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Why do we need more research on pineapple (*Ananas comosus* L. Merr.)? A discussion based on a bibliometric review

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Abstract: Pineapple is the most exported tropical fruit in the world in terms of volume. This study aimed to comprehensively analyze the scientific publications on pineapple, with an emphasis on the agricultural sciences. 7,885 documents published between 1893 and 2022 (February 22nd), 2,350 of which belonged to the agricultural sciences, were retrieved from the Scopus-indexed database to be analyzed using the word pineapple. VOSviewer software was used for a bibliometric network analysis using author keyword mapping. 78.2% of the documents were articles, with an increase in the volume of publications over time. The scientists were from 138 countries, with India, the United States, and Brazil accumulating 36.2% of the total number. The research has focused on topics such as chemistry, food technology (primarily juice), the use of pineapple as a medicinal plant, and the clinical benefits of its main enzyme (bromelain). Scientists in the chemical field reported more research than in the agricultural and biological areas due to the properties of the fruit. Our results indicate that few studies focus on rural extension or technology transfer to growers. More efforts should be made to help local pineapple growers improve their yields and attain a sustainable and more environmentally friendly approach to the production of this fruit.

Keywords: antioxidant, bromelain, bioplastic, tropical fruit, science mapping.

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Por que precisamos de mais pesquisas sobre abacaxi (Ananas comosus L. Merr.)? Uma discussão a partir de uma revisão bibliométrica

Resumo: O abacaxi é a fruta tropical mais exportada no mundo em termos de volume. Este estudo teve como objetivo analisar de forma abrangente as publicações científicas sobre abacaxi, com ênfase nas ciências agrárias. 7.885 documentos publicados entre 1893 e 2022 (22 de fevereiro), 2.350 dos quais pertencentes às ciências agrícolas, foram recuperados da base de dados indexada pelo Scopus, para serem analisados usando a palavra abacaxi. O software VOSviewer foi usado para uma análise bibliométrica da rede, usando o mapeamento de palavras-chave do autor. 78,2% dos documentos eram artigos, com aumento do volume de publicações ao longo do tempo. Os cientistas eram de 138 países, com Índia, Estados Unidos e Brasil acumulando 36,2% do total. A pesquisa enfocou temas como química, tecnologia de alimentos (principalmente sucos), uso do abacaxi como planta medicinal e benefícios clínicos de sua principal enzima (bromelina). Cientistas da área química relataram mais pesquisas do que nas áreas agrícola e biológica, devido às propriedades da fruta. Nossos resultados indicam que poucos estudos focam a extensão rural ou a transferência de tecnologia aos produtores. Mais esforços devem ser feitos para ajudar os produtores locais de abacaxi a melhorar seus rendimentos e a alcançar uma abordagem sustentável e mais ecológica para a produção dessa fruta.

Termos de indexação: antioxidante, bromelina, bioplástico, frutas tropicais, mapeamento científico.

Introduction

Pineapple (*Ananas comosus* (L.) Merr.) is a tropical fruit that is native to South America and was introduced in Africa and India by the Portuguese; in many other places around the globe, there is no accurate account of how it was introduced (COLLINS, 1949). It belongs to the Bromeliaceae family, "one of the most diverse and ecologically important plant groups of the American tropics" (ZIZKA et al., 2020: 183). It is mainly grown in tropical regions (KUMAR et al., 2021), where it has become a relevant crop and plays a crucial role in the international trade of tropical fruits (VOLLMER et al., 2021). Pineapple is consumed fresh and as juice due to its pleasant taste and flavor (KUMAR et al., 2021).

Pineapple fruit contains fibers, vitamins, minerals, and bromelain, a digestive enzyme (RANI and TRIPATHY, 2021). Along with avocado and mango, it was the most exported tropical fruit in 2020. Except for bananas, pineapple was the most predominant commodity in quantity due to its shallow average export unit values: 39% of the share of quantities exported and 16% of the value (FAO, 2021). The relevance of the crop has increased over time; the harvested area worldwide rose from 369,000 hectares in 1961 to one million in 2020. Production went from three to twenty-seven million tons in the same period. Yields have more than doubled, increasing from 103 Mg/ha to 258 Mg/ha. In terms of harvested area, Asia is the most crucial production region, followed by Africa. In the case of production, America is the most important region. In 2020, 84 countries reported having areas where pineapple is cultivated. Of these countries, those that had the largest harvested area were China (16.3%), Nigeria (15.7%), India (9.1%), Thailand (5.8%), the Philippines

(5.7%), and Brazil (5.5%); another 77 countries had the rest of the total harvested area (42%). The countries that reported the most significant production volume were China (16%), the Philippines (8.9%), Costa Rica (8.6%), Brazil (8.1%), Indonesia (7.3%), and 80 other countries that produced the remaining 50% of the total. The average world yield for 2020 was 258,000 Mg/ha, and the countries with the highest yields for the same year were Israel (4,000 Mg/ha), Indonesia (1,200 Mg/ha), Costa Rica (656 Mg/ha), Côte d'Ivoire (636 Mg/ha), and Ghana (631 Mg/ha) (FAO, 2022).

Tropical areas in less developed and developing countries typically produce pineapple. These regions are not competitive and do not have a sustainable approach to agricultural practices (DESCLEE et al., 2021), which is strategic for two main reasons. First, to cope with global warming and second, to reduce the farmers' impact on carbon dioxide emissions (CO_2e). Some studies have concluded that innovation can mitigate such effects and help reduce emissions (WEIMIN et al., 2022). Along this line of thinking, understanding the research patterns makes it possible to determine the areas that matter more for researchers, especially if they have been focusing on environmental research. We wish to focus on primary production as this area has more sustainability problems (BROWN et al., 2020; LEÓN ARAYA, 2018). Therefore, the first level of analysis will explore global patterns and then focus on the agricultural sciences.

Bibliometrics is a quantitative research method that makes it possible to visualize trends based on scientific data in diverse types of publications using statistical methods (ARRIOLA et al., 2022). This method uses data mining, so it provides a summary of the most representative results of bibliographic material (MARTÍNEZ-LÓPEZ et al., 2018). This kind of analysis sheds light on the patterns of worldwide scientific literature. For example, using bibliometrics, scientific activities in agriculture sciences have been analyzed, *e.g.*, agricultural pollution (LI et al., 2022), production of ethanol from biomass (RAJESWARI et al., 2022), and antimicrobial substances produced by *Lactobacillus* spp. (MÖRSCHBÄCHER and GRANADA, 2022), to name a few.

