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Bibliometric Analysis on the Use of Microorganism-Based Biofertilizers for the Growth and Yield of Agricultural Crops

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Abstract*– Biofertilisers based on microorganisms can improve the soil environment, contribute greatly to the growth and sustainable production of crops, benefiting the environment and the quality of human life. The objective of the research was to conduct a bibliometric analysis on the use of microorganism-based biofertilisers for agricultural crop growth and yield from January 2011 to September 2021. Data was collected from the Scopus and Web of Science databases, and processed using VOSviewer software for the generation of bibliometric maps. The analysis was based on 1245 research studies and the results showed that the most widely used types of microorganism-based biofertilisers for agricultural crops are nitrogen-fixing biofertilisers such as Azotobacter, Rhizobium and Azospirillum sp. In both databases, India and China were the first countries in the world to publish studies related to the topic. In addition, it was found that Aspergillus flavus biofertiliser (phosphate solubiliser) at a dose of 4 ml/kg effectively promoted the growth and yield of maize (Zea mays). The journal with the highest scientific output was "Indian Journal of Agricultural Sciences" and the subject area with the most publications was "Agricultural and Biological Sciences". It was concluded that biofertilisers based on microorganisms can be used in agricultural systems to improve growth, yield and nutrient accumulation in various crops.

***Keywords*-- bibliometric analysis, microorganisms, biofertilizers, crop growth, crop yield.**

I. Introduction

Currently, chemical fertilizers are used in agricultural practice to increase crop production and meet the demand for food due to human population growth [1]. These fertilizers contain hazardous compounds that result in poor soil quality, low crop nutrition and contaminate the water table [2]. The main fertilizers added to crops contain nitrogen (N) and phosphorus (P), and research indicates that almost 35% of N is used by crops and more than 50% of P becomes pollutants that end up in water bodies and natural environments [3].

In China, farmers apply excessive amounts of fertilizers because of their hope to maintain higher grain yields [4]. However, excessive application of nitrogen fertilizers does not increase crop yields; on the contrary, it causes a series of environmental problems, such as soil acidification, air pollution, increased greenhouse gas (GHG) emissions, and eutrophication of surface waters [5]. In Peru, in recent years, the yield of some crops, such as camu-camu fruit, has decreased due to the reduction of certain indispensable soil nutrients, N, K and Mg, generally caused by flooding and the absence of new fertilizer technologies [6]. Similarly, Ref [7] found that vitamin C concentration in fruits such as melons, apples and citrus is affected by lack of macronutrients and excessive nitrogen fertilization. Therefore, studying biofertilizers that can maintain and increase production and synergistically protect the environment is a major challenge. In view of this, studying microorganisms as biofertilizers is crucial, since several studies indicate that biofertilizers promote plant growth when applied directly to seeds or soil [8], In addition, microorganisms help improve nutrient absorption and increase crop yields. [9].

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Biofertilizers are inoculant microorganisms, defined as microbial preparations that include live or dormant cells [10]. The most widely used worldwide to improve soil properties, nutrient availability and crop yield are Rhizobium, Azotobacter, Azospirillum, Bacillus, Pseudomonas, Mycorrhiza, etc. [11]. These biofertilizers can be classified into nitrogen fixers, phosphate solubilizers and mobilizers, micronutrients and plant growth promoters [12].

Within the nitrogen-fixing biofertilizers are 2 groups of microorganisms: free-living belonging to the genus Azotobacter, Azospirillum, Anabaena, etc., and the most studied symbiotic rhizobacteria are the Rhizobium of the Rhizobiaceae family (Rhizobium, Mesorhizobium, Azorhizobium, Bradyrhizobium, Sinorhizobium and Allorhizobium) [13]. Other types of biofertilizers, such as phosphate solubilizers are composed of Pseudomonas, Bacillus, Rhizobium and Enterobacter, together with Penicillium and Aspergillus fungi [14]. On the other hand, microorganisms capable of mobilizing phosphates are arbuscular mycorrhizae, ectomycorrhizae, etc. [15]. Also, the best-known plant growth promoting rhizobacteria are the genus Pseudomonas, Azospirillum, etc. [10].

The use of biofertilizers is a powerful alternative that can not only feed the emerging population, but can also avoid the harmful and irreparable effects of agrochemicals on the environment, and is affordable in economic terms [16]. For this reason, a bibliometric analysis of published and reviewed articles is of great value to identify trends and research networks of microorganism-based biofertilizers.

Therefore, the general objective of the present research was to identify the types of microorganism-based biofertilizers most commonly used for agricultural crop growth and yield, from January 2011 to September 2021, and as specific objectives:(a) identify the number of research on the use of microorganism-based biofertilizers for crop growth and yield, (b) identify the countries with the most research on the use of microorganism-based biofertilizers for crop growth and yield, c) to identify the journals with high scientific production on the use of biofertilizers based on microorganisms for crop growth and yield, d) to determine the thematic areas with the most research on biofertilizers based on microorganisms for crop growth and yield, and e) to determine the effect of biofertilizer doses on the growth and yield parameters of agricultural crops.

II. METHODOLOGY

A. *Type of Study*

This bibliometric research was of an applied type, which seeks a solution to the problem posed based on the research findings. The quantitative approach was used since it used statistical tools to measure the interrelationships and impacts of publications within a given area of research [17]. This approach allows visualizing the co-citation network of journals and authors, the keyword co-occurrence network, and the co-authorship and country networks.

B. *Information Sources and Search Strategy*

The Scopus and Web of Science databases were used in this research. These databases are multidisciplinary tools, which are used because they contain most of the indexed journals, in addition to facilitating navigation and access to production documents in the context of scientific research [18].

For the bibliometric analysis, the following search strategy was used ((Biofertilizer OR "natural fertilizer" OR bio-fertilizer) AND (agriculture or agricultural) and ("crop growth" OR "crop yield" OR benefits OR productivity or cultivation)). In addition, the keywords, subject area, language (English) and types of documents (scientific articles and reviews) published between 2011 and 2021 were included.

C. *Data Analysis*

The data acquired from the different databases were entered into the VOSviewer software and then processed in order to analyze and visualize the bibliometric networks. "This software includes the distributions of publication journals, authors, affiliations and most cited articles, as well as the frequency of keywords and their relationships found in the search engine" [19]. The results obtained from this tool were used to develop the analysis and give visibility to the bibliometric networks, this by generating maps of co-occurrence, citations and co-citations of keywords based on bibliographic data on the use of biofertilizers for the growth and yields of agricultural crops.

