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Analysis of Scientific Contributions to Agricultural Development and Food Security in Ecuador

Gricelda Herrera-Franco[1*], Victor Sánchez-Arizo[2], Paulo Escandón-Panchana[3,4], Jhon Caicedo-Potosí[3], María Jaya-Montalvo[3], José Zambrano-Mendoza[2]

[1] Faculty of Engineering Sciences, Santa Elena Peninsula State University (UPSE), La Libertad 240204, Ecuador
[2] Dirección de Investigaciones, Instituto Nacional de Investigaciones Agropecuarias (INIAP), Quito 170518, Ecuador
[3] Centre for Research and Projects Applied to Earth Sciences (CIPAT), ESPOL Polytechnic University, Guayaquil P.O. Box 09-01-5863, Ecuador
[4] Geo-Resources and Applications GIGA, ESPOL Polytechnic University, Guayaquil P.O. Box 09-01-5863, Ecuador

Corresponding Author Email: grisherrera@upse.edu.ec

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ABSTRACT

In alignment with the 2030 Sustainable Development Goals (SDGs), Ecuador's National Development Plan accentuates SDG 2's commitment to escalating agricultural productivity for food security. Notably, Ecuador contributes significantly as a producer and exporter of foods such as bananas, cocoa, and frozen vegetables, with bananas encompassing 27% of non-oil exports. The past decade has witnessed an appreciable growth in the country's scientific contributions to the agricultural sector. This study employs bibliometrics and systematic reviews, leveraging mapping techniques via bibliometrix and VOSviewer tools, to analyse 1,300 scientific documents spanning from 1973 to 2022. Within this corpus, distinct research trends materialised across three distinct eras. The period from 1973-2000 was characterised by studies on indigenous plants, ivory vegetable production, and the nutritional value of quinoa. The subsequent decade (2001-2010) witnessed an expansion into the realms of pollination, properties of Ishpingo oil, genetics, and biomass. The latest period (2011-2022) marked a shift in focus towards cocoa fermentation, genetics, soil analysis, strawberry antioxidants, and eucalyptus properties. Considering Ecuador's growing reliance on global trade integration, the need to address postharvest diseases using biocontrol agents, and the advancement of irrigation automation for water efficiency have emerged as critical areas. The assessment of the quality of scientific contributions in agriculture underscores a direct correlation between food production, the extent of the country's agricultural coverage, and the proportion of employment within the agricultural sector.

1. INTRODUCTION

Agriculture plays a critical role in the economic development of developing countries, accounting for 4% of the global gross domestic product (GDP) and exceeding 25% in certain emerging nations [1, 2]. Beyond economic impact, agriculture also serves as a livelihood strategy, contributes to food security, creates employment, and aids in poverty reduction [3]. To meet the anticipated demand driven by a global population increase to 10 billion by 2050, a 70% surge in global food production is necessitated [4].

Ecuador, occupying a mere 0.06% of the Earth's land surface, is a hotspot of biodiversity. Astonishingly, this small country hosts 16% of the world's bird species, 8% of amphibians, 5% of reptiles, and 8% of mammals [5, 6]. Its rich biodiversity is spread across a variety of ecosystems, including mangroves, forests, and tropical rainforests, spanning four distinct biomes: the Galapagos Islands, Coastal, Andean, and Amazon. These regions support diverse economic activities, including agriculture, which sustains a population of 18 million in Ecuador [7].

The significance of agriculture in Ecuador stretches back to before the advent of Spanish settlers in the late 14th century, when the landscape was dominated by woody plants and crops such as maize, potatoes, cassava, and beans [8]. During the colonial era, agricultural productivity was enhanced through the introduction of new techniques like shifting cultivation, monoculture, ploughing, and livestock farming [9]. By the 19th century, Ecuador had garnered recognition as a producer of premium cocoa, a crop valued for its ecological and environmental contributions, particularly its promotion of soil biodiversity [10].

However, the 1930s saw the cocoa industry decimated by diseases such as Moniliophthora perniciosa and Crinipellis perniciosa (witches' broom), which reduced cocoa production by 60% and pushed Ecuador off its pedestal as the leading producer [10]. This downturn paved the way for the rise of banana production between 1948 and 1964 [11]. Since then, Ecuador has demonstrated a remarkable adaptability, maintaining its position as the world's top banana exporter [12].

The first oil palm cultivation was introduced in La Concordia, near Esmeraldas, in the 1950s. As it proved to be a potentially lucrative crop, farmers began to switch from bananas to oil palm. By the 1970s, the oil palm was seen as a viable alternative to bananas [13]. Following the oil boom, the country experienced the highest GDP growth in its history, which led to a decrease in the share of agriculture in the GDP [14]. Despite this, changes in the agricultural productive structure were initiated, focusing on crops with higher added value [14]. In 1982, flower production was introduced in the highlands of Ecuador, leading to the development of flower agribusinesses for export [15]. This shift resulted in a gross value added (GVA) of 15.9% for agriculture [16].