Despite the relevance of pineapple, there is not a comprehensive review using bibliometric tools. There is a review for applications in pineapple agro-industrial residues (LIMA et al., 2018), but it remains partial. Therefore, this study aims to carry out a comprehensive analysis of the scientific publications on pineapple and provide information that will guide current research.

Materials and methods

Source and data collection and processing

Data were obtained from the Scopus database (Elsevier). This database was chosen due to its coverage and accuracy, as well as its coverage of peer-reviewed scientific literature and high citation records (MÖRSCHBÄCHER and GRANADA, 2022). The Scopus search using the word pineapple was conducted on February 22nd, 2022. A total of 8,038 articles were retrieved. At this point, no filtration had been done. After carefully reviewing the data, 153 documents were excluded: data papers, editorials, errata, letters, notes, reports, and short surveys (Figure 1). After an initial preview of the data maps for the general pathway, the decision was made to use the word 'pineapple' only in the title to better target research done in the agricultural sciences. This limited the research to publications in the agricultural and biological sciences. After those two criteria were established, 2,350 publications were retained for the analysis.

As these are global databases following text mining techniques (VAN ECK and WALTMAN, 2014), the decision to homogenize keywords was made. Therefore, all words in British English were changed to American English. Likewise, plurals became singular. Scientific names and common names of plants were unified. When possible, the use of a hyphen was avoided.

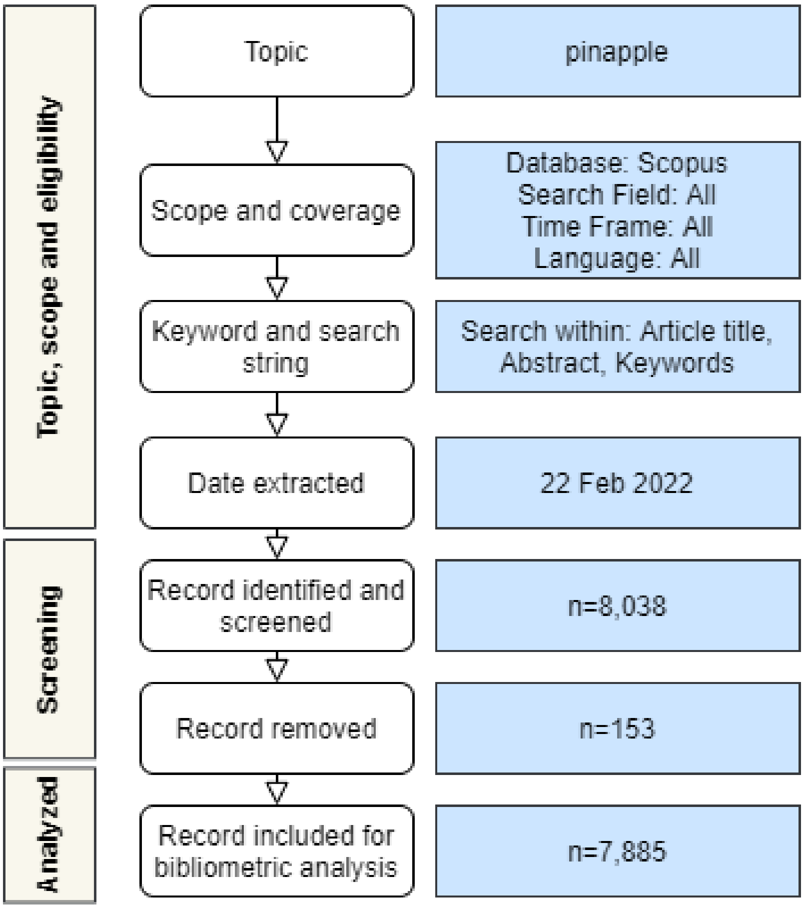

Figure 1. Methodology flow chart for the review of literature on pineapple.

Bibliometric mapping

VOSviewer, a free software for data visualization, was used in order to construct and view bibliometric maps. One of the most frequently used programs in scientometric studies, it analyzes data co-occurrence of information such as country, institution, author, and keywords (VAN ECK and WALTMAN, 2010). Term maps were produced to illustrate a network of recurring keywords and evidence their co-occurrence and relative citation impacts. Only terms that occurred at least ten times under binary count were considered. Two thousand one hundred and ten keywords met the threshold for the global analysis and 276 for the agricultural and biological sciences. In the first case, only 500 with the highest relevance score calculated with VOSviewer were used to create a map showing network visualization. In the second case, all terms were used. Before the final map was created, it was visually inspected and irrelevant terms were removed (article, pineapple, *ananas comosus*, fruit, nonhuman, and human). The maps used the following parameters: visualization scale of 1.0, association strength method, and clustering visualization of 1.00.

Results

This section provides a comprehensive bibliometric analysis of publications related to pineapple, and pineapple in the agricultural and biological sciences. It is divided into a performance analysis followed by the mapping of the publications.

Document and source types

For the global patterns, most of the documents selected were original articles (*n*=6283; 78.2%), followed by conference papers (*n*=1242; 15.5%), reviews (*n*=259; 3.2%), book chapters (*n*=234; 2.9%), and books (*n*=20; 0.2%). Considering that each article can be classified in more than one research area, most of the documents belonged to the area of agricultural and biological science (n=4173). Biochemistry, engineering, chemistry, material sciences and physics, and mathematics (n=5342), medicine, immunology, pharmacology, neurosciences and health professions (n=1915) were also relevant. In contrast, the areas with fewer documents were environment and energy and environmental sciences (n=1470), as well as social and economic sciences (n=783).

For the agricultural and biological sciences, 80% of the publications were articles, followed by conference papers (17%), two book chapters, one review, and two books. As stated above, some publications can be classified in more than one area. This was the case for 1362 publications, meaning that 42% belonged only to the agricultural and biological sciences. For the rest, 28% could also be classified in biochemistry, genetics, and molecular biology (n=375); 13% in engineering (n=174): 10% of which belonged to environmental sciences (n=143), 10% to chemistry (n=135), and 8% to chemical engineering (n=110), while another 19 areas were listed with fewer than one hundred publications.

Evolution of published studies and citations by year

Through a systematic search for publications on pineapple, we found 8,038 documents. Figure 2 shows the time trend of these publications. The first document on this subject was published in 1893, in the *Journal of Physiology* (CHITTENDEN, 1893). The year with the most publications was 2021, with 696 publications, indicating an increase over time. The same figure shows an increase over time in the number of citations *per* paper, achieving a total of 113,182 citations. The most cited articles related to pineapple are generalist, meaning that they do not focus only on pineapple but on fruits in general (SUN et al., 2002) or their compounds (MOHANTY et al., 2002). Only two articles had more than one thousand citations; 170 had between 100 and 771 citations. The mode was 1, and 25% of the documents were not cited.

