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IoT application technologies for agriculture in Latin America during the COVID-19 pandemic

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Abstract: ***IoT digitizes any plant of agricultural processes simplifying the activities; producing products of higher quality in a set period and optimizing automatic irrigation systems. Evaluate IoT application technologies for Latin American agriculture during the COVID-19 pandemic, through systematic search engine database vision; obtaining 78 publications between 2019 and 2022, considering 14 studies by inclusion criteria of methodological heterogeneity. The main IoT application technologies for smart agriculture: according to the quantitative approach in dimension 1; 3 articles contribute to architecture and 1 to irrigation control; while in dimension 2; 2 articles contribute to environmental monitoring and 4 to efficient water management; the same in qualitative approach in dimension 1; 2 articles show trends of the industrial revolution in food, 2 in automation architecture and 2 in the intelligent decision by artificial vision; also in dimension 2; 2 articles studied trends of industrial revolution 4.0 and 4 intelligent precision agriculture and computer vision. Therefore, quantitative studies were based on experimental applications of data architecture design to optimize water consumption according to environmental conditions; reviewing in qualitative approach trend documents of the Industrial Revolution 4.0 applying artificial vision.***

Keywords: IoT, smart agriculture, wireless sensors, irrigation systems, automation

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I. Introduction

The Internet of Things (IoT) makes it possible to digitize the monitoring and control system of any agricultural process plant, simplifying the activities carried out by humans from any time and place using a smartphone [1]. At present, all economic activities mainly agriculture require quality production in a set period. Globally by 2050 to meet the growing population demand food production must increase by 70%. In the future, "precision" agriculture will ensure sustainability, stability, and food supply with very efficient smart irrigation systems for a long-range network with low energy consumption [2], to mitigate challenges in agriculture there are effective approaches to data detection of environmental conditions [3] and communications within the interoperability zone [4] of IoT-based data [5], intensifying food products efficiently and safely for the great demand in quantity and quality [6]. In Latin America, for low-cost crop yielding as a challenge, a flexible architecture has been implemented to easily link IoT and machine learning (ML) devices for precision irrigation [7]. In recent years with the appearance of COVID-19, in Peru digitized agricultural practices are being promoted by collecting soil and climate information to make the best decisions within production considering all existing obstacles such as energy and communication [8]. However, the vast majority of agricultural enterprises lack technology due to a lack of knowledge and financial competitiveness. The implementation of low-cost production process monitoring and control systems could be used by small and medium-sized enterprises (SMEs), composed of open software and hardware tools, allowing the modification and programming of measurement and control strategies much easier [9]. Likewise, few entrepreneurs in Latin American countries are in the experimental transition from artisanal agriculture to digital agriculture monitoring and controlling the crop field through sensors promoted in the period of survival of COVID-19 [10]; In this sense, to make better decisions taking advantage of the data [11] from the sensors that are transmitted to a gateway and encourage the optimization of production in smart agriculture [12] using the advancement of technologies, ensuring the demand for food due to the increase in population [13] in the long term it is proposed to diagnose the general problem PICOC: What are the IoT application technologies for agriculture in Latin America during the COVID-19 pandemic? . The justification is based on the use of updated technologies very practical for researchers and SMEs thus guaranteeing demand according to food traceability [14] of quality at low cost and in the long term applying the systematic methodology according to the guidelines of the PRISMA declaration [15]. Being the general objective: to evaluate IoT application technologies for agriculture in Latin America during the COVID-19 pandemic.

II. Methods

To learn about "IoT application technologies for agriculture in Latin America during the COVID-19 pandemic", a systematic exploration of the articles based on the PRISMA 2020 declaration [16] was carried out. The methodology requires a protocol for the review in order to achieve an orderly sequence of assessment of the activities developed within the research process.

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A. Eligibility criteria

To answer the research question, the inclusion and exclusion criteria are represented in Table 1, they were also grouped into 2 dimensions for synthesis.

TABLE II
INCLUSION CRITERIA

Criterion	**Inclusion**
Period	2019 -2022 (COVID-19 pandemic)
Languages	English, Spanish and Portuguese
Place of publication	Latin America
Information	Scientific articles
Topics	Technology, industry and communications
Level of education	Higher University
Field of action	Agriculture, agriculture, fruits.
Methodology	Systematics
Database Search Engines:	Scielo, Redalyc Ebsco, MDPI, Google Scholar, ScienceDirect
Bibliographic search strategy	Title, abstract, keywords

B. Sources of Information and Search Strategy

The electronic database engines cited, reviewed in October 2022, are detailed in Table 1, to apply the main search strategy, two variables or descriptor terms were selected: "Internet of things" and "agriculture". Likewise, a Boolean equation was formulated to extract the search for information from the titles, abstract and keywords of the research articles represented in Table 2.