Agriculture remains fundamental to Ecuador's economy, food security [17], and provision of raw materials for industry. Over the past decade, the agricultural sector has accounted for approximately 9.3% of the GVA [18]. The main contributors to this GVA are bananas (17.4%), cocoa (6.9%), roses (6.9%), maize (6.9%), rice (3.9%), sugar cane (3.3%), and oil palm (2.8%) [19].

The initiation of public agricultural research in Ecuador traces back to 1942 with the establishment of the Agricultural Experimental Station of Ecuador, in cooperation with the United States of America [20]. In 1962, the National Institute for Agricultural Research (INIAP) was founded with financial support from the Rockefeller Foundation and the Inter-American Development Bank (IDB) [21]. INIAP focused on essential food crops (e.g., wheat, rice, maize, potatoes, milk, and barley) and export products such as cocoa and coffee [22].

Agricultural education in Ecuador commenced in 1931 with the establishment of schools of agronomy at the Universidad Central del Ecuador, followed by the Universidad de Loja in 1945, and the Universidad de Guayaquil in 1948 [23]. Research funding was initially limited, but increased with the creation of the National Council of Universities and Polytechnic Schools in 1982 [24]. Between 2010 and 2020, the Ecuadorian government implemented policies to promote research, leading to an 86.98% increase in scientific publications [24-26].

Under this exploratory approach, agriculture is essential for Ecuador's economy and food security. In the last decade, exports of foodstuffs such as coffee, cocoa and palm oil have increased by 1% annually. Agricultural production and consumption within the country of food sovereignty products such as maize, sugar cane and soya have also increased by 1.6 to 2.2% annually [17]. Agricultural production contributes to the national economy with a 14% share of GDP. However, there is a need to study the contribution of local research to the country's agricultural development. Moreover, publishing scientific research articles indicates research progress and knowledge generation [27].

In this context, bibliometric analysis is a fundamental methodological tool for quantifying scientific activity, developing areas of study, the most productive institutions, research trends and collaboration patterns [28]. This study uses the bibliometric approach to synthesise research on agricultural development, food production and food security in Ecuador, which will contribute to decision-making on future lines of research. This work aims to analyse scientific contributions in the area of agricultural sciences through literature review and bibliometric methods for the identification of collaborators, trends and evolution of the researched topics that have contributed in the context of scientific knowledge and food production in Ecuador.

2. MATERIALS AND METHODS

This work reviews publications in scientific databases, processing reference information on topics, keywords and authors, and analysing the research. Also, this relates the connection of publications with policy developments, realities, and trends in the agricultural sector in Ecuador. The method consists of three phases: (i) definition of the topic and scientific databases; (ii) database processing; and (iii) analysis and interpretation of results (Figure 1).

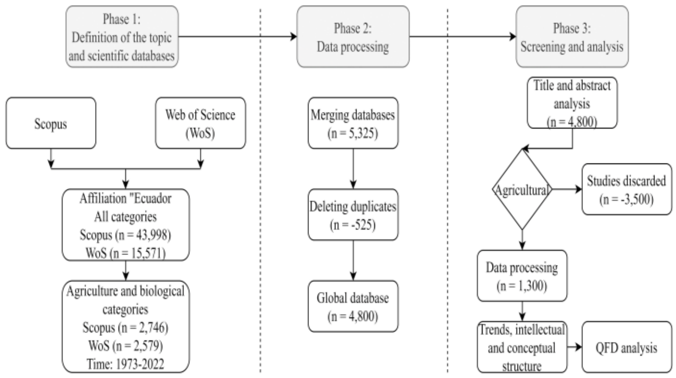

Figure 1. Outline of the methodological approach: QFD (Quality Function Deployment)

The phase 1 corresponds to the topic of agricultural sciences in Ecuador. Subsequently, the Scopus and Web of Science (WoS) databases were selected because they index quality documents. The term "Ecuador" was searched for in the database country affiliation field. In WoS, the Ecuadorian universities indexed in this database were selected [29]. The Scopus search limited the areas of knowledge: agricultural and biological sciences, biochemistry, genetics-molecular biology, and environmental sciences [30]. In addition, the areas of agricultural, biological and environmental sciences were selected in the WoS categories. In the second week of October 2022, this phase performed the search and included all available years, languages, and documents. Additionally, it obtained general data and identified the study time from 1973-2022, the number of records with Ecuador affiliation in Scopus (43,998) and WoS (15,571), of which in Scopus 2,746 (6.24%) correspond to agricultural sciences and biological, while in WoS 2,576 (16.56%) records are in these areas (Figure 1). The phase 2 included the databases (i.e., Scopus and WoS) were merged using Bibliometrix v.4.0.1 [31]. The merged file was exported to Excel to remove duplicate records, no information in the author field, and records from 2023 [32].