When the focus is shifted to the agricultural and biological sciences, the trend observed is very similar to that presented for the general pineapple publications. A total of 29,560 citations were retrieved, the mean was 15.6 citations *per* article, and the mode

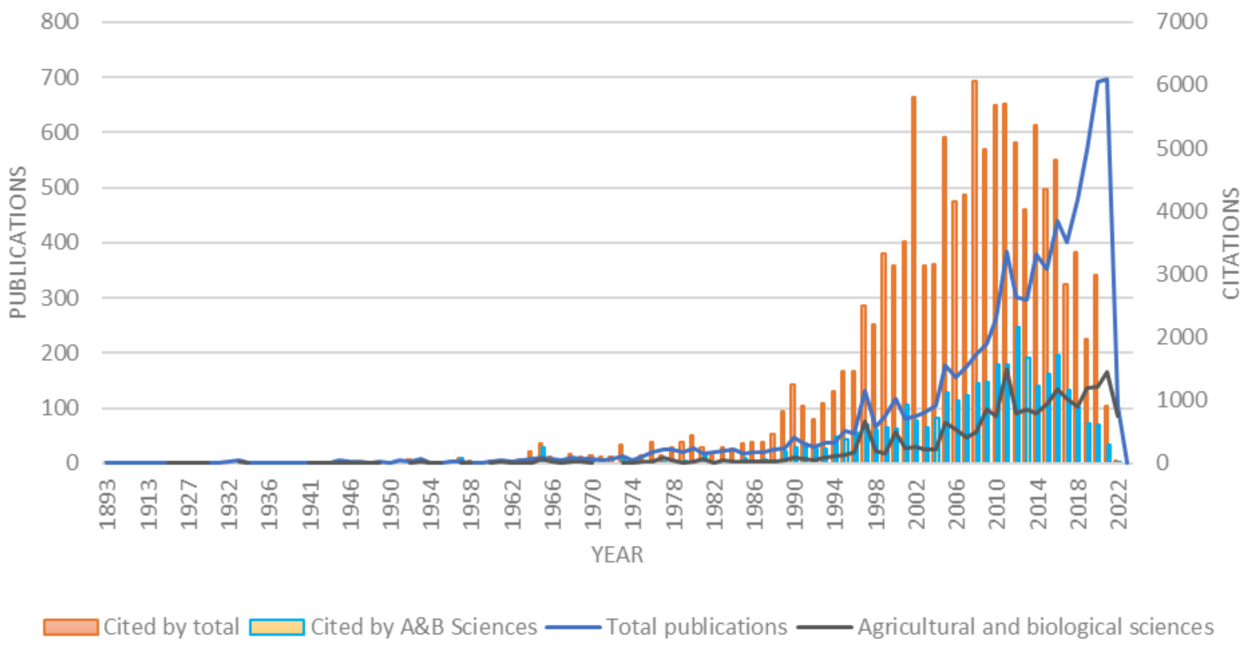

Figure 2. Number of scientific publications and citations on pineapple from 1893 to 2022 for all sciences (total) and agricultural and biological sciences (A&B).

was one; 458 publications were not cited. The most cited articles focused mainly on the properties of the fruit, *e.g.*, antioxidants (MARTÍNEZ et al., 2012), its conservation, *e.g.,* shelf-life extension (AZARAKHSH et al., 2014), as well as leaf characterization and properties (SANTOS et al., 2013). The second most cited article revolved around micropropagation (215 citations).

Influential countries

Scientists from 138 countries had publications regarding pineapple. India, the United States, and Brazil accumulated 36.2% of the total number. Seventy-eight countries that do not produce pineapple nevertheless have research related thereto, accounting for 30% of the total publications, the most productive being France, *n*=241; followed by Spain, *n*=239; Germany, *n*=221; Italy, *n*=189; and the United Kingdom, *n*=177. There does not seem to be a pattern regarding the number of publications from a certain country with that country's production of pineapple; for example, Nigeria, which in 2020 had the largest harvested area (15.7% of the global production) (FAO, 2022), had only 199 publications (2.5% of the total). Nor does the number of publications seem to be related to level of development; for example, India, Brazil, Malaysia, and Indonesia have many publications.

The countries with high harvested area and a large number of publications are India, Brazil, Malaysia, the United States, and China. For the rest of the countries, the level of scientific production remained low. Although Brazil, Malaysia, the United States, and China remained in the high yields/high level of publications cluster, India did not have the same level of yields as the rest; hence it separated from the cluster (Figure 3).