TABLE II
SEARCH STRATEGY FOR DIMENSIONS ACCORDING TO THE BOOLEAN EQUATION

OR	**Dimension 1**	**AND**	**Dimension 2**
	"Internet of Things"	AND	Agriculture
	"IoT"	AND	Smart farming
	"Industry 4.0"	AND	
OR	("Internet of Things" and agriculture)	OR	
	("Internet of Things" and "smart farm"*)	OR	
	("IoT" and agriculture)	OR	
	("IoT" and "smart farm"*)	OR	
	("Industry 4.0" and agriculture)	OR	
	("Industry 4.0" and "smart farm"*)	OR	

Website databases and search equations are shown in Table 3, with all filter and boundary criteria used considering languages according to Table 1.

Linear equation in English:

("Internet of Things" and agriculture) or ("IoT" and agriculture) or ("Internet of Things" and "smart farm"*) or ("IoT" and smart farm"*) or ("Industry 4.0" and agriculture) or ("Industry 4.0" and smart farm"*))

Linear equation by descriptors in English:

("Internet of Things" or "IoT" or "Industry 4.0") and (agriculture or "smart farming"))

TABLE III
WEBSITES AND SEARCH EQUATIONS

Quantity	**Including**	**Website Database**	**Equation**
10	7	Scielo	("Internet of Things" and agricult*) or ("Internet of Things" and "smart farm"*) or ("IoT" and agricult*) or ("IoT" and "smart farm"*) or ("Industr* 4.0" and agricult*) or ("Industr* 4.0" and "smart farm"*) or ("Internet de las cosas" and agricult*) or ("Internet de las cosas" and "smart farm"*) or ("Internet das coisas" and agricult*) or ("Internet das coisas" and "smart farm"*))
20	2	Redalyc	(IoT or "Internet of Things") and Agriculture and (Latin America) first 20/3505
14	12	Ebsco	((IoT or "internet of things" or "smart devices") OR ("Industry 4.0" or i4.0 or "Industrie 4.0")) AND (agriculture or farming or farm)
3	1	MDPI	("Internet of Things") and (agricult*)
14	6	Google Scholar	title-abs-key ("Internet of Things" or "IoT" or "Industry 4.0") and title-abs-key (agriculture or "smart farming"))
17	9	Science Direct	("IoT" or "internet of things" or "smart devices") AND (agriculture or farming or farm) and extracting by countries: Argentina 4, Brazil 9, Chile 2, Colombia 1, Mexico 4 and Peru 4
78	**37**	**TOTAL**	

The selection process was carried out according to the main descriptors "Internet of Things" and " agriculture" validating the articles of quantitative approach, it was verified if the criterion meets in the title, abstract and / or in the keywords formulated in the equations of search database engines according to Table 3. Sifting 390 authors, being possible in some cases the search download of results according to automated Excel tools.

As elements the databases and/or search engines in the study after the inclusion and exclusion criteria, the results were obtained the articles on the databases consulted according to Table 3., without considering reports or reports.

The risk of bias in the articles involved has not been determined since they do not correspond to a single process or to different research approaches.

Table 4 was used for the bibliographic review, which allows to visually tabulate the results of individual studies and syntheses with the following fields: Author, year, dimensions, purpose, keywords, method and instrument and contribution according to bibliographic reference.

For the evaluation of certainty, it was verified according to the results found in the type of study field of Table 4, as quantitative experimental research.

III. Results

78 studies have been included in this study. The results of the information search are shown in Fig. 1. Table 1 presents the period, search engines and place of publication of inclusion of the main characteristics of the 37 studies included in Table 3. The studies were developed in Latin America, such as Argentina, Brazil, Chile, Colombia, Ecuador, Mexico and Peru. There are only 14 articles left for this review.

A. Selection of studies

The articles found were analyzed in terms of their methodological quality according to an evaluation protocol, classifying the information according to the flowchart (PRISMA) Fig. 1.