The phase 3 analysed the title and abstract of the records in the merged file to determine agricultural science studies in Ecuador [33]. In addition, this phase included records that are articles, book chapters and conferences. Bibliometrix processed the selected records to obtain publication trends by year, international collaboration, and intellectual and conceptual structure [34]. Also, this software determines the intellectual structure using the affiliation field for university contributions, sources, and the citations. For the analysis by universities and institutions, the records were classified according to the Scimago Journal Rank Indicator (SJR) quartile to quantify their quality and quantity [35]. Also, Bibliometrix identifies the conceptual structure considering authors' keywords. The keywords are analysed using Biblioshiny (Bibliometrix user-friendly app). It groups the keywords in nodes, considering their co-occurrences and association, and classifies the nodes in a four-quadrant thematic map: (i) motor topics are the most relevant, (ii) niches are well-developed topics, (iii) emerging or declining topics are not relevant, and (iv) basic topics are highly relevant but need developing. The thematic map highlights the most relevant topics and emerging and declining trends in the field, i.e., it identifies research trends to understand the most studied agricultural products. On the other hand, VOSviewer processed the author's keywords to generate the co-occurrence map, which orders the topics in clusters according to their frequency and relationship [36]. This phase divided the publications into three periods: a) 1973-2000, b) 2001-2010, c) 2011-2022 to analyse the evolution of publications because from 2001 onwards, the country's scientific production increased, motivated by the impulse of the knowledge society [25]. The highest number of citations was considered for selecting outstanding articles because they are a bibliometric indicator of quality. Furthermore, by analysing the abstracts of the selected articles, they were ordered according to the United Nations Educational, Scientific and Cultural Organisation's (UNESCO) international standard classification of education [37]. This phase also includes an analysis to validate the quality of the scientific contribution in agriculture through an adaptation of Quality Function Deployment (QFD). QFD is a tool used for quality management improvement of products, services and processes, research planning, general and strategic, and decision making [38]. Under this scheme, the study identified as output the scientific contribution in the agricultural sector and determined parameters for its evaluation (i.e., bibliometric, socio-economic and environmental variables). These are represented as Whats and the relationship to the methods for analysing these indicators as Hows in the House of Quality. In this step, the researchers assigned the weight of the indicators (importance of scientific contribution) and found the correlation between Whats and Hows.

3. RESULTS

3.1 Overall metrics

The screening identified 1,300 documents in the area of agricultural sciences. Figure 2 shows the trend in the number of publications and the sum of total citations per year.

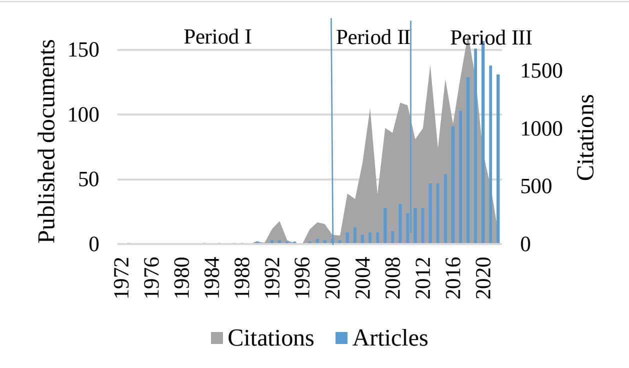

Figure 2. Cavity geometry evolution of scientific publications and citations in Ecuador from 1973 to 2022

In period I (1973-2000), highlighted publications such as the native plant's analysis for chloroform production [39] and the industrial production of vegetable ivory (made from *Phytelephas* (Arecaceae)) as a resource for textile applications [40]. On the other hand, this period studies the importance of quinoa for food by its nutritional quality [41]. In addition, tuber species (wild potatoes) were compared according to their region, Central and South America [42]. Viruses were tested in potato and tomato crops, considering factors such as isolation and grouping, and it was recognised that isolated crops presented more problems [43]. Moreover, in this period, studied the morphological characterisation of these species (potato and tomato) [44].

In period II (2001-2010), studies of the pollination of flowers in Andean forests of the country were highlighted, mainly the bat-flower interaction [45]. Also, this period studied Ishpingo oil and its antioxidant and antifungal properties in the Amazon [46]. On the other hand, genetic relationships between *Bactris gasipaes Kunth* (peach palm) cultivars and their wild relatives were analysed, detecting high polymorphism [47]. In addition, the relationship of biomass as a function of wood in forests in different regions was studied, and it found no direct relationship between the two [48]. Another study analysed macroinvertebrates and fungi in mature forests and grasslands concerning litter processing in the country's northeast.