III. RESULTS AND DISCUSSION

A. *Scientific Papers Published in the Scopus and Web of Science Databases*

Figure 1 presents the Venn E. diagram to identify the number of articles and reviews extracted from the Scopus and Web of Science (WoS) databases. In the study of [20], they indicate that these citation databases are globally leading databases that compete with each other and are the most progressively used by researchers from different countries. In this research, the database that presents the highest number of research on biofertilizers is Web of Science during the period 2011-2021.

Fig. 1 Venn diagram to identify the overlap of documents in the databases

B. *Analysis of the Types of Documents in the Scopus and WoS Databases*

In the Scopus database, it can be observed that it is made up of articles (72%) and reviews (14%) of 592 documents (Figure 2). Likewise, in the Web of Science database, articles represent 90% and 10% tend to be reviews of 653 documents (Figure 3). Similarly, [21] indicate that the highest percentage of documents in environmental sciences, agriculture and biological sciences are articles.

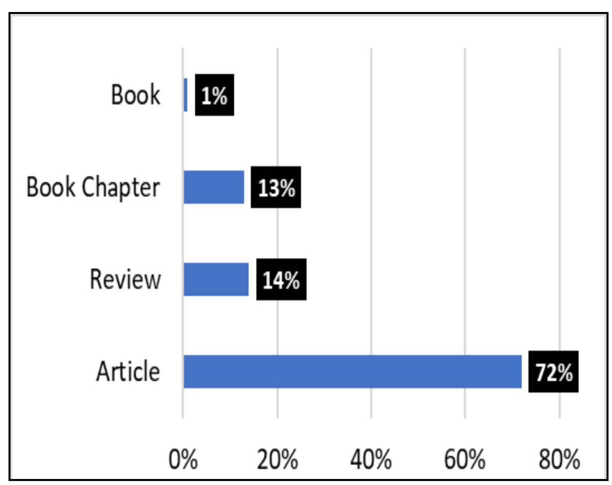

Fig. 2 Types of documents in the Scopus database

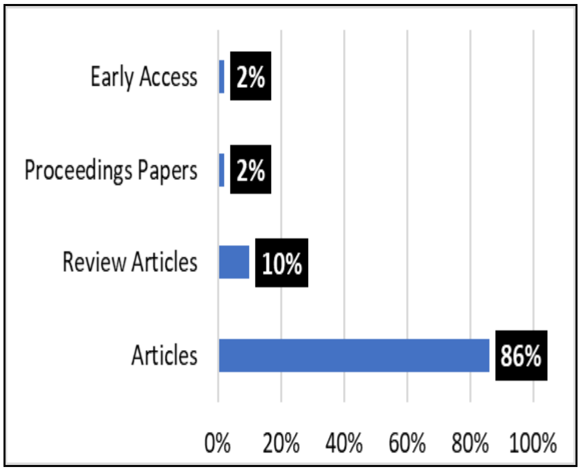

Fig. 3 Types of documents in the Web of Science database

C. Types of Microorganism-Based Biofertilizers Used for Growth and Yield of Agricultural Crops

Table 1 shows the data according to the type of biofertilizer based on microorganisms and the methodology used for different agricultural crops. According to the results, the different types of biofertilizers used for the growth and yield of agricultural crops in different research studies can be seen. Most of the studies worked with bacteria that fix atmospheric nitrogen (BFN) and increase the N content available to plants, among the organisms that stand out are Azotobacter bacteria, Rhizobium sp that fix N up to 184 kg/ha, and the genus Azospirillum. This is followed by research on phosphate solubilizing biofertilizers such as Enterobacter cloacae, Bacillus subtilis and Rahnella aquatillis bacteria. Similarly, Ref. [22] in their study of biofertilizers for agricultural production determined that the most important microorganisms that have been used in the formulation of biofertilizers are Rhizobium, Azotobacter, Pseudomonas, Bacillus, vesicular-buscular mycorrhizae and Azospirillum. Ref [23] studied Azospirillum bacteria and determined that these bacteria fix N up to 10-20 kg/ha, improve both mineral and water intake and increase root development, promote plant growth and improve the yield of maize, rice, wheat, millet, sorghum and bajra crops. However, the amount of N provided by BFN will vary with plant species and environmental factors, which will ultimately determine successful colonization [24].

TABLE I
TYPE OF BIOFERTILIZERS BASED ON MICROORGANISMS USED FOR AGRICULTURAL CROP GROWTH AND YIELDS

Type of Biofertilizer	**Type of crop**	**Application method**	**Function**	**Name of the microorganism**	**Observations**	**Reference (Authors)**
Nitrogen fixers	Rice	Seed inoculation before sowing	Increase soil nitrogen content by fixing atmospheric N and making it available to plants	*Rhizobium*	The N content in the soil increased (184 kg/ha)	[25]
	Wheat	Seeds treated with liquid microbial consortia		*Azotobacter*	Productivity and nutrient profile increased	[26]
	Peanut	Inoculation with suspension strains		*Rhodopseudomonas palustris*	The content of N (770,22 mg/kg) and K (236,85 mg/kg)	[27]
	Rice	Inoculation with seed		*Anabaena variabilis*	Increased N content by approximately 36%	[28]
	Guava (*Psidium guajava L.*)	Application of the biofertilizer mixture around the trunk		*Azotobacter chroococcum, Azospirillum brasilense y Bacillus megaterium*	Nutrient content increased: N (0,5%), P (0,5%) and K (1,17%)	[29]
	Chickpea and maize	Application before sowing		*Rhizogold*	Significant improvement in the content of N (2,79g/kg), P (0,61g/kg) and K (1,56g/kg)	[30]
	Sugarcane	Seed inoculation before sowing		*Azotobacter chroococcum*	Available N content 376 kg/ha	[31]
	Stevia (*Stevia rebaudiana Bertoni*)	Irrigation by immersion after transplanting		*Rhodopseudomonas palustris*	The content of N (2,5%), P (0,7%) and K (4%)	[32]
	Eggplant	Root immersion of seedlings		*Rhizobium sp., Azotobacter sp., Azospirillum sp.*	Nutrients available: N (364kg/ha) and P (27,70kg/ha)	[33]
	Green chickpea (*Vigna mungo L.*)	Application by foliar spray		*Chlorella vulgaris*	Nutrient content in the soil: N (3,56mg/kg), P (25,4mg/kg), and K (446mg/kg)	[34]
	Rice	Soil soaking method		*Chlorella*	Nutrient content: N	[35]