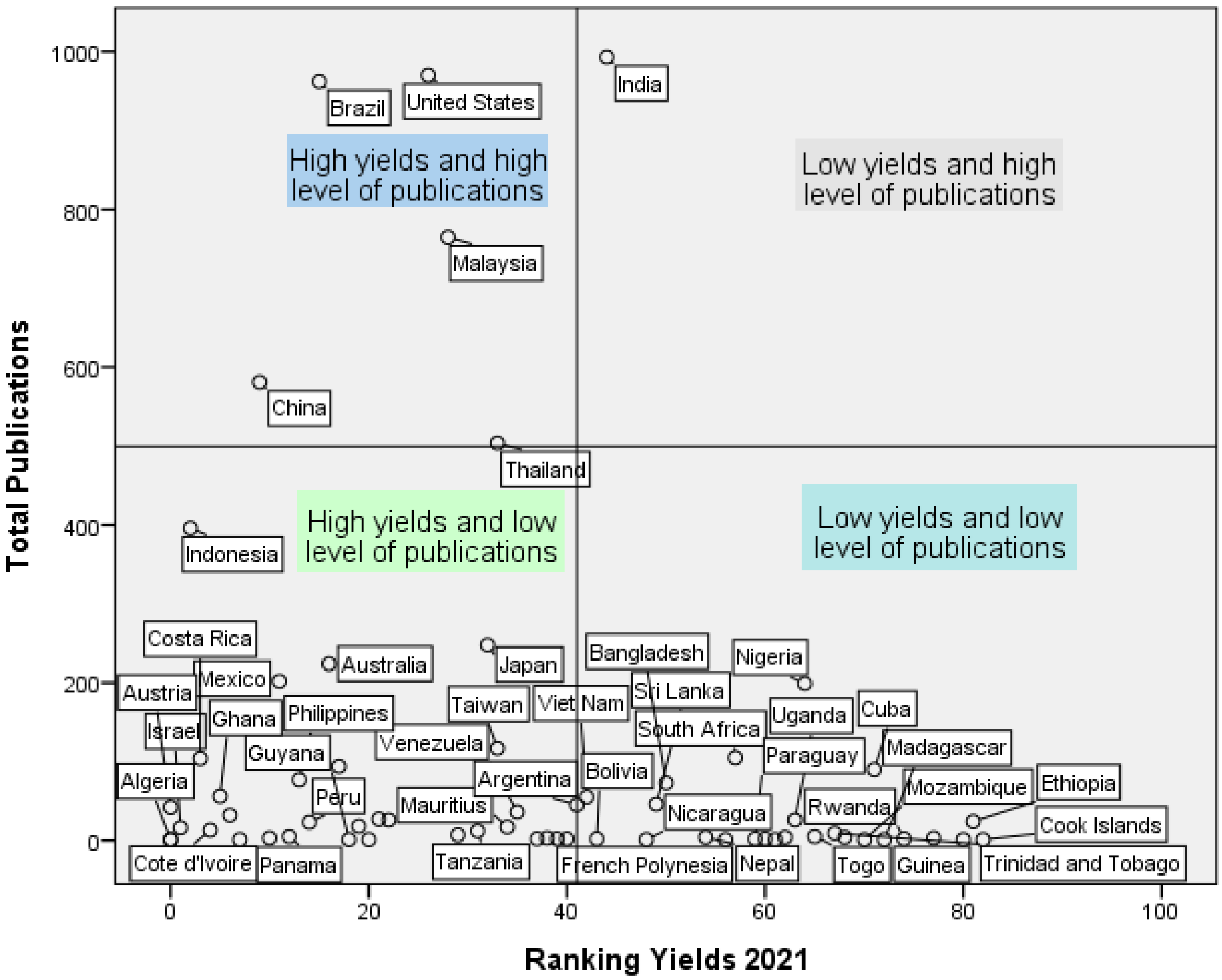

Figure 3. Total publications on pineapple (from 1893 to 2022) and ranking by country yield 2021.

Thailand and Indonesia are transitioning towards a high yield ranking/high level of publications. Finally, we found that most countries producing pineapple do not have many scientific papers.

Agricultural and biological science publications show the same general patterns: a large group of countries with low levels of publications in all positions of harvested area and yields. In addition, there is a group of 51 countries that do not produce pineapple but do conduct research on the topic; they contribute 18% of the publications, concentrated in five countries: France, *n*=78; Spain, *n*=61; Italy, *n*=46; Germany, *n*=38; and the United Kingdom, *n*=35. These countries had colonies in tropical regions until the middle of the last century; therefore, some commercial relationships and research collaborations continue to exist. With regard to harvested area, Brazil and the United States made up the cluster of high-area/high-level publications. Nevertheless, Brazil has had more interest in the topic, while China, Malaysia, Thailand, and China have dropped to the high area/low level of publications (Figure 4). If the analysis considers the yield ranking, the most productive cluster was Brazil and the United States. On the other hand, China, Malaysia, Thailand, and India reduced their levels of publications, so they remained in quadrants corresponding to a low level of publications.

Most influential institutions

A total of 160 institutions belonging to 33 countries have authored publications regarding pineapple; however, only seven institutions are responsible for 20% of the publica-

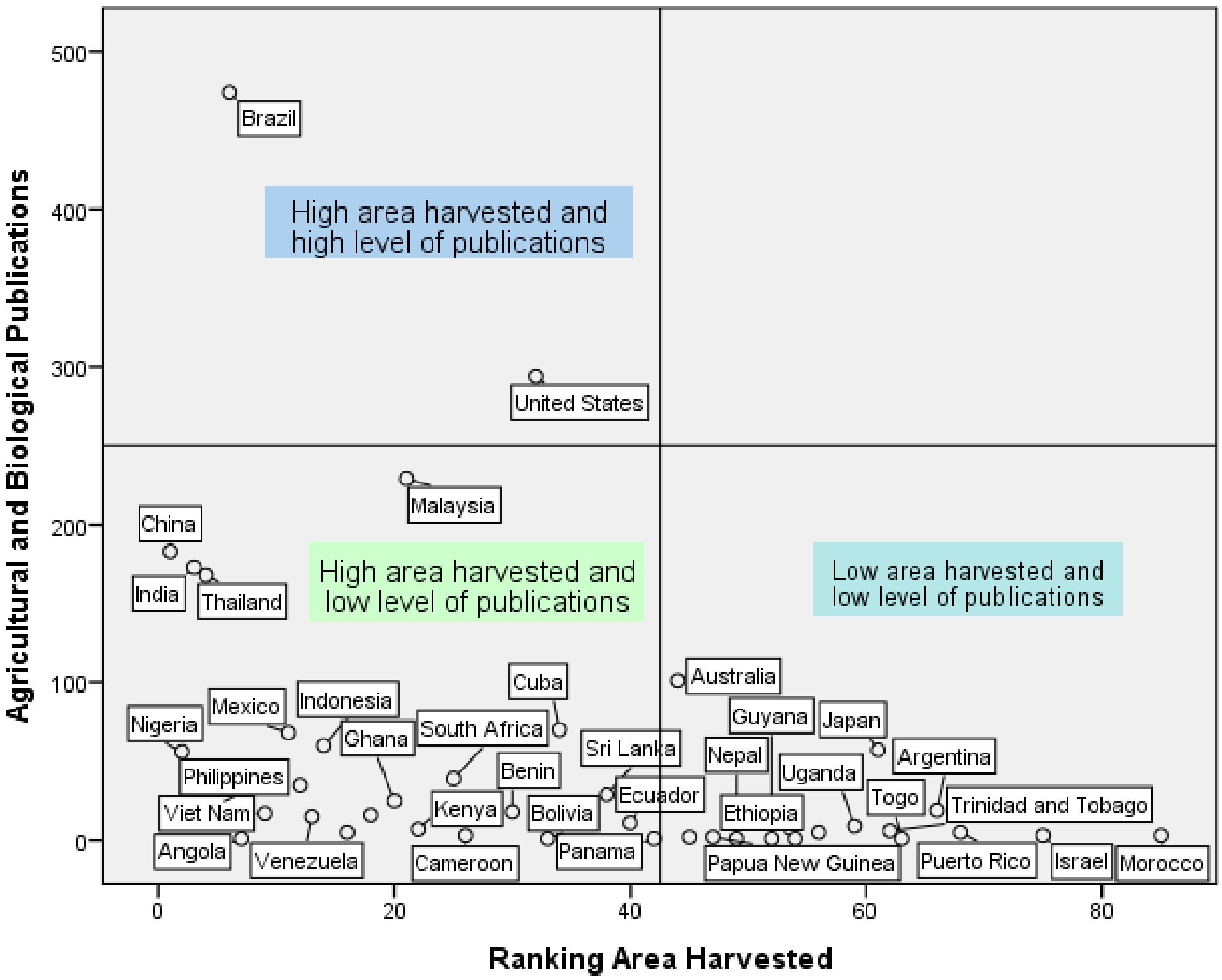

Figure 4. Total publications on pineapple (only agricultural and biological sciences from 1893 to 2022) and harvested area ranking in 2021.