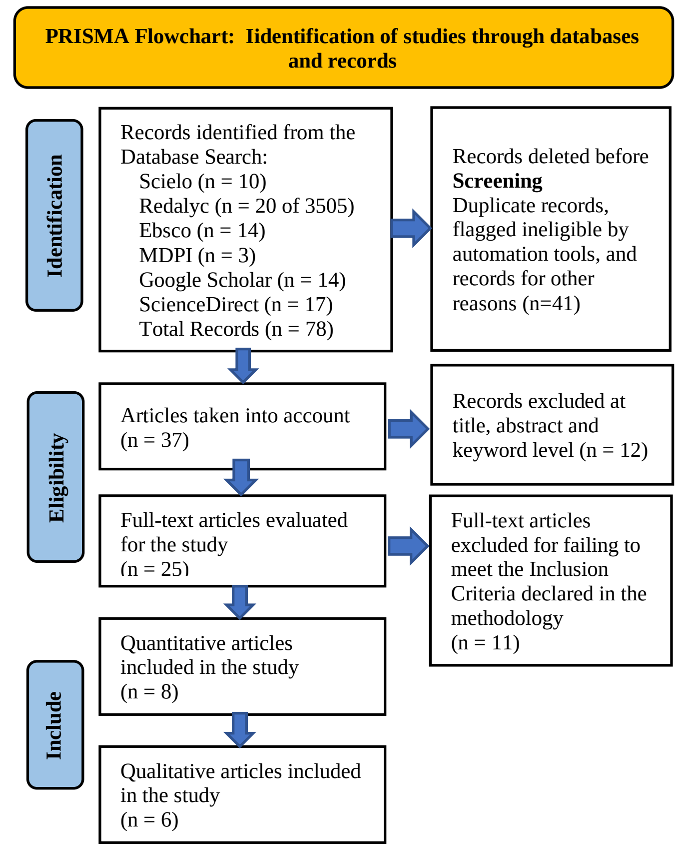

Fig. 1 Flowchart according to Prisma Declaration 2020 for systematic reviews of only databases and records. *Source: Adequacy [16]*

B. Study characteristics

The research included in the systematic review is detailed in Table 4.

TABLE IV

RESEARCH INCLUDED IN THE SYSTEMATIC REVIEW

N°	BD	Author/s	Dimension 1	Dimension 2	Objective	Methodology Type of study	Instrument, technique or methodology used	Author's contribution	Ref.
1	Scielo	Ruiz-Ortega et al. (2022)	Low-cost IoT architecture per wireless connection	Monitor the variables involved within a greenhouse,	Wireless connection and communication via the Internet to publish the collected data.	Quantitative	Laboratory record	Design on a Low Cost IoT Architecture for Greenhouse Monitoring.	[17] MEX
2	Scielo	Cohen-Manrique et al. (2020)	Management through IoT	Control of irrigation in crops	Remote crop control system and real-time management of historical data to estimate crop irrigation needs based on atmospheric and soil variables.	Quantitative	Laboratory record	Design of Irrigation Control in ahuyama crops in Sincelejo, Sucre (Colombia) managed through the Internet of Things	[18] COL
3	Ebsco	J. Laverde & C.	Iot	Agriculture	The possibility of applying IoT through sensors to	Quantitative	Laboratory record	Internet of Things applied in Ecuadorian agriculture: A	[19] ECU

N°	BD	Author/s	Dimension 1	Dimension 2	Objective	Methodology Type of study	Instrument, technique or methodology used	Author's contribution	Ref.
		Laverde (2021)			agricultural irrigation systems.			proposal for irrigation systems.	
4	Ebsco	Oliveira De Lima et al. (2020)	Use of IoT sensors in coffee irrigation	Evaluation of water and electricity consumption	Evaluation of the water and electricity consumption of two irrigation systems in a drip system for coffee cultivation (Coffea arabica L.)	Quantitative	Laboratory record	Evaluation of water and electricity consumption using IoT sensors in coffee irrigation.	[20] BRA
5	MDPI	Yascaribay et al. (2022)	Internet of Things in agriculture	Evaluation of the performance of communication systems	Method for evaluating the performance of agricultural IoT communication systems, considering metrics such as packet transmission rate, power consumption, and packet collisions.	Quantitative	Laboratory record	Evaluation of the performance of communication systems used for the Internet of Things in agriculture	[21] ECU
6	Redalyc	Ruiz-Martinez (2019)	Application of IoT through a network of wireless sensors in a coffee crop	Monitoring and control of environmental variables.	Monitor and control multiple environmental variables that the growth and final quality of coffee.	Quantitative	Laboratory record	Application of the Internet of Things through a Network of Wireless Sensors in a Coffee Crop for the Monitoring and Control of its Environmental Variables	[22] COL
7	Redalyc	C. Villarroel; V. Goykovic and P. Collao (2019)	Performance evaluation of a greenhouse through IoT	Atacama Desert.	Improve water efficiency.	Quantitative	Laboratory record	Performance evaluation of a greenhouse located in the Atacama Desert, Chile, through IoT	[23] CHL
8	Google Scholar	Hassoun et al. (2022)	Fourth industrial revolution	Food industry	Emerging Food Trends	Qualitative	Critical review	The fourth industrial revolution in the food industry, part II: Emerging food trends and their connection to Industry 4.0 innovations	[24] BRA
9	Google Scholar	Menendez (2022)	Scientific development	Agriculture 4.0	Overview of the contribution of scientific and technological institutions in the field of agricultural knowledge and development 4.0, in data analysis, sensors and robotics, and IoT.	Qualitative	Revision	Argentine Scientific Development of Agriculture 4.0. State of the art.	[25] ARG
10	Science Direct	To. Sinha, G.Shrivastava and P. Kumar (2019)	User-centric Internet of Things architecture	Smart agriculture	The proposed architectural system will allow farmers to monitor their fields in real time and receive recommendations to produce good quality crops.	Qualitative	Revision	User-centric Internet of Things architecture for smart agriculture	[26] MEX
11	Science Direct	Jha et al. (2019)	Automation in agriculture	Artificial intelligence	Automation practices such as IoT, wireless technology, machine learning , and artificial intelligence.	Qualitative	Revision	A comprehensive review on automation in agriculture using artificial intelligence	[27] MEX
12	Science Direct	Campos et al. (2022)	Smart Decision Framework	Prediction of the incidence of thrips in organic banana crops	Development of a framework to facilitate the prediction of pest occurrence in organic banana crops.	Qualitative	Revision	A smart decision framework for predicting the incidence of thrips in organic banana crops	[28] PER