				vulgaris, Spirulina platensis	(0,24g/kg), P (1,81g/kg) and K (2,18g/kg)	
	Maize (Zea mays L.)	Soild treated with microalgae			N (18,9mg/kg), P (14,29mg/kg) and K (60,86mg/kg)	[36]
Phosphate solubilizers	Wheat	Seeds treated with liquid microbial consortia	Solubilize insoluble forms og P in the soil into soluble forms by secreting organic acids and lowering soil pH to dissolve bound phosphates	*Enterobacter cloacae*	Solubilized phosphorus and increased crop productivity	[26]
	Rice	Seed inoculation		Phosphobacterium *(T10)*	Solubilized the available P content (11.8 kg/ha)	[25]
	Wheat	Commercial producto used as a biological		*Bacillus subtilis*	Improved P content (2kg/ha)	[37]
	Peanut	Inoculation with bacterial strains in suspension		*Burkholderia cepacia*	Phosphorus content (506,69mg/kg) available in the soil	[27]
	Raice (*Oryza sativa L.*)	Inoculation of sedes with each bacterial suspensión for 5 hours at room temperature		*Rahnella aquatillis, Enterobacter sp., Pseudomonas fluorescens y Pseudomonas putida*	Increased grain yield (7%), number of stems (7%) and plant height (20%)	[38]
	Maize (*Zea mays L.*)	Inoculation of seeds in spore suspension		*Aspergillus flavus*	The phosphate solubilized in 5 days in the amount of 6,63 mg/kg	[39]
	Eggplant	Root immersion of seed lings		*Bacillus sp.*	Soil P content (27,7 kg/ha)	[33]
Phosphate mobilizers	Guava (*Psidium guajava L.*)	Application of biofertilizer around the trunk	Transfer phosphorus from soil to root bark	HMA *(Glomus mosseae)*	Soil available P content (0,47kg/ha)	[29]
Plant growth promoters (PGP)	Sunflower (*Helianthus annuus* L.)	Inoculation with bacterial strain	Promote plamt growth, such as exopolysaccharide production, chitinase activity, phosphate solubilization, siderophore production, auxin production and ACC-deaminase activity	*Pseudomonas aeruginosa*	Improves crop yield and quality	[40]
	Rice	Inoculation of seeds with bacteria		*Enhydrobacter aerosaccus* *Aspergillus sp.*		[25]
	Lentil	Seed inoculation		*Serratia marcescens, Bacillusmegaterium y Pseudomonas fluorescens*	Increases the availability of nutrients or plant growth factors	[41]
	Peppers (*Capsicum annuum L.*)	The prepared solid broth (with more than 10^10 g/dry weight of conidia from NJAU4742 conidia) and biological organic fertilizers were mixed with the air-dried soils		*Trichoderma guizhouense*	Increased crop yield and positively correlated with enzyme activities, soil organic carbon, total N and available P	[42]
Subilizer and K mobilizers	Wheat	Inoculation of seeds before sowing	They solubilize potassium (silicates) through the production of organic acids	*Enterobacter hormaechei*	Improved nutrient content including K	[26]
	Rice	Inoculation with fungus		*Aspergillus sp*	Available K content in the soil (2kg/ha)	[25]
Zinc solubilizers	Wheat	Inoculation of seeds before sowing	Solubilize zinc by proton, chelates, ligands, acidification and by oxidoreductive systems	*Pantoea agglomerans*	Improved micronutrient content including K	[26]
Lactic acid bacteria (Accelerated	Stevia (*Stevia rebaudian*	Irrigation by immersion after transplanting	Producers of lactic acid that promotes the	*Lactobacillus casei, Lactococcus*	Improves growth, performance and nutrient accumulation	[32]

biofertilizers)	*a Bertoni*)		descomposition of organic matter	*lactis,*		

D. Analysis of the Types of Microorganism-Based Biofertilizers Most Used in Studies in Scopus and WoS Databases

Figure 4 and Figure 5 show the amount of research on the types of microorganism-based biofertilizers published per year. In the Scopus database (Figure 4), the types of biofertilizers based on microorganisms most used for agricultural crops over the years are N-fixing biofertilizers, which represent the highest percentage, followed by phosphate solubilizers and plant growth promoters. Likewise, the WoS database (Figure 5) shows that the most used types of biofertilizers based on microorganisms are N fixers, followed by plant growth promoters and phosphate solubilizers. This research is similar to a study conducted by Ref. [12] where they explore the global trends in biofertilizer research through a bibliometric approach, referring that biofertilizers and the ability to fix nitrogen is the topic that has attracted the most attention among the different areas of research on biofertilizers. On the other hand, Ref. [43], in their bibliometric study of scientific production on biofertilizers in Cuba in the period 2008-2012, indicated that the most studied biofertilizers are Glomus, Rhizobium, Bradyrhizobium, Azotobacter, Gluconoacetobacter and Pseudomonas.