tions. The most prolific is the Universiti Putra Malaysia (n=253), followed by the University of Hawaiʻi at Mānoa (n=202). The country with the largest number of institutions was Brazil (28 institutions with 1135 publications), and in second place was Malaysia (16 institutions and 858 publications). Coming in third place was India (14 institutions and 297 publications) and China (14 institutions and 533 publications). 75.5% of the institutions were universities, 22% were research centers, and 2.5% were government institutions. Only one research institution devoted to pineapple existed on the list. It is the Pineapple Research Institute of Hawaii, in the United States.

The Pineapple Research Institute of Hawaii was created when Hawaii was a leader in pineapple production (1930-1957), a position they lost when the large canneries moved to the Philippines and Thailand. In the 1970s, Del Monte established a fruit plantation in Costa Rica, which led to the downfall of the industry in Hawaii. However, they are responsible for many innovations that are currently used today, for example, the MD-2 cultivar (BARTHOLOMEW et al., 2012).

As for the agricultural and biological sciences, a total of 160 institutions belonging to 33 countries had publications. Brazil's institutions accounted for 26.3% of the publications (publications=629; 32 institutions), followed by Malaysia (publications=271; 11 institutions), the United States (publications=264; 12 institutions), China (publications=231; 12 institutions), Thailand (publications=181; 12 institutions), France (publications=136; 9 institutions), and India (publications=107; 14 institutions). The rest of the countries had fewer than 100 publications each. The most prolific institution was EMBRAPA (*n*=149), followed by the University of Hawaiʻi at Mānoa (*n*=122) and the Universiti Putra Malaysia (*n*=104). 66.9% of the institutions were universities, 28.1% were research centers, and 5% were government institutions. As noted above, only the Pineapple Research Institute of Hawaii exists as an institution devoted exclusively to this fruit.

Most influential sources

Acta Horticulturae was the most relevant source regarding pineapple at the general level and in the agriculture and biological sciences. It is a peer-reviewed series, mainly the proceedings of ISHS Symposia and the Congress of the International Society for Horticultural Science (Table 1). Four other conference proceedings were also popular sources for publishing research at the global level. The orientation of the rest of the journals was food science, chemistry, fruticulture, and materials research. The impact factor of the sources is also low. The research regarding pineapple does not remain in one field, nor does a specialized journal on pineapple exist. When the focus is on agriculture and biological sciences, the most important sources are related to food technology and chemistry, not agriculture.

Mapping for pineapple

Figure 5 presents the co-occurrence mapping of author keywords, revealing five clusters. The red cluster mainly includes the nodes on chemistry related to juice and leaf fiber. It is one of the leading clusters (201 items). The green cluster is the second in relevance (100 items) and is related to medicinal use in ethnopharmacology and ethnobotany. It also includes studies that advance our knowledge of diverse plants and fruit trees. These studies tend to compare the fruits (RODRÍGUEZ-ROMERO et al., 2011) or analyze a problem that affects them all, such as pathogens (RAMACHANDRAN et al., 2015). The third cluster in relevance is the blue one with 92 items. The central node relates to clinical studies on allergens, immunology, or diet. They included mixed vegetables and other fruits. The fourth cluster is yellow and comprises 63 items; the primary node focuses on controlled studies, especially with animals, to establish the effect of various plant components used as drugs or as dietary supplements, bromelain being the main topic (MAURER, 2001). The last cluster, the purple one, includes 38 items, and the central nodes correspond to genetics and metabolism (MING et al., 2015).

Table 1. Most influential sources for publications on pineapple.

Ranking	Global				Agriculture and biological sciences			
	SJR 2021	Source	n	%	SJR 2021	Source	n	%
1	0.16	Acta Horticulturae	555	6.7	0.16	Acta Horticulturae	419	17.5
2	0.20	Iop Conference Series Earth and Environmental Science	125	1.5	0.36	Revista Brasileira de Fruticultura	78	3.3
3	0.25	Iop Conference Series Materials Science and Engineering	103	1.2	0.65	Journal of Food Science	56	2.3
4	0.65	Journal of Food Science	99	1.2	0.84	Scientia Horticulturae	39	1.6
5	1.49	Food Chemistry	98	1.2	1.02	Journal of Agricultural and Food Chemistry	36	1.5
6	0.36	Revista Brasileira de Fruticultura	97	1.2	0.3	International Food Research Journal	32	1.3
7	1.02	Journal of Agricultural and Food Chemistry	89	1.1	1.12	Journal of Food Engineering	32	1.3
8	0.19	Aip Conference Proceedings	81	1.0	1.49	Food Chemistry	31	1.3
9	0.21	Journal of Physics Conference Series	65	0.8	0.64	Journal of Food Science and Technology	29	1.2
10	0.00	Advanced Materials Research	60	0.7	0.47	Journal of Food Processing and Preservation	26	1.1

SJR= Scimago Journal & Country Rank, in https://www.scimagojr.com/ date 06/21/2022