Period III (2011-2022) studied the influence of traditional fermentation practices for cocoa considering yeast species, bacterial community dynamics in pulp samples, cocoa beans and sensory analysis of the chocolate produced [49]. In addition, the genes of cocoa cultivars were studied concerning criollo cocoa and the influence of the genome to improve its quality, mainly pigmentation [50]. On the other hand, soils in the Ecuadorian Andes and their nutrients available for agricultural activities were analysed, considering that these areas are affected by logging and the burning of forests [51]. In addition, tropical mountain soils were experimented with additions of nitrogen and phosphorus for interacting these minerals with tree roots and arbuscular mycorrhizal fungi, finding a preference for phosphorus [52]. Also, the study of antioxidants extracted from strawberries with anti-inflammatory properties through biomarker measurements and molecular reactions was highlighted [53]. Moreover, the properties of eucalyptus were reviewed, mainly its antimicrobial properties; its extract does not represent carcinogenicity or genotoxicity [54]. Due to its importance worldwide, Eucalyptus honey's physicochemical, chemical and curative properties were also reviewed.

3.2 Intellectual structure

3.2.1 International collaboration

Ecuador's international collaboration is shown in Table 1, highlighting participation with the United States of America, Spain, France, Brazil, and Belgium and the most cited contributions. Products are studied to protect them from pests, viruses and pathogens, sustainable practices, and the nutritional benefits of the products.

3.2.2 Contribution by universities and research institutes

The contributions of Ecuadorian institutions doing research in agricultural areas evaluate according to the number of documents, their quality and citations (Figure 3). The following institutions highlight Escuela Superior Politécnica del Litoral (205), Universidad Central del Ecuador (156), Pontificia Universidad Católica del Ecuador (143), Instituto Nacional de Investigaciones Agropecuarias (129) and Universidad de las Fuerzas Armadas ESPE (108). Table 2 shows the contributions of universities and centres in this area.

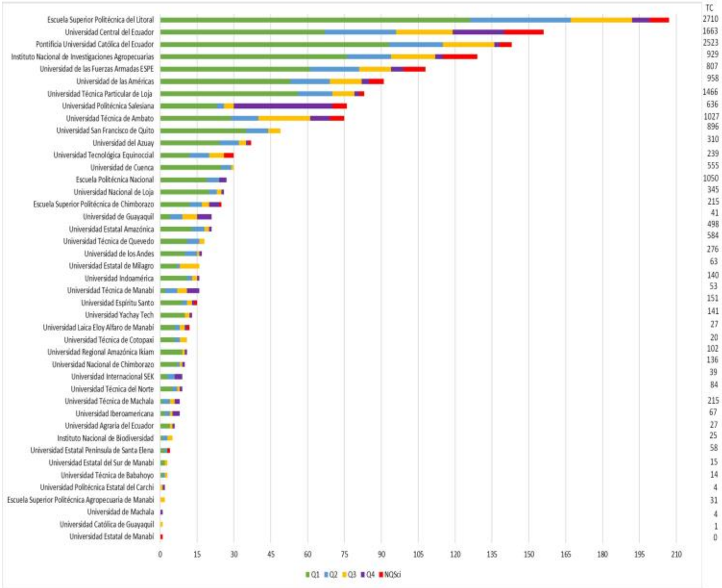

Figure 3. Scientific production in agricultural sciences by institutions

Categories in SJR (Q1, quartile 1; Q2 quartile 2; Q3 quartile 3; Q4 quartile 4; NQSci not indexed in SJR); TC (Total citations).

Table 1. Outstanding country contributions in agricultural sciences with Ecuador

Country (%)	Main Contribution
United States of America n = 351 (27.8%)	Malhi et al. [55] studied the relationship between soil and climate in the Amazon, considering soil and plant properties.
Spain n = 330 (25.4%)	Martínez et al. [56] evaluated the antioxidant properties of tropical fruits after the industrialisation process.
France n = 145 (11.2%)	Puillandre et al. [57] conducted a review of an invasive pest threatening the agricultural sector, the Guatemalan tuber moth.
Brazil n = 115 (8.92%)	Archanjo et al. [58] conducted an analysis of components that improve soil characteristics, biochar, with inorganic-organic material interactions in soil.
Belgium n = 101 (7.76%)	Buytaert et al. [59] studied the relationship of pine afforestation with water yield in the Andean zone of Ecuador, which decreases the water yield of natural watersheds.