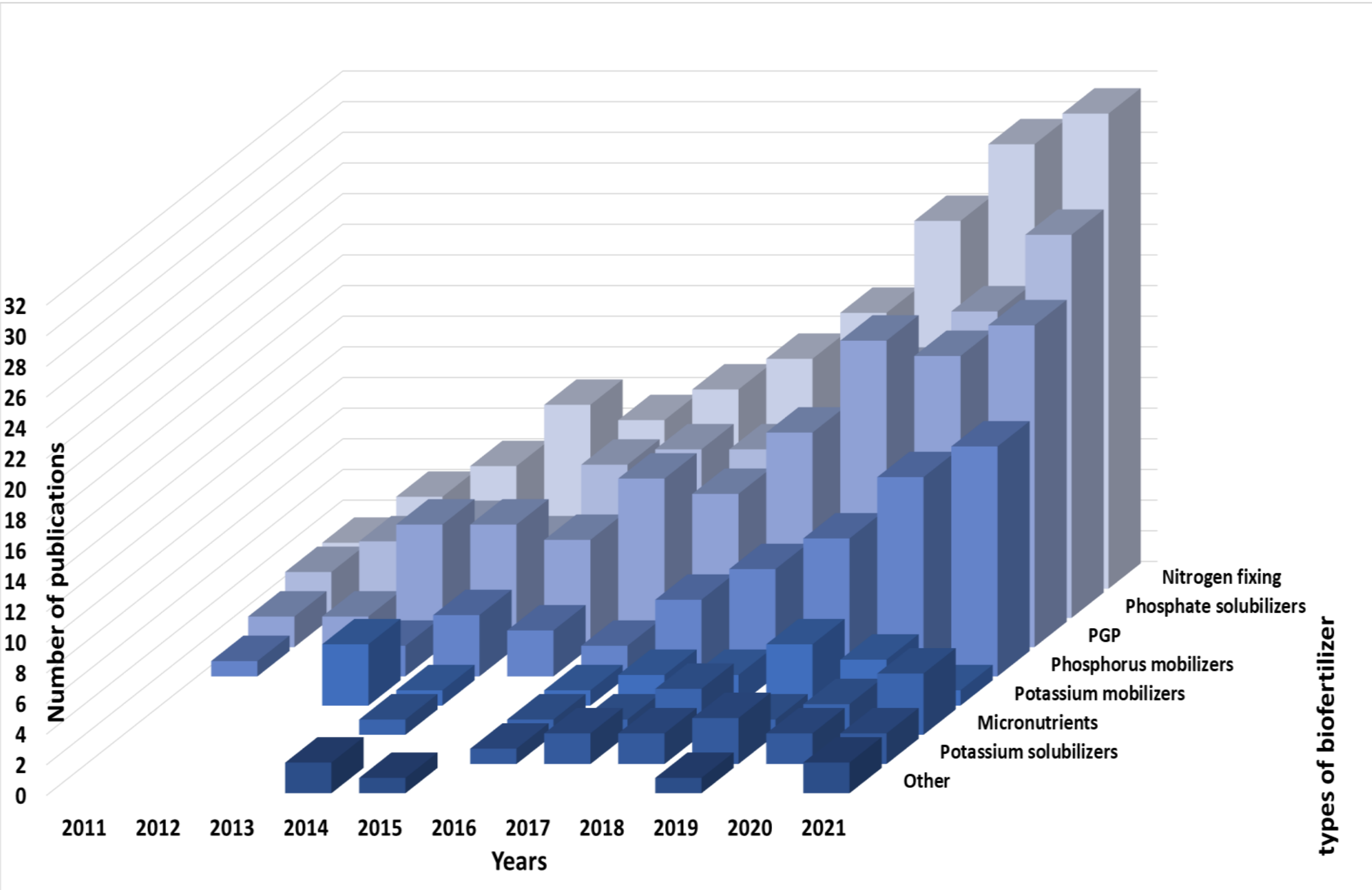

Fig. 4 Trend of types of biofertilizers used for crop growth and yield as a function of years - Scopus database

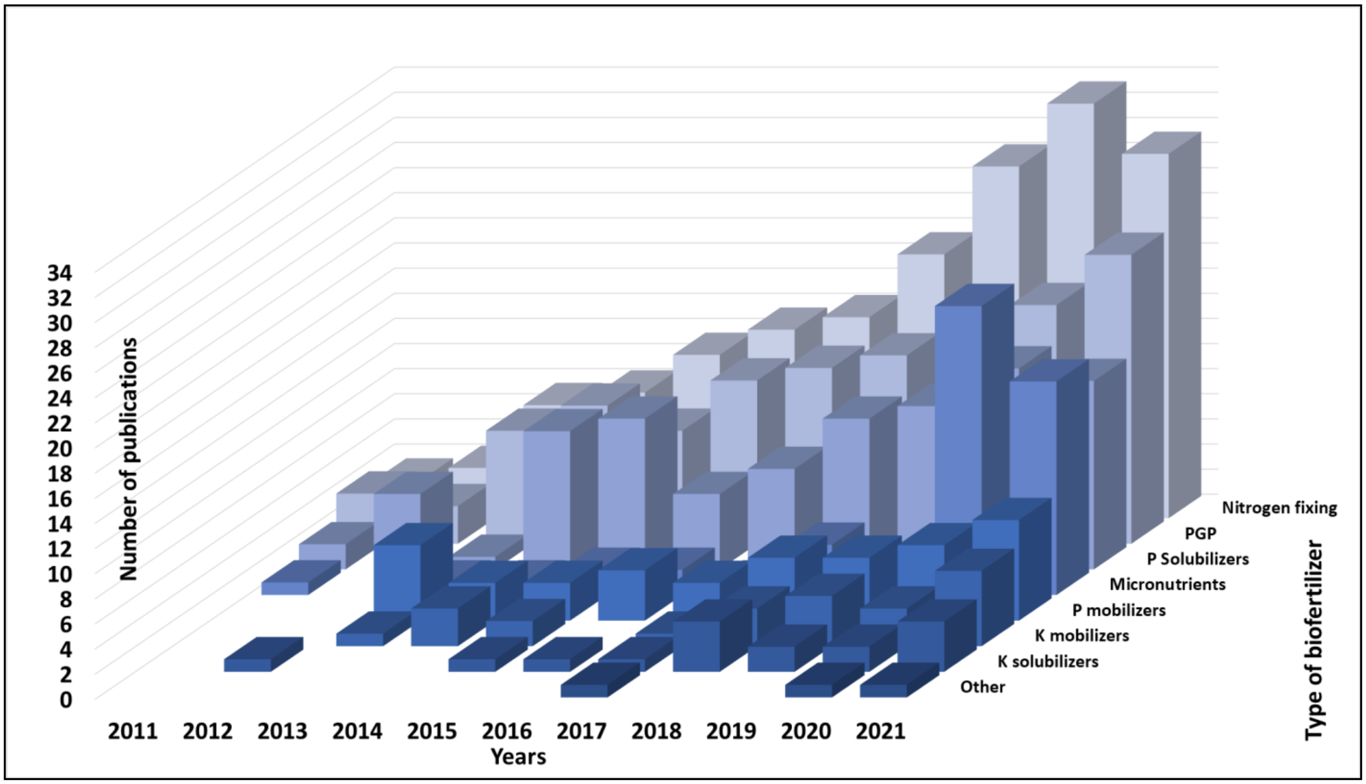

Fig. 5 Trend of types of biofertilizers used for crop growth and yield as a function of years - WoS database

E. Analysis of Scientific Research by Countries

The leading countries in publishing studies on the use of biofertilizers based on microorganisms are India (193 publications), China (65 publications) and the United States (45 publications) in the Scopus database (Figure 5). While, in the WoS database, India, China, Brazil and Pakistan are the countries in the world with the highest number of researches with figures of 184, 74, 55 and 51 publications, respectively (Figure 6). According to Ref. [44], India is the second largest producer and consumer of fertilizers in the world. Likewise, Ref. [45] reports that fertilizer consumption in India could double by 2050, which is why there is an urgent need for scientific research to support better nitrogen management in agriculture. Another country with greater scientific production related to the subject is China, which is the first country to make excessive use of chemical fertilizers to increase its agricultural production. Therefore, in relation to the problem, in 2015 an action plan for zero growth in the application of pesticides and chemical fertilizers was launched for this country, and by the end of 2017 more than 4,600 biofertilizers that were used with 151 functional microbial species/ strains were registered only with 8 generic names by companies due to rigorous safety evaluation [46].