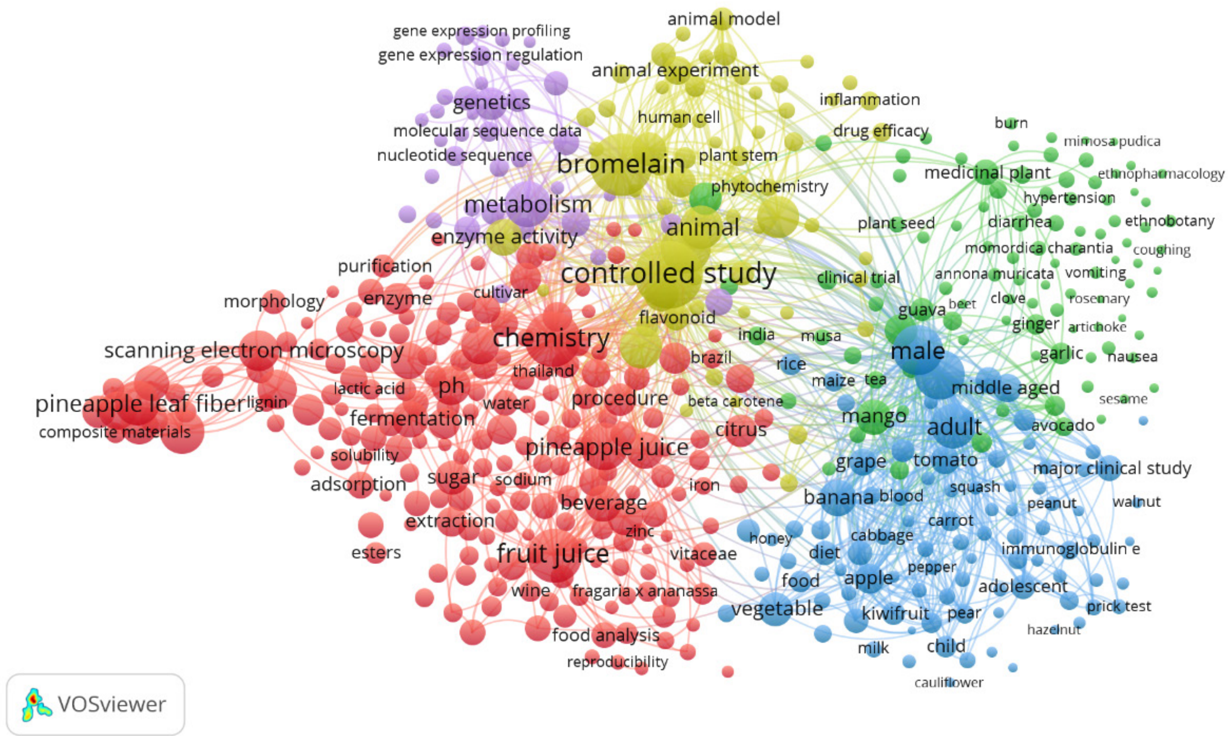

Figure 5. Co-occurrence mapping of author keywords for papers on pineapple.

Temporal mapping for pineapple

It can be observed in Figure 6 that the latest research terms are those related to genetics (expression and regulation); this follows the latest scientific trends. The cluster related to chemistry has changed from juice to pineapple leaf fiber, especially cellulose, mainly due to the potential of the leaf for polymer production. Many yellow dots are scattered around the right side of the map; these are other fruits, vegetables, and plants used in combination with pineapple for medical purposes. At the center of the map there is also a significant node in yellow, which corresponds to pineapple's antioxidant activity. Initially, researchers focused on pineapple juice at the level of chemistry and controlled studies to better understand the efficacy of diverse compounds used in pharmacology.

The map also allows one to foresee the future of this research. For example, the topic of pineapple as a medicinal plant in combination with other plants will become more frequent as well as research into genetics and alternative services such as bioenergetics.

Mapping for agricultural and biological sciences

When the agricultural and biological science publications are analyzed (Figure 7), similarities are found compared to the global level. However, before presenting these similarities, a general map overview is given. Seven clusters emerged. In the first of those (red), 80 items were related to agricultural aspects such as irrigation, micropropagation, fungal diseases, and genetics. The second, in green, had 54 items focusing on food technology, particularly juice. The third cluster, in blue with 30 items, had bromelain as the central topic. The fourth, in yellow, comprises 28 items centered on fermentation publications. The fifth, in purple with 27 items, included studies that evaluated the chemistry of pineapple waste as a dietary component for animals and their metabolism. Cluster six, in light blue with 25 items, focuses on antioxidant activity. The seventh and final cluster in orange concerned 25 items related to the effects of dehydration on sucrose and color as well as other indicators.

The similarity between the global and the agricultural and biological science levels lies in the relevance of juice and the studies on bromelain. Chemistry seems to be a central area of research in both groups. As to the differences in the science mapping, in the agricultural and biological sciences, the topics related to agricultural items and the relationship between pineapple and animal science research can be more clearly observed. Sustainability plays an essential role for researchers, mainly in the use of byproducts. Otherwise, there is no consideration for terms such as gas emissions. Also, social and economic aspects are not present on the map; therefore, research on these topics is not abundant.

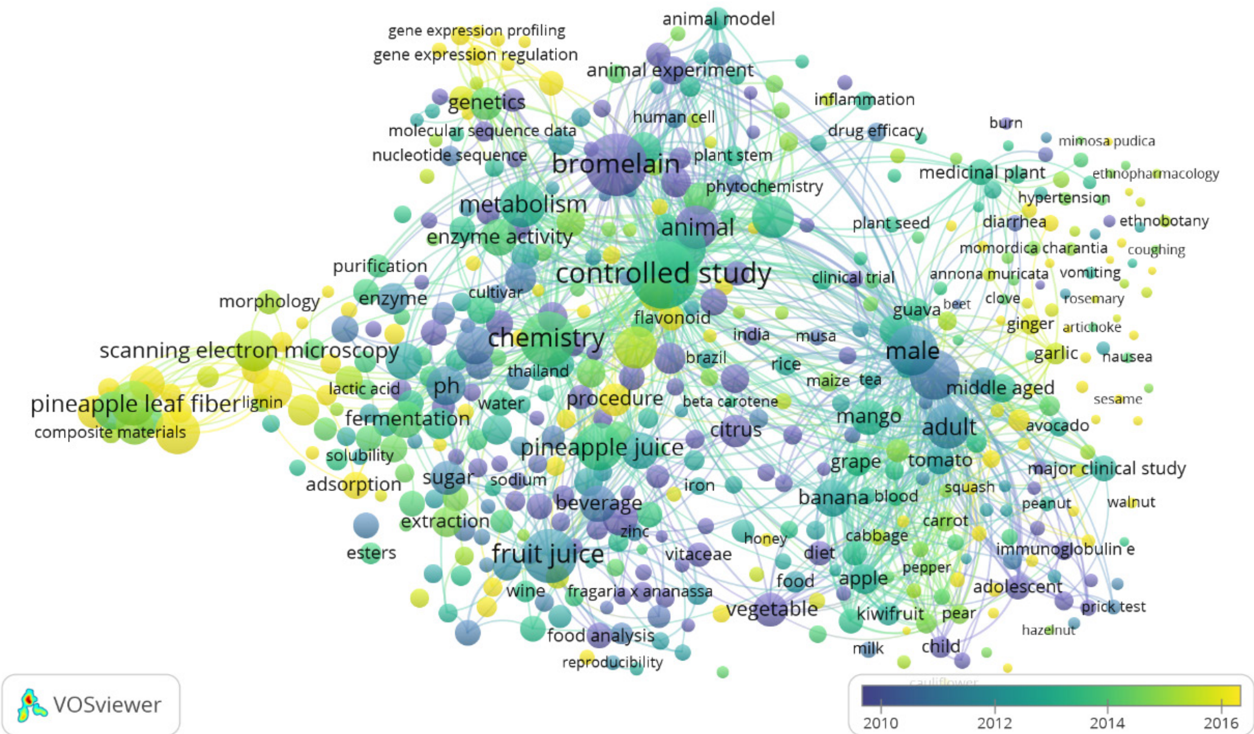

Figure 6. Temporal mapping of author keyword co-occurrence.