Notes: n (number of contributions); % (contribution rate relative to 1,300).

Table 2. Outstanding contributions from universities and research centres in the agricultural sciences in Ecuador

University	Contribution
Escuela Superior Politécnica del Litoral n = 207 (15.92%)	Cornejo et al. [60] determined the effects on the nutritional quality of rice flour bread during the germination process.
Universidad Central del Ecuador n = 156 (12%)	Valencia-Chamorro et al. [61] reviewed the use of natural films and coatings with added antimicrobials to preserve food products such as fruits and vegetables.
Pontificia Universidad Católica del Ecuador n = 143 (11%)	Queenborough et al. [62] analysed the survival of *Myristicaceae* seedlings over three years in a tropical rainforest using spatial scales (1-9 metres and 25 hectares), finding that the most abundant species have a higher mortality rate at the 25-hectare scale.
INIAP n = 119 (9.92%)	Melgarejo et al. [63] studied viruses influencing tomato curly top disease by genetic analysis in Ecuador and Peru.
Universidad de las Fuerzas Armadas ESPE n = 108 (8.30%)	Gaguancela et al. [64] studied physiological changes using stress sensors in *Arabidopsis thaliana*, *Nicotiana benthamiana*, and *Solanum tuberosum* to assess their virus tolerance.

Notes: n (number of contributions); % (contribution rate relative to 1,300).

3.2.3 Contributions in journals

Processing in Bibliometrix showed the journals were also analysed, the top five are presented according to the percentage of publications (Table 3).

Table 3. Most relevant journals in the agricultural sciences in Ecuador, according to the percentage of publications

Journal	%	Country	QS	QW
Granja - Revista de Ciencias de la Vida	5.20	Ecuador	3	4
Food Chemistry	2.09	United Kingdom	1	1
PloS One	1.86	United States	1	2
LWT-Food Science and Technology	1.40	United States	1	2
Plants	1.24	Switzerland	2	3

Notes: % (percentage of articles in these journals, relating to 1300); QS (Quartile in Scopus); QW (Quartile in WoS).

3.3 Conceptual structure

Figure 4 shows the thematic map. In particular, conservation and taxonomy issues in the Galapagos Islands are related in the quadrant of niche topics; niche topics are functional foods, maize, and resilience; emerging topics are biocontrol and livestock. Finally, basic topics focus on cocoa, cadmium, fermentation, land use and pesticides in the Amazon.

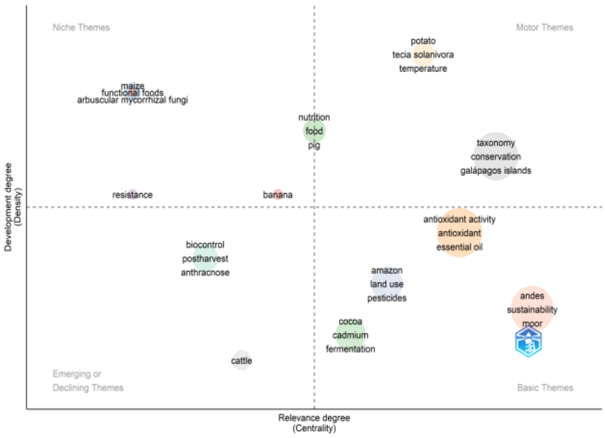

Figure 4. Thematic map exported from Bibliometrix

The conceptual structure exported from VOSviewer, shows 88 interrelated topics in eight clusters (Figure 5). Cluster 1, "Antioxidant and phenolic compounds" (red colour), includes topics related to antimicrobial and antibacterial activity. In addition, it considers essential oils for their antioxidant properties. Cluster 2, "Andes and the Galapagos Islands" (green colour), involves soil, conservation and moorland issues. Also, these regions present problems, such as deforestation and invasive species due to agricultural activities. Cluster 3, "Ecuador and food" (blue colour), includes issues related to agricultural production such as rice, maize, bananas and pigs. Also, it shows the vulnerability of cereals to fungal contamination. Cluster 4, "Cocoa and fermentation" (yellow colour), mainly has issues related to cocoa production and cadmium concentration on plantations. Cluster 5, "Sustainability and fruits" (purple colour), addresses fruit production and sustainability issues in rural contexts. It also recognises biocontrol applied to agriculture for crop protection and production. Cluster 6, "Amazon and pesticides" (pink colour), considers issues related to biomass, biodiversity and forests. It considers the effects of forestry on tree growth in tropical forests. Cluster 7, "Genetic diversity" (orange colour), considers population structure and tropics issues. It also includes genetic differences between the fruits of *Bactris gasipaes Kunth* (domesticated palm) and its wild relatives. Cluster 8, "Taxonomy and phylogeny" (brown colour), has themes related to morphology and medicinal plants. It considers the content of seeds and fruits of *Arecaceae* (palm trees) due to their importance in producing vegetable oil.