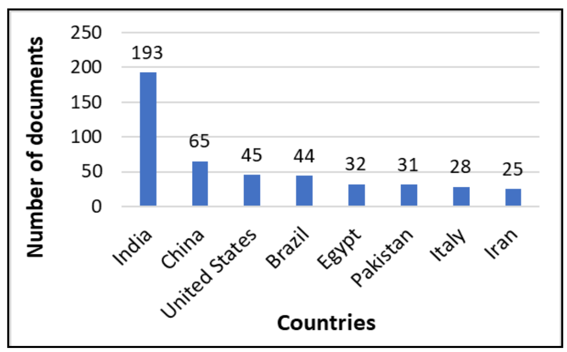

Fig. 6 Number of research papers published according to countries - Scopus database

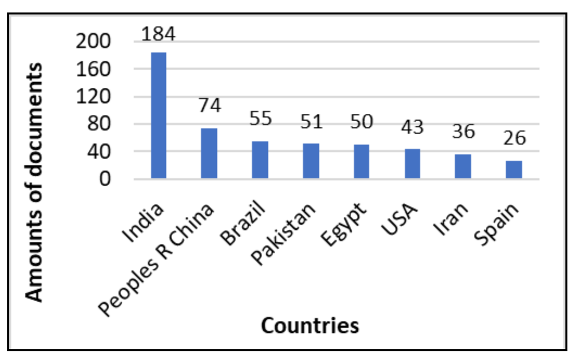

Fig. 7 Number of research papers published according to countries - WoS database

F. Analysis of the Main Journals with the Highest Scientific Production

The journals with the highest number of articles on microorganism-based biofertilizers in the Scopus database are "Science Of The Total Environment" (14 publications), followed by "Ecology Environment And Conservation" (12 publications) and "Frontiers In Microbiology" (12 publications) (Figure 5a). On the other hand, in the Web of Science database, the scientific journals with the highest number of publications are "Indian Journal of Agricultural Sciences" and "Journal Plant of Nutrition" (23 publications), followed by "Agronomy Basel" (19 publications) (Figure 5b). On the other hand, in the bibliometric study exploring global trends of biofertilizers by Ref. [12], they indicated that the "Revista Brasileira de Engenharia Agrícola e Ambiental" was the first in the list with the highest number of articles published on the subject (14 researches) and, "Semina-Ciencias Agrarias" was the second journal with 10 researches".

Journal	Number of documents
Science Of Té Total Environment	14
Ecology Environment And Conservation	12
Frontiers In Microbiology	12
Journal Of Plant Nutrition	12
Communications In Soil Science And Plant Analysis	11
Pestology	11
Scientia Horticulturae	11
Agriculture Ecosystems And Environment	10
Industrial Crops And Products	10
Sustainability Switzerland	10

Fig. 8 Journals with the highest scientific production - Scopus database

Journal	Number of documents
Indian Journal of Agricultural Sciences	23
Journal of Plant Nutrition	23
Agronomy Basel	19
Legume Research	14
Communications in Soil Science and Plant Analysis	13
AppliedSsoil Ecology	11
Biocatalysis and Agricultural Biotechnology	9
Frontiers in Microbiology	9
Science of the Total Environment	9
Journal of Soil Science and Plant Nutrition	8

Fig. 9 Journals with the highest scientific production - WoS database

G. Number of Publications per Year in the Scopus and WoS Databases

From the 592 documents in the Scopus database and the 653 documents in the Web of Science database, the variation of research publication during the period 2011 - 2021 is presented quantitatively. In the Scopus database, a constant trend is observed between 15 and 37 studies published from 2011-2013, and in the years 2016, 2018, 2019, 2019, 2020, 2021 this trend increased by 54, 62,111 and 125 studies, respectively (Figure 10). Likewise, in the Web of Science database there is a constant trend of increase between 4 and 5 publications per year in the period 2011 - 2015, for 2018, 2019, 2020 and 2021, the number of publications was 70, 93,144 and 135, respectively (Figure 10). This reaffirms that, research concerning the use of biofertilizers for growth and yield for agricultural crops has been increasing over the years. In contrast, a study by Ref. [43] on the scientific production on biofertilizers in Cuba in the period 2008-2012, recorded a decrease in publications, and the highest productivity occurred in 2008 and 2010. In contrast, in their study by Ref. [12] they indicated that it is evident that research on biofertilizers is increasing in importance from the following years, having 80% of 344 articles on biofertilizers that were published during the period of 2015-2019.

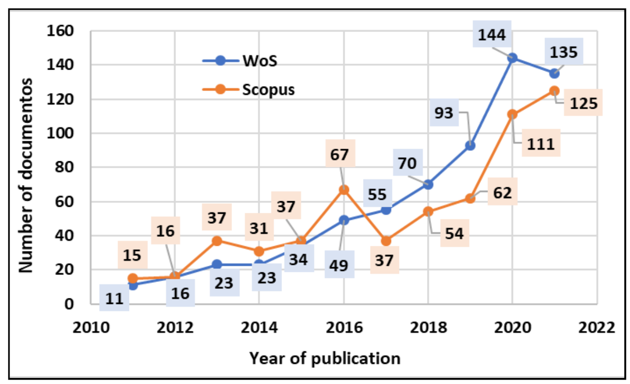

Fig. 10 Trend of scientific production per year in Scopus and WoS databases

H. Number of Studies Published by Subject Area in the Scopus and WoS Databases

Figure 11 and Figure 12 show the top 10 subject areas with the most publications in the Scopus and Web of Science databases, respectively. In the Scopus database, the most representative thematic area is "Agricultural and Biological Sciences" with 346 researches, "Environmental Science" with 194 researches, followed by "Biochemistry, Genetics and Molecular Biology" with 111 researches. On the other hand, in the Web of Science database, the thematic area "Agriculture" (286 researches) has the most publications, followed by "Plant Sciences" (131 researches) and "Environmental Sciences" (118 researches). Likewise, Ref. [12] in their bibliometric study on biofertilizer trends, indicated that the most important subject areas that published articles on the topic were "Agronomy" (16%), Biotechnology and Applied Microbiology (14%) and "Agriculture Multi-disciplinary" (12%).