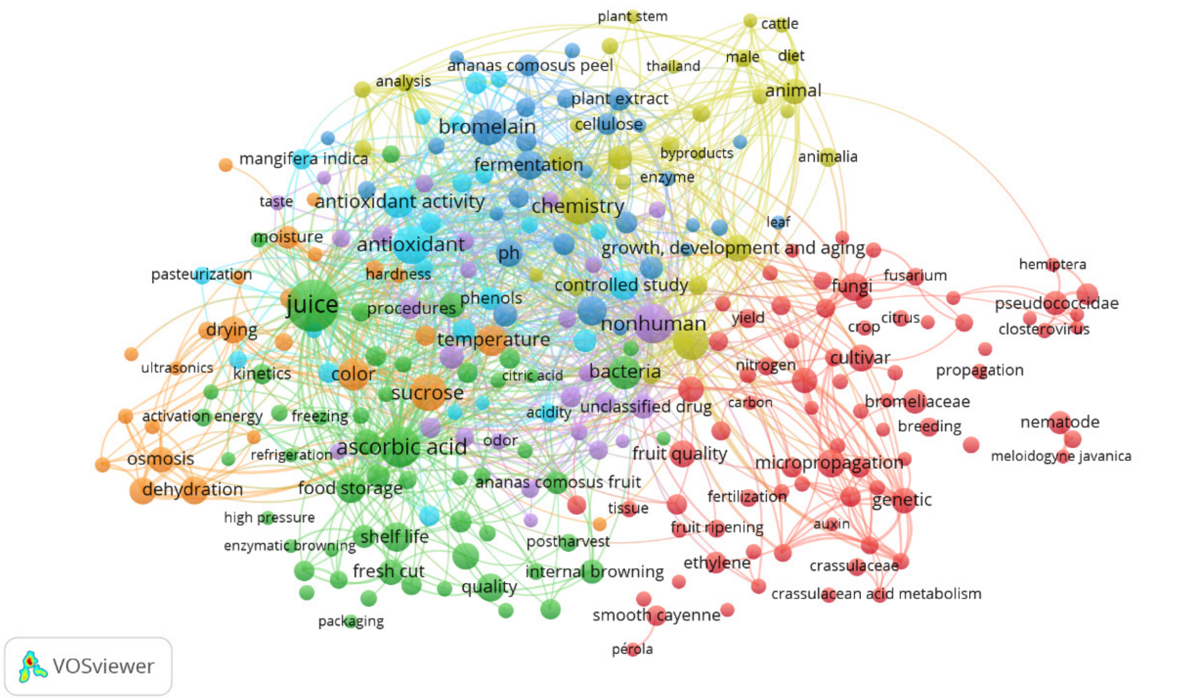

Figure 7. Co-occurrence mapping of author keywords for agricultural and biological sciences.

Temporal mapping for agricultural and biological sciences

As shown in Figure 8, agricultural topics seem to be the oldest, while those related to bromelain and antioxidant capacity are the most recent. In the agricultural aspect, micropropagation was relevant around ten years ago. Researchers have recently focused more on gene expression and regulation, with fewer publications. Although this map was made with publications in the agricultural and biological sciences, the chemistry component is more relevant than the crop production component.

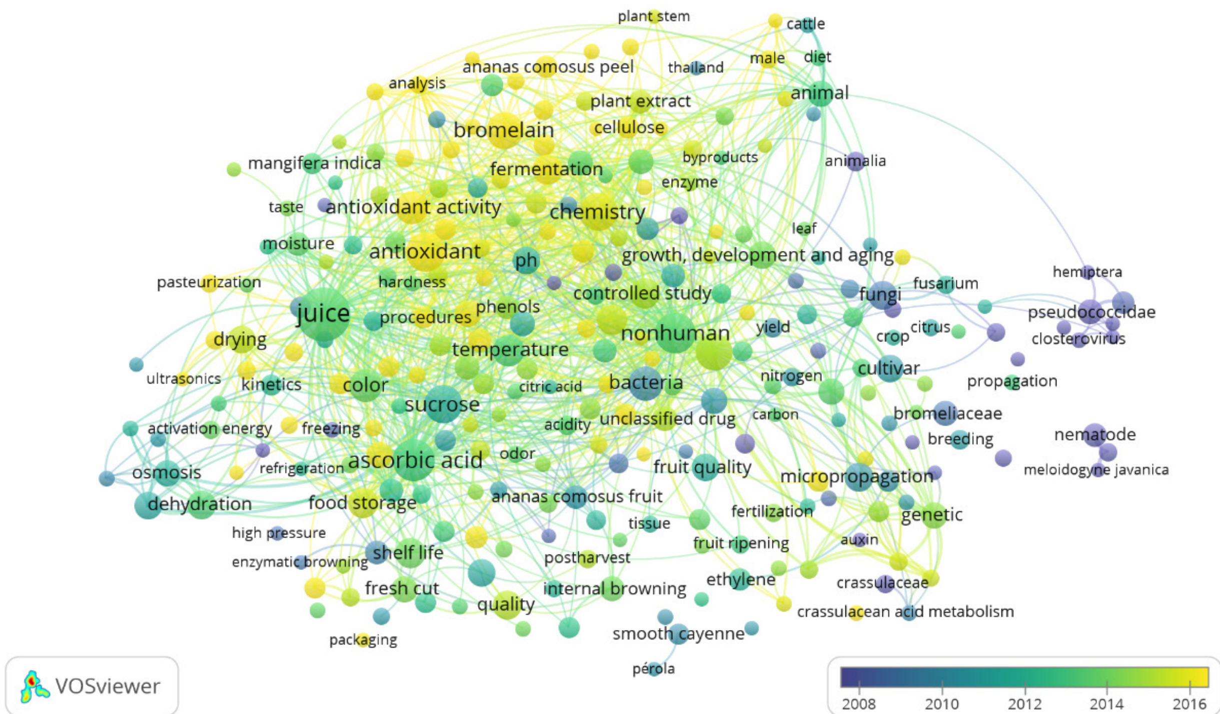

Figure 8. Co-occurrence temporal mapping of author keywords for agricultural and biological sciences.