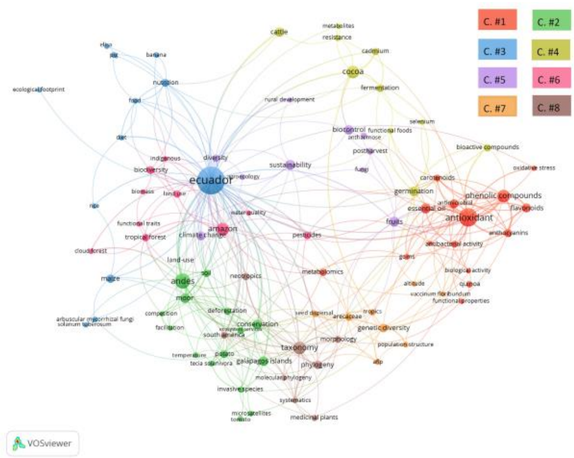

Figure 5. Network of thematic clusters using the authors' keywords. C. # (Cluster No.)

3.3.1 Research trends and UNESCO classification

The records addressed were analysed considering the UNESCO classification for the areas of Agriculture (Figure 6): (i) *Crop and livestock production* (76%), which emphasises the agricultural sciences (20%); fruit growing (19%); crop science (13%); grain growing (9%); animal husbandry (6%); farming (5%), related to traditional practices; soil science (5%); Pig (4%); Crop growing (4%); and others (wine, sugar cane, horse breeding, poultry husbandry). Also, Figure 6 shows (ii) *Horticulture* (15%), which mainly includes flower surveys, nursery management. And (iii) *Forestry* (9%), which deals with issues related to crops and farming in forests.

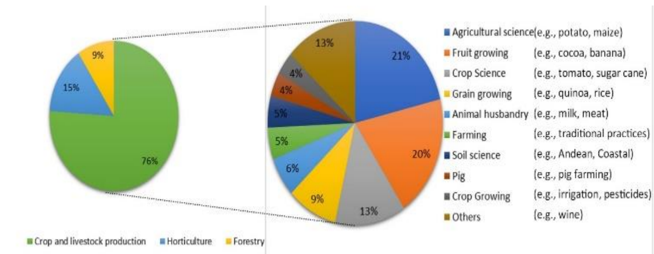

Figure 6. Themes addressed in terms of the UNESCO International Standard. % (percentage contribution relative to 1,300)

3.4 Quality assessment

Ecuador has a surface area of 256,370 Km^2, and the available territory for agricultural activities is 55,160 Km^2 (5,516,000 ha). However, 21,914.05 Km^2 (2,191,405 ha) are produced, which is 39.73% [65]. Figure 7 shows the nine most produced agricultural products in Ecuador by province.

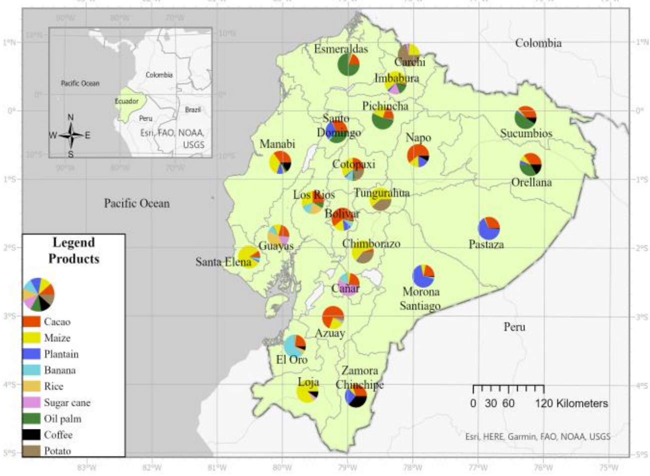

Figure 7. A) The geographical location of Ecuador exported from ArcGIS Pro. B) Main agricultural products by provinces. Based on data from Ministry of Agriculture and Livestock (MAG, an acronym in Spanish) [66]

Figure 8 shows the parent or house of quality with the validation of the scientific contribution to agriculture. The researchers' criteria defined ten validation indicators with 15 variables explaining the indicators. The relationship between the indicators and their variables shows their degree of dependence. The weight of the indicators determines that the highest importance of scientific contribution is based on international collaboration and research topics related to knowledge, sustainability and climate change. The house of quality highlights the high relationship between international collaboration with citations in high-impact indexed journals, countries that collaborate in this research, the quality of publications per university and research topics related to UNESCO. Also, the country's productive matrix has a high relationship concerning food production, exports and imports of products. In addition, the sustainability and climate change criteria are strongly related to the UNESCO themes, the percentage of employment in the agricultural sector, the incidence of floods-droughts, and the use of pesticides and fertilisers. The agricultural sector reveals that it could increase food supply by around 70% through local food consumption or export markets for the country's food security and decrease the percentage of malnutrition in the population [67]. Also, organic and agroecological production is projected with specialised international markets that contribute to rural development, poverty reduction and production systems [68].