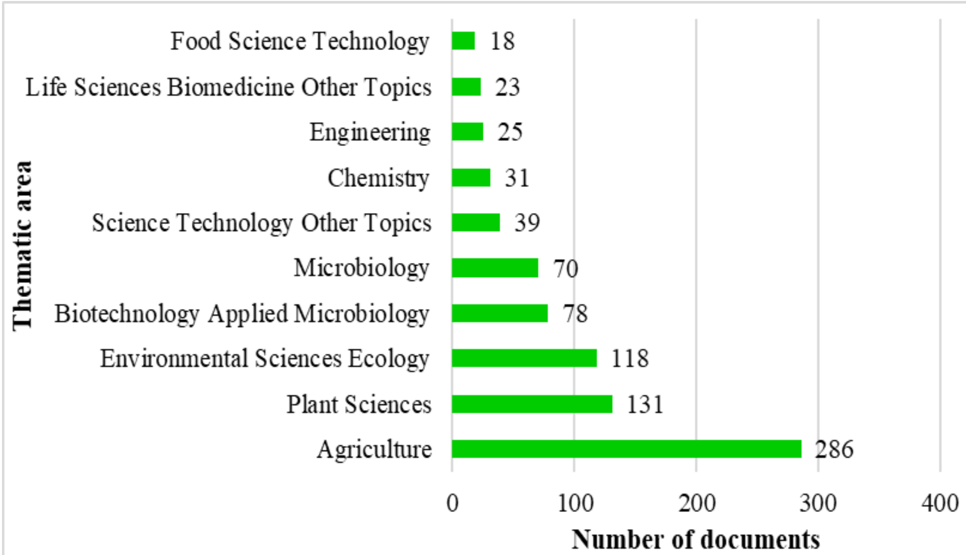

Fig. 11 Number of research studies by subject area - Scopus database

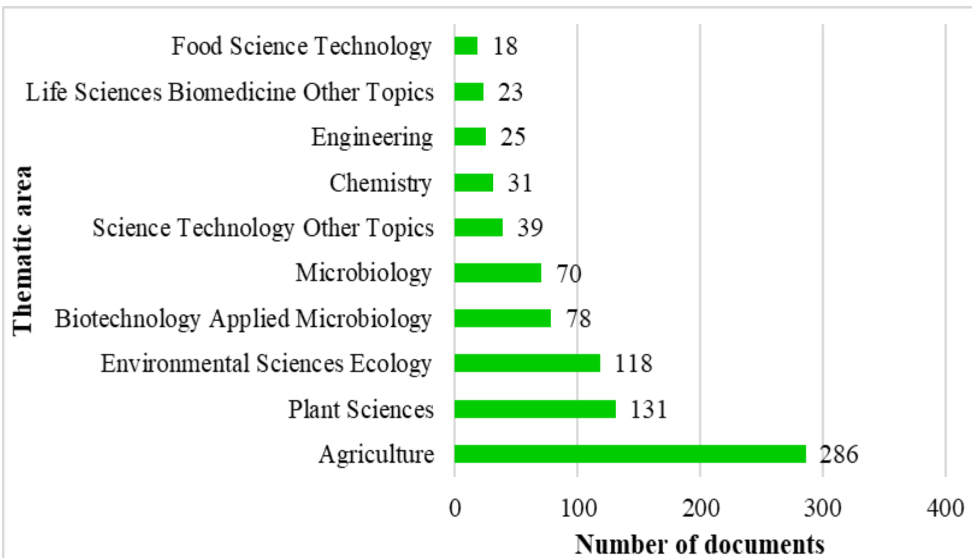

Fig. 12 Number of research studies by subject area - WoS database

I. Analysis of Scientific Research by Countries in the Scopus and Web of Science Databases

Figure 13 and Figure 14 present the most active countries in microorganism-based biofertilizer research. According to the Scopus network map, the countries with the highest number of researches during the period 2011-2021 are India (193 publications), China (65 publications) and United States (45 researches). Likewise, in the Figure of the Web of Science database it is visualized that India (184 publications) has the highest number of researches, followed by China (74 publications) and Brazil (55 publications). This study is related to the bibliometric analysis exploring global trends in biofertilizers, carried out by Ref. [12], which indicated that the countries with the highest number of publications during the period 2000-2019 were Brazil (83 documents), India (66 publications) and China (38 publications).

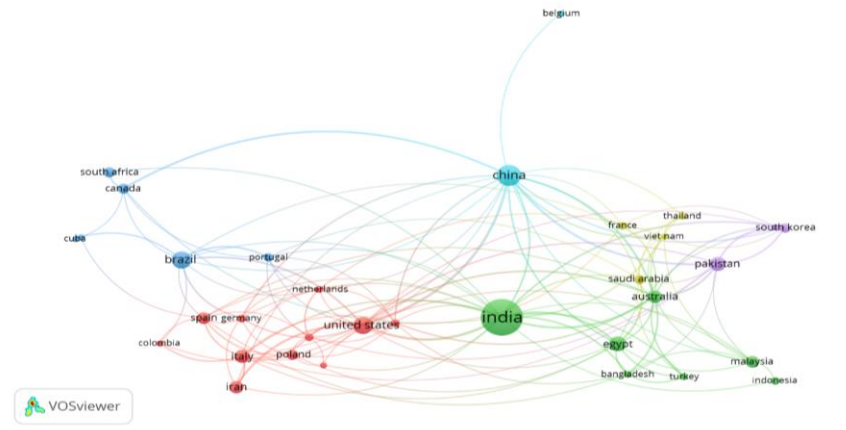

Fig. 13 Network map of research according to countries - Scopus database

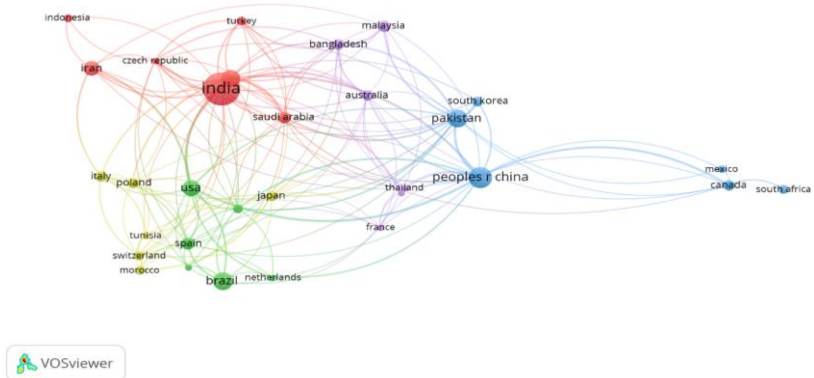

Fig. 14 Network map of research according to countries - WoS database

IV. Conclusions

The types of biofertilizers based on microorganisms most commonly used in agricultural crops are nitrogen fixers such as Azotobacter, Rhizobium and Azospirillum brasilence and phosphate solubilizing biofertilizers such as Enterobacter cloacae, Bacillus subtilis and Rahnella aquatillis. The most important results were:

The number of research indexed in Scopus and Web of Science databases were 592 and 653, respectively. India and China are the first countries in the world in terms of total number of publications related to microorganism-based biofertilizers.

