East Africa, the grain weevil (*Sitophilus spp*. Coleoptera: Curculionidae) and the Angoumois grain moth (*Sitotroga cerealella* (Olivier) Lepidoptera: Gelechiidae) on cereals, and three genera of the family Chrysomelidae, sub-family Bruchinae (Acanthoscelides, Zabrotes and Callosobruchus), are notorious insect pests in grain stores [20]. *Coleoptera bruchidae* alone, the most common pulse weevil, was responsible for up to 24% loss in stored pulses in Nigeria. In addition, about 23% of the losses found in stored maize grains were mainly caused by infestations of *Sitophilus zeamais* and *Prostephanus truncatus*. On the other hand, wheat grains stored for 3 months under laboratory conditions can experience a loss of about 25% due to *R. dominica* [21].

Furthermore, in the third cluster, it is also shown the risk of inappropriate insect pest control. Improper control of insect pests in time and dose, for example, in chemical fumigation, can lead to genetic resistance in insects and health hazards due to toxic residues. For example, phosphine resistance in pest populations develops primarily due to failure to maintain recommended concentrations in storage spaces [22]. Several factors that can lead to inadequate fumigation include leaky storage structures, doses too low, and fumigation temperatures lower than those recommended for fumigating phosphine. In addition, repeated fumigation efforts to compensate for leakage of storage space are considered to increase insect pest resistance [23].

According to Collins [22], efforts to suppress this resistance can be made by ensuring the storage structure is airtight, limiting the number of fumigation repetitions in the same batch of commodities, and minimizing the use of fumigation through rotation of other protective treatments on grains. In addition, early detection of infestations would help reduce the magnitude of losses because it would allow prompt treatment of grains. For example, acoustic detection is a promising method for detecting insect larvae inside stored product grain kernels [24].

Cluster 4. The fourth cluster focuses more on types of fungal contamination in the postharvest period that can cause disease and decrease food safety. Fungi, wheat, and mycotoxins were the keywords with the highest co-occurrence weights at 25, 21, and 19, respectively. Fungi synergize more with keyword storage, mycotoxin, and Fusarium, which indicates that these keywords often appear together.

Mycotoxins are secondary metabolites produced by filamentous fungi, mainly of the genus Fusarium [25]. Fusarium mycotoxin is a natural contaminant in food commodities. Mycotoxins pose a real threat to human health and can cause disease and even death. Mycotoxins can form both before harvest and after harvest. Postharvest prevention strategies are only effective for mycotoxins formed during the postharvest process chain. Damage due to the activity of this fungus can be minimized by controlling humidity in a clean storage room and measuring the moisture content regularly in stored grain [26].

Grains stored at high relative humidity are more at risk of fungal damage. According to Carbas et al. [27], using sensors to monitor relative humidity, temperature, and CO_2 levels during maize grain storage was a good tool to warn of increased fungal activity that can trigger mycotoxin accumulation. Therefore, further research is needed on applying good postharvest practices and solutions to reduce mycotoxin contamination in grains.

Cluster 5. The last cluster appears to be related to factors that must be considered in developing grain handling procedures. The top keywords included animal (22), edible grain (11), food grain (11), procedures (10), and genetics (7). Among these keywords, "animal" strongly correlates with prominent items from other clusters, such as maize in cluster 2, storage in cluster 1, hexapods in cluster 3, and cereals in cluster 4. In addition, this cluster also includes the terms microbiology, physiology, economics, and chemistry.

Table 3 Top-ten countries with the highest number of publications.

	Country	Documents	Citations
1	United States	77	2380
2	Nigeria	34	543
	India	34	285
3	Kenya	31	924
4	Brazil	27	242
6	Germany	18	639
7	Ethiopia	17	92
8	Pakistan	14	65
9	United Kingdom	13	967
	Mexico	13	265
	China	13	150
10	Australia	11	207

Good grain handling, especially storage, is challenging in many developing countries because best practices and good storage protection are not followed. One of the challenges of grain storage in developing countries is the lack of specially constructed storage facilities [28]. Smallholders and micro small and medium enterprises (MSMEs) generally store grain in inappropriate places, usually by changing idle places. Such a place may not meet the requirements for good grain storage. According to [29], significant losses, for example, from insects, usually only occur after 3-4 months of grain storage, but in inappropriate buildings, it can occur earlier. Farmers often make this choice for economic reasons because the cost of building the right structure is very high, while the duration of storage of their grain is shorter than that of the government, which needs to store more than 12 months [18]. So even though the storage period is shorter, a poorly constructed storage structure can cause grain storage by smallholders and MSMEs experiencing problems associated with insects, rodents, and fungi.

Grain storage can be done in bags or bulk. Bag storage is the most common and flexible storage technique [30]. Woven polypropylene (WPP) bags are generally more popular than jute bags. Besides being cheaper and widely available, WPP bags are also convenient for frequent and dynamic trading activities. However, the use of WPP bags for the long term can be limited by grain physiology, where respired grains can accumulate heat and moisture [31].

For this reason, the repeated use of jute bags is often an alternative, even though they are easily damaged by rodents and birds and are prone to causing losses due to spills and contamination. Another option that tends to be better is using hermetic bags, which have been discussed previously. Therefore, postharvest handling of grain generally needs to consider the economic aspect, the physiological aspect of the grain, and the microbiological aspect that causes damage through the implementation of good storage protection. Thus, training is needed to build grain handlers' capacity while monitoring and enforcing standards need to be strengthened.