The correlation matrix shows the correlations between the quality indicators (Figure 8). It highlights the strong positive correlations between citations in high-impact indexed journals with the number of publications and total citations per university. In addition, the direct correlation between food production with the country's agricultural coverage and the percentage of employment in the agricultural sector. The results of this analysis, according to the relative weights of the variables suggest five strategies that contribute to the quality of scientific contribution in agriculture: (i) Contribute with scientific publications in the areas and sub-areas of knowledge UNESCO related to agriculture in the context of sustainability and climate change. (ii) To promote international collaboration in scientific research in universities and research centres in the country. (iii) Foster agriculture-related research in universities through scientific publication in high-impact journals. (iv) Support the development of sustainable agriculture considering the impact of natural phenomena and the use of pesticides and fertilisers. (v) To propose research projects aimed at making use of the country's agricultural land.

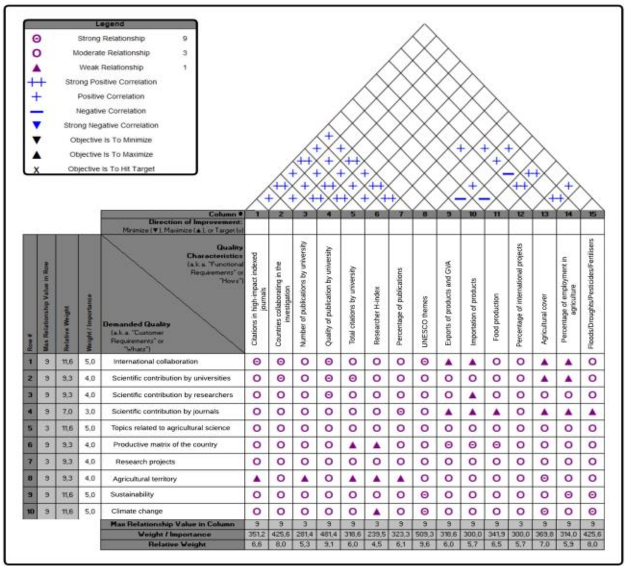

Figure 8. Quality house for the validation of scientific contribution in agriculture

4. DISCUSSION

This study provides insight into scientific activity in Ecuador's agricultural sciences framework. It identifies the development of knowledge, current status, trends, needs and research gaps to be considered by academics, researchers and decision-makers [69]. In addition, the contributions of scientific research help to improve agricultural productivity and food security in emerging countries such as Ecuador.

Ecuadorian universities have contributed 57% (n = 741) in Q1 publications in the SJR. In which the following stand out: Escuela Superior Politécnica del Litoral - ESPOL, Universidad Central del Ecuador - UCE, Pontificia Universidad Católica del Ecuador - PUCE, Universidad de las Fuerzas Armadas - ESPE, Universidad San Francisco de Quito - USFQ, and these universities are in the QS World University Rankings, belonging to the top ten in the country [26]. The journal that indexes the highest number of publications on the subject of agricultural sciences in Ecuador is the regional journal of Life Sciences of Universidad Politécnica Salesiana, called Granja, Q4 - SJR, it has 5.20% (n = 68) of total publications (Table 3). Therefore, the number of publications indicates quality in evaluating universities at national and international levels [27]. However, the universities with the fewest articles likely publish their work in regional journals (indexed in Latindex, SciELO, and RedALyC databases) [70]. Furthermore, the number of postgraduate degrees offered nationally does not indicate a higher number of publications, even though postgraduate degrees can improve university research.

The growth in this area, it highlights from 2010 onwards, is related to trends such as sustainable land use and agriculture due to the importance of this area for developing countries [71]. It also highlights quinoa production in the Andean region [72] and maize worldwide from that year onwards [73]. Some organisations encourage research to promote food security, particularly: (i) The Consultative Group on International Agricultural Research, which has cooperated with Ecuador through the Rethinking Food Markets project [74], contributing to poverty reduction and increasing employment opportunities; (ii) The Agricultural Science and Technology Indicators, which directly funds researchers to develop research and technology in this area [75]. These projects promote adaptation to climate change and consider its threats, such as erosion, desertification, and crop loss due to flooding.