The journal with the highest scientific output in the Scopus database was "Science Of The Total Environment" (14 publications). On the other hand, the journal with the highest number of publications in the Web of Science database was "Indian Journal of Agricultural Sciences" (23 publications).

The subject area with the highest number of publications was "Agricultural and Biological Sciences" (346 publications) and "Agriculture" (286 publications) in the Scopus and Web of Science databases, respectively.

The study showed that biofertilizers such as microorganisms are of vital importance in crops because they facilitate nutrient absorption, promoting plant growth and yield.

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References

[1] B. R. GLICK, “Soil Microbes and Sustainable Agriculture,” *Pedosphere*, vol. 28, no. 2, pp. 167–169, Apr. 2018.

[2] J. Mary Isabella Sonali *et al.*, “Application of a novel nanocomposite containing micro-nutrient solubilizing bacterial strains and CeO2 nanocomposite as bio-fertilizer,” *Chemosphere*, vol. 286, p. 131800, Jan. 2022.

[3] H. Ritchie, “Our world in Data,” *Excess fertilizer use: Which countries cause environmental damage by overapplying fertilizers?*, 2021. https://ourworldindata.org/excess-fertilizer

[4] D. Yang, T. Cai, Y. Luo, and Z. Wang, “Optimizing plant density and nitrogen application to manipulate tiller growth and increase grain yield and nitrogen-use efficiency in winter wheat,” *PeerJ*, pp. 1–26, Feb. 2019.

[5] H. ZHANG *et al.*, “Optimizing integrative cultivation management improves grain quality while increasing yield and nitrogen use efficiency in rice,” *J. Integr. Agric.*, vol. 18, no. 12, pp. 2716–2731, Dec. 2019.

[6] C. Abanto-Rodriguez *et al.*, “Relation between the mineral nutrients and the Vitamin C content in camu-camu plants (Myrciria dubia) cultivated on high soils and flood soils of Ucayali, Peru,” *Sci. Agropecu.*, vol. 7, no. 3, pp. 297–304, Sep. 2016.

[7] R. M. Welch, "Micronutrients, agriculture and nutrition; linkages for improved health and well being.," in *Perspectives on the micronutrient nutrition of crops*, Scientific Publishers, 2001, pp. 247–289.

[8] D. C. Suyal, R. Soni, S. Sai, and R. Goel, "Microbial Inoculants as Biofertilizer," in *Microbial Inoculants in Sustainable Agricultural Productivity*, New Delhi: Springer India, 2016, pp. 311–318.

[9] B. N. Aloo, E. R. Mbega, J. B. Tumuhairwe, and B. A. Makumba, "Advancement and practical applications of rhizobacterial biofertilizers for sustainable crop production in sub-Saharan Africa," *Agric. Food Secur.*, vol. 10, no. 1, pp. 1–12, Dec. 2021.

[10] S. Umesha, P. K. Singh, and R. P. Singh, "Microbial Biotechnology and Sustainable Agriculture," in *Biotechnology for Sustainable Agriculture: Emerging Approaches and Strategies*, Woodhead Publishing, 2018, pp. 185–205.

[11] J. Mishra and N. K. Arora, "Bioformulations for Plant Growth Promotion and Combating Phytopathogens: A Sustainable Approach," in *Bioformulations: for Sustainable Agriculture*, New Delhi: Springer India, 2016, pp. 3–33.

[12] P. Koovalamkadu Velayudhan, A. Singh, and A. Korekallu Srinivasa, "Exploring the global research trends in biofertilizers: a bibliometric approach," *3 Biotech*, vol. 11, p. 304, Jun. 2021.

[13] A. Shamseldin, A. Abdelkhalek, and M. J. Sadowsky, "Recent changes to the classification of symbiotic, nitrogen-fixing, legume-associating bacteria: a review," *Symbiosis*, vol. 71, pp. 91–109, Nov. 2016.

[14] K. Anand, B. Kumari, and M. A. Mallick, "Phosphate solubilizing microbes: An effective and alternative approach as biofertilizers," *Int. J. Pharm. Pharm. Sci.*, vol. 8, no. 2, pp. 37–40, 2016.

[15] H. Etesami, B. R. Jeong, and B. R. Glick, "Contribution of Arbuscular Mycorrhizal Fungi, Phosphate–Solubilizing Bacteria, and Silicon to P Uptake by Plant," *Front. Plant Sci.*, vol. 12, pp. 1–29, 2021.

[16] S. Mukhtar, I. Shahid, S. Mehnaz, and K. A. Malik, "Assessment of two carrier materials for phosphate solubilizing biofertilizers and their effect on growth of wheat (Triticum aestivum L.)," *Microbiol. Res.*, vol. 205, pp. 107–117, Dec. 2017.

[17] I. S. Lee, H. Lee, Y. H. Chen, and Y. Chae, "Bibliometric Analysis of Research Assessing the Use of Acupuncture for Pain Treatment Over the Past 20 Years," *J. Pain Res.*, vol. 13, pp. 367–376, 2020.

[18] E. I. Chaparro-Martinez, P. Álvarez-Muñoz, and M. D'Armas-Regnault, "Gestión de la información: Uso de las bases de datos scopus y web of science con fines académicos," *Universidad, Cienc. y Tecnol.*, vol. 20, no. 81, pp. 166–175, 2016. [19]I. Hamidah, R. E. Pawinanto, B. Mulyanti, and J. Yunas, "A bibliometric analysis of micro electro mechanical system energy harvester research," *Heliyon*, vol. 7, no. 3, p. e06406, Mar. 2021.

[20] J. Zhu and W. Liu, "A tale of two databases: the use of Web of Science and Scopus in academic papers," *Scientometrics*, vol. 123, pp. 321–335, Apr. 2020.

[21] S. Prabakaran, T. Mohanraj, A. Arumugam, and S. Sudalai, "A state-of-the-art review on the environmental benefits and prospects of Azolla in biofuel, bioremediation and biofertilizer applications," *Ind. Crops Prod.*, vol. 183, p. 114942, Sep. 2022.

[22] J. L. Zambrano-Mendoza, C. A. Sangoquiza-Caiza, D. F. Campaña-Cruz, and C. F. Yánez-Guzmán, "Use of Biofertilizers in Agricultural Production," in *Technology in Agriculture*, IntechOpen, 2021.