Discussion

Pineapple, a tropical fruit, can be found in markets all over the globe. Although research regarding this plant has focused on its alternative uses, sustainability has not been the main topic. Only 62 documents of 7,885 had the word 'sustainable' in their title, and they mainly focused on the use of pineapple waste (HIKAL et al., 2022). Studies rarely dealt with topics such as the N and C footprints (MUNGCHAROEN and SUWANMANEE, 2021) or the reduction in the use of fertilizers (HAQUE et al., 2021), still many of them were not limited to pineapple (VERMA, 2016).

However, the environment has been a more common subject, as evidenced by the fact that 601 documents were related to this topic. Environmental research is mainly related to environmental protection, management, conditions, health, impact, monitoring, exposure, issues, pollution, and technology. Furthermore, as the environment plays an essential role in regulating plant life, researchers have been measuring its implications for evaluating the adaptation of *ex vitro* plants (ARAGÓN et al., 2012) or the use of shade (KISHORE et al., 2021), to mention a few. This area will remain of interest in the future.

Pineapple has been an essential topic in health due to its antioxidant, dietary and antiproliferative properties, as for its polyphenols, and anthocyanins. Most studies have focused on bromelain, a crude extract from pineapple, as a phytotherapeutic drug that may be a component of a promising treatment option for Alzheimer's disease (KUMAR et al., 2022) or used to mitigate different types of cancer (CHANG et al., 2019; ROMANO et al., 2014). Another venue is its use as a natural anti-obesity agent (MOHAMED et al., 2014). Due to its properties, pineapple has gained attention from the health sciences area, which explains why more research exists in this field than in agricultural and biological science.

Another line of investigation has related to pineapple juice, which has been studied in health research and food technology research. In the former, researchers have focused on its antioxidant properties (GARDNER et al., 2000), and in the latter, on how to improve its quality (RATTANATHANALERK et al., 2005), its stability during storage (ADEDOKUN et al., 2022), as well as sensory evaluation (JOOMWONG and JOOMWONG, 2018), to name a few. However, this topic has been left behind for new ventures, such as pineapple leaf fiber, which allows it to become a bioplastic with high biodegradable properties (ARMYNAH et al., 2022). Therefore, researchers have been evaluating combinations that allow for diverse uses such as concrete (KAROLINA et al., 2022).

It was discovered by 1874 that pineapple plants could be induced to flower in the agricultural and biological area, and by 1920, growers in Puerto Rico had implemented some practices to force flowering. The United States patented some components, and from those years until today, in commercial plantations, pineapple plants are induced to flower, especially using ethylene. This chemical product has been an important topic in research to generate new components or formulations that are adequate for newer varieties (MANEESHA et al., 2022). One variety is the MD2, also known as "gold," which is sensitive to native induction of flowering where the photoperiod during winter is less than 11.5 h (BARTHOLOMEW, 2014). In more recent publications, researchers have aimed to understand gene expression during flower induction (LIU et al., 2021). Genetics will continue to be an essential line of research not only due to flowering but also to better understand the plant's molecular mechanisms in response to short photoperiods, low temperatures, or changes in the rainy season, all attributed to global climate change. Furthermore, the introduction of sustainable agricultural practices as part of environmental issues will continue to be an essential research topic. Examples include the optimization of the use of fertilizers or the use of new fertilization patterns (LIANG et al., 2022), water management (MA et al., 2022), pest management using organic or inorganic amendments (PÉREZ et al., 2021), and the use of robots (KURBAH et al., 2022).

The utilization of technologies such as plastic mulch (REBOLLEDO-MARTÍNEZ et al., 2005), fertigation (MANEESHA et al., 2022), and shading nets (WEIFENG et al., 2020), has been studied in pineapple for several decades. Farmers who can afford such technologies and those who must comply with international trade regulations (ANKRAH, 2021) or supply international packing firms (LEON-ARAYA, 2021) have adopted them. These technologies will continue to be evaluated by researchers under different conditions as there is pressure to comply with international regulations, especially when large international firms are involved. The impact of these technologies will also be of interest to environmental research regarding, for example, the environmental risk of the use of pesticides (RÄMÖ et al., 2018).

Practical implications

The comprehensive framework developed in the current study offers valuable insights to practitioners and scientists for a better understanding of the trends in pineapple research. More research will be carried out in future years regarding genetics, robotics, and sustainability issues. To better profit from these findings, pineapple growers and rural extension bodies should participate in international organizations such as the Workgroup Pineapple of the International Society for Horticultural Science.

Policymakers may obtain inputs for policy formulation from the present study's findings, which indicate firstly that many countries where pineapple production is relevant are still lacking in scientific publications and consequently research on the topic. Therefore, governments of the countries concerned with production should make stronger efforts to increase the percentage of GDP (Gross Domestic Product) dedicated to research and extension, while new research directions should focus on sustainable assessment and social sustainability.

Conclusions

Pineapple is an important tropical fruit in the international trade market; it is mainly consumed fresh, with many studies oriented to the use of one of its main components: bromelain, mainly due to its potential uses in the medical field. The objective of this study was to conduct a comprehensive analysis of the scientific publications on pineapple. Our results show that researchers have focused primarily on the fruit and its byproducts, especially in terms of chemistry and food technology. In recent years, leaf fiber has been a hot topic as a substitute for fossil fuel products. Although this approach could be considered sustainable, it remains a relatively unexplored area of research. The findings from this analysis may be useful for researchers who wish to contribute to this field on their own or through international collaboration.

Researchers in the agricultural area at the global scale have not been overly interested in this tropical crop, which is mainly produced in tropical areas of the least developed and developing countries. Therefore, general scientific production remains scant when compared to research on other tropical crops such as sugarcane. The present investigation allowed us to observe that few studies focus on rural extension or technology transfer to growers, which remains an area of research opportunity and explains why much of the research remains only as scientific publications. Greater effort should be made to help local pineapple growers improve their yields and attain a sustainable and more environmentally friendly approach to the production of this fruit. Such research might include: the reduction in the use of pesticides and glyphosate-based herbicides that biotechnological solutions can replace; new irrigation methods that reduce the water footprint; the development of alternative fertilizers and the use of precision agriculture and robotic systems that aim to decrease greenhouse gas emissions and carbon footprint; as well as waste management.

Although our results are significant, the research was limited by its broad scope and the large number of documents considered. Therefore, some specific topics may have been overlooked and some essential references regarding pineapple may not have been cited. Thus, future research ought to concentrate on the identification of specific research topics.

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