3.3. Geographical Distribution

A total of 314 articles were drawn on postharvest handling of grains obtained from over 79 contributing countries. Table 3 presents the top 10 countries contributing 96.2% of the total publication. These countries published 302 articles and received 6759 citations.

As of 2021, the United States published the most articles, followed by Nigeria, India, and Kenya. In addition to dominating global scientific and engineering research [32], the United States also leads the innovation ranking in the 2021 global innovation index, which for

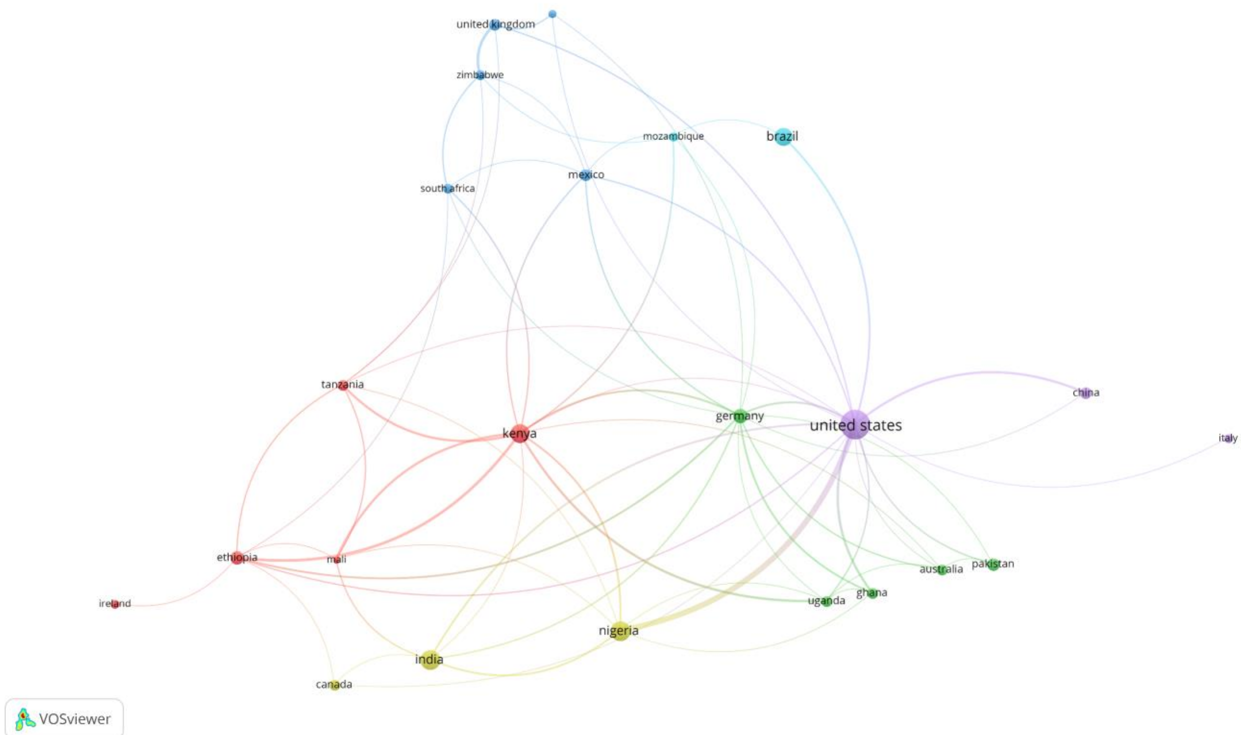

Figure 5 Geographical distribution map.

the previous 3 consecutive years has always been in the top 5 [33]. More importantly, the United States also dominates the impact of its scientific output on postharvest handling of grain, with a total of 2380 citations or 28.9% of the total citations for this research topic, followed by the United Kingdom, Kenya, and Germany. Almost all 4 countries with the most dominant articles cited had sufficient funding and suitable tools, equipment, and structure. In the case of Kenya, agriculture is the backbone of its economy, which is around 35% of the gross domestic product (GDP) and makes Kenya the most developed country in the East and Central Africa region. Therefore, the government's funding share of the budget has mainly been invested in agricultural research [34].

Furthermore, the co-authorship between countries is illustrated in Figure 5. The United States was more collaborative with researchers from Nigeria, China, and Ghana. Kenya has more collaborations with Ethiopia, Mali, and Tanzania.

4. CONCLUSION

This paper uses the properties of bibliometric analysis to assess the current state and development of scientific output trends on postharvest handling of grain. Based on a performance analysis of 314 articles taken from Scopus, this study can claim that interest in this research topic has increased 10-fold over the past 15 years and that the research hotspot is primarily storage related. As well as being a frequent topic, it was also revealed that the suppression of postharvest losses during storage is gaining interest and has been increasingly cited in the scientific community since 2017. In addition, this study also reveals that high-income countries with adequate grain storage facilities significantly contribute to promoting good storage protection for grains.

In addition, there is still a lack of publications on this topic while many postharvest losses need to be addressed in the grain handling sector for food supply. The availability of grain reserves will remain critical to supporting food demand from its global consumers in the future. As technical barriers to providing adequate and affordable grain handling facilities still exist, as well as disciplinary issues in implementing good postharvest practices, the significant scientific effort will be more important to uncover them.

AUTHORS' CONTRIBUTIONS

Conceptualization, data curation, formal analysis, investigation, methodology, resources, validation, visualization: Redika Ardi Kusuma. Writing – original draft, writing – review and editing: Redika Ardi Kusuma, Jamaludin.

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