[23] R. Kumar, N. Kumawat, and Y. K. Sahu, "Role of Biofertilizers in Agriculture," *Pop. Kheti*, vol. 5, no. 4, pp. 63–66, 2017.

[24] J. J. Parnell *et al.*, "From the Lab to the Farm: An Industrial Perspective of Plant Beneficial Microorganisms," *Front. Plant Sci.*, vol. 7, Aug. 2016.

[25] S. Thiyageshwari, P. Gayathri, R. Krishnamoorthy, R. Anandham, and D. Paul, "Exploration of Rice Husk Compost as an Alternate Organic Manure to Enhance the Productivity of Blackgram in Typic Haplustalf and Typic Rhodustalf," *Int. J. Environ. Res. Public Health*, vol. 15, p. 358, Feb. 2018.

[26] D. Jain *et al.*, "Effect of microbial consortia on growth and yield of wheat under typic haplustepts," *Plant Physiol. Reports*, vol. 26, pp. 570–580, Sep. 2021.

[27] Y. Wang *et al.*, "The Long-Term Effects of Using Phosphate-Solubilizing Bacteria and Photosynthetic Bacteria as Biofertilizers on Peanut Yield and Soil Bacteria Community," *Front. Microbiol.*, vol. 12, pp. 1–14, Jul. 2021.

[28] J. Bao *et al.*, "Potential applicability of a cyanobacterium as a biofertilizer and biopesticide in rice fields," *Plant Soil*, vol. 463, pp. 97–112, Jun. 2021,.

[29] K. Das, P. Datta, and D. Sengupta, "Influence of Bio-fertilizer on guava (Psidium guajava L.) cultivation in gangetic alluvial plain of West Bengal, India," *J. Exp. Biol. Agric. Sci.*, vol. 5, no. 4, pp. 476–482, Sep. 2017.

[30] M. F.-Z. Akhtar, M. Jamil, M. Ahamd, and G. H. Abbasi, "Evaluation of biofertilizer in combination with organic amendments and rock phosphate enriched compost for improving productivity of chickpea and maize," *Soil Environ.*, vol. 36, no. 1, pp. 59–69, Nov. 2017.

[31] S. K. Gosal *et al.*, "Assessing the Benefits of Azotobacter Bacterization in Sugarcane: A Field Appraisal," *Sugar Tech*, vol. 14, pp. 61–67, Mar. 2012.

[32] M. A. Youssef *et al.*, "Exogenously applied nitrogenous fertilizers and effective microorganisms improve plant growth of stevia (Stevia rebaudiana Bertoni) and soil fertility," *AMB Express*, vol. 11, pp. 1–10, Dec. 2021.

[33] G. K. Upamanya, A. Bhattacharyya, and P. Dutta, "Consortia of entomo-pathogenic fungi and bio-control agents improve the agro-ecological conditions for brinjal cultivation of Assam," *3 Biotech*, vol. 10, p. 450, Oct. 2020.

[34] R. Dineshkumar, J. Subramanian, and P. Sampathkumar, "Prospective of Chlorella vulgaris to Augment Growth and Yield Parameters Along with Superior Seed Qualities in Black Gram, Vigna mungo (L.)," *Waste and Biomass Valorization*, vol. 11, pp. 1279–1287, Apr. 2020.

[35] R. Dineshkumar, R. Kumaravel, J. Gopalsamy, M. N. A. Sikder, and P. Sampathkumar, "Microalgae as Bio-fertilizers for Rice Growth and Seed Yield Productivity," *Waste and Biomass Valorization*, vol. 9, pp. 793–800, May 2018.

[36] R. Dineshkumar *et al.*, "The Impact of Using Microalgae as Biofertilizer in Maize (Zea mays L.)," *Waste and Biomass Valorization*, vol. 10, pp. 1101–1110, May 2019.

[37] İ. Erdemci, "Effects of Seed Microbial Inoculant on Growth, Yield, and Nutrition of Durum Wheat (Triticum Durum L.)," *Commun. Soil Sci. Plant Anal.*, vol. 52, no. 7, pp. 792–801, 2021.

[38] E. Bakhshandeh, H. Rahimian, H. Pirdashti, and G. A. Nematzadeh, "Evaluation of phosphate-solubilizing bacteria on the growth and grain yield of rice (Oryza sativa L.) cropped in northern Iran," *J. Appl. Microbiol.*, vol. 119, no. 5, pp. 1371–1382, Nov. 2015.

[39] I. O. Omomowo, O. E. Shittu, O. I. Omomowo, and O. N. Majolagbe, "Influence of phosphate solubilizing non-toxigenic Aspergillus flavus strains on maize (Zea mays L.) growth parameters and mineral nutrients content," *AIMS Agric. Food*, vol. 5, no. 3, pp. 408–421, 2020.

[40] M. S. Arif *et al.*, "Associative interplay of plant growth promoting rhizobacteria (Pseudomonas aeruginosa QS40) with nitrogen fertilizers improves sunflower (Helianthus annuus L.) productivity and fertility of aridisol," *Appl. Soil Ecol.*, vol. 108, pp. 238–247, Dec. 2016.

[41] Y. El-Tahlawy and S. A. A. Hassanen, "Response of lentil to crude humates and rhizobacteria inoculation under calcareous soils conditions," *Egypt. J. Agron.*, vol. 433, no. 1, pp. 105–121, 2021.

[42] Q. Liu, X. Meng, T. Li, W. Raza, D. Liu, and Q. Shen, "The Growth Promotion of Peppers (Capsicum annuum L.) by Trichoderma guizhouense NJAU4742-Based Biological Organic Fertilizer: Possible Role of Increasing Nutrient Availabilities," *Microorganisms*, vol. 8, no. 9, p. 1296, Aug. 2020.

[43] M. D. Peña Borrego, M. R. De Zayas Pérez, and R. M. Rodríguez Fernández, "La producción científica sobre biofertilizantes en Cuba en el periodo 2008-2012: Un análisis bibliométrico de las revistas cubanas," *Cultiv. Trop.*, vol. 36, no. 1, pp. 44–54, 2015. [44] The Fertilizer Association of India, "Annual Report (2019-20)," India, 2019.

[45] A. Móring *et al.*, "Nitrogen Challenges and Opportunities for Agricultural and Environmental Science in India," *Front. Sustain. Food Syst.*, vol. 5, pp. 1–16, Feb. 2021.

[46] L. Fang, "Overview of Biofertilizer Registration in China," *ChemLinked Agrochemical*, 2020. https://agrochemical.chemlinked.com/chempedia/overview-biofertilizer-registration-china (accessed Feb. 28, 2023).