The most researched themes were detected through the conceptual structure, highlighting cattle and postharvest such as emerging topics; in the basic topics is cocoa; motor topics are the most relevant, i.e., potato, food and pig; and marginal topics are maize and functional foods (Figure 4), which are related to the main products consumed in Ecuador (e.g., banana, maize, rice) [76] (Figure 7), and to exported products (e.g., banana, cocoa, roses and flowers) [19]. In addition, universities are focusing on studies related to crop care (e.g., cocoa, potato, tomato), and nutritional properties of products (e.g., brown rice, honey, quinoa) (Table 3). The country's public research institute, INIAP, has defined research on plant breeding, integrated crop and livestock management, biotechnology, conservation of natural resources, agro-industry and agricultural economics, related to 17 crops and production systems for all regions of the country, including the Galapagos region [77]. An analysis of scientific publications of INIAP from 2014 to 2019 was published before [22].

This study recognises the importance of universities and INIAP researching for food security and exporting products. Agricultural production at the national level satisfies domestic food consumption because this sector produces 95% of the food consumed in the country [65]. Furthermore, according to the Government of Ecuador's One-Stop Investment Shop [65], the country has 55,160 Km^2 of arable land in the country, 39% of which is used for agricultural production. The challenges in agricultural land use are mainly climate change due to flooding of crops, production of greenhouse gases, and poverty in rural areas, where 30% of the rural population in December 2020 faced problems of food insecurity. Some strategies to address these challenges are investment in social programmes, microcredit, and mentoring, which aim to increase agricultural productivity and maintain fertile soil. Opportunities to exploit agricultural land depend on environmental conditions, economic level, climate change, water availability for irrigation, deforestation and soil characteristics [78]. Agricultural land use can be expanded: (i) through public investment in the agricultural sector [79], because in Ecuador, 0.2% of GDP is invested in this sector [80]; (ii) in adaptability to climate change; and (iii) in practices with a sustainable agricultural approach. On the other hand, the QFD matrix highlighted: (i) The promotion of international projects in this area, based on inter-institutional agreements; (ii) Citations and indexation to high-impact journals can measure the quantity-quality of publications as an indicator of university quality; (iii) Research in sustainable agriculture considering climate variability, the use of pesticides, fertilisers, and water use; (iv) Investment in research projects that promote the use of arable land. According to the results of this study, they show that QFD evaluation indicators can improve the quality of scientific contribution through management strategies in this area. Similarly, other studies use evaluation indicators to improve the business quality of agri-food small and medium enterprises [81], biofuel policies [82], and industrial waste management [83].

5. CONCLUSIONS

This work analysed the agricultural sciences from a scientific perspective using bibliometric methods, mainly 1,300 records from high-quality scientific databases, Scopus and WoS. Where a period of study between 1973 and 2022 is recognised, countries prominent in collaboration in the subject, such as the United States, Spain, France, Brazil and Belgium. These countries help study products, their properties, pests, viruses, benefits, conservation and agricultural sustainability.

The classification of each record allowed us to recognise that, of the 1,300 records, 57% correspond to Q1, 16.8% to Q2, 12.6% to Q3, 8.23% to Q4, and 5.23% are not included in SJR. Also, the total citations complement the quality indicators in the research process on this subject. In addition, productivity and quality could be higher in some universities that offer related degrees in this area. On the other hand, the conceptual structure includes topics about products with antimicrobial and antioxidant properties. It also shows the risks to crops from fungi and biocontrol as a solution to this problem. On the other hand, current research trends include conservation, phenolic compounds, and biocontrol.

This article shows publications linked to national agricultural production, mainly cocoa, potatoes, bananas, maize and tomatoes. However, it is necessary to highlight that the country's agricultural potential is not exploited, i.e., these territories can be researched to increase agricultural productivity by considering adaptability to climate change and sustainable agricultural methods. Furthermore, this article highlights that most studies consider food security in the country, the sustainable development of rural communities through horticulture, and the conservation of forests for forestry. The implementation of the QFD method shows the importance and interrelationship between the variables considered (what-how), mainly: (i) the UNESCO themes, (ii) the quality of publications, (iii) the effects of climate change (e.g., floods, droughts), the use of pesticides and fertilisers. Furthermore, the fusion of bibliometrics and QFD enhances the scientific contribution in agriculture by successfully developing strategies according to the sector's needs. The limitations, the articles included in the review have a high number of citations, so this article did not include articles with few citations that may be relevant to this area. Future research trends are small, medium and large-scale irrigation and water-saving automation projects. Geomatic applications using artificial intelligence technologies. The use of renewable energies in agricultural activities to mitigate carbon dioxide emissions. Furthermore, the adaptation of agricultural greenhouses in sectors such as the Amazon and Galapagos to improve food security.

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