N°	BD	Author/s	Dimension 1	Dimension 2	Objective	Methodology Type of study	Instrument, technique or methodology used	Author's contribution	Ref.
13	Science Direct	Radoglou-Grammatikis et al. (2020)	UAV Applications	Precision agriculture	Proper implementation and use of Information and Communication Technology (ICT) services, which provide capacity to increase the productivity of agrochemicals, such as pesticides and fertilizers, while minimizing operating costs.	Qualitative	Revision	A collection of UAV applications for precision agriculture	[29] PER
14	Science Direct	H. Ccalli (2022)	Simulation of temperature control and irrigation time	Tulip production using Fuzzy logic	Simulate how it controls temperature and irrigation time to produce tulips in a greenhouse in Ilo, Moquegua, Peru.	Quantitative	Laboratory record	Simulation of temperature control and irrigation time in tulip production using Fuzzy logic	[30] PER

Fig. 2 Percentage (%) of articles published by country.

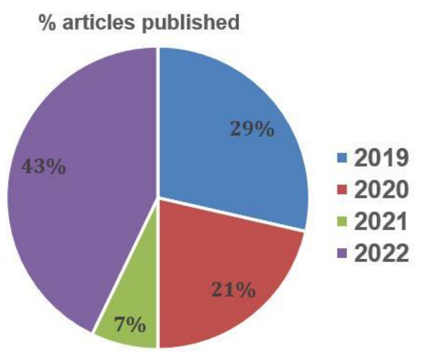

Fig. 3 Percentage (%) of articles published by year

C. Results of individual studies.

Researchers studied the following in times of COVID-19 pandemic:

First, according to the quantitative approach, researchers [17], [18], [19], [22] and [30] contributed to the design of IoT architecture. While [20], [21] and [23] were assessments of data communications on water and energy consumption within agriculture.

- *In Dimension 1*

As stated, [17], [19] and [22] researched IoT architecture through wireless sensors while [18] researched on irrigation control. In the same way [20], [21] and [23] dealt with evaluation of water and electricity consumption, performance of communication systems and performance of a greenhouse.

- *In Dimension 2*

According to [17] and [22] they dealt with monitoring the environmental variables of the crop. [18], [19], [20], [23] and [30] | discussed water management through IoT in agriculture; while [21] studied IoT communications systems considering metrics such as transmission rate, packet collisions and energy consumption.

Secondly, according to the qualitative approach, the researchers [24] and [25] exhaustively reviewed the relevant information according to technology as trends of industrial revolution in food. Consequently [26], [27], [28] and [29] reviewed on machine vision automation architecture and incident predictions for precision agriculture.

- *In Dimension 1*

According to [24] and [25] they dealt with trends and contribution of scientific institutions in the development of the industrial revolution 4.0. [26] and [27] architecture and automation with IoT, [28] Intelligent decision framework for predicting pest occurrence and finally [29] machine vision applications

- *In Dimension 2*

Similarly [24] and [25] studied about food industry within the industrial revolution 4.0. And [26], [27], [28] and [29] precision smart agriculture by intelligence and artificial vision applying ICTs for productivity improvements.

D. Result of the synthesis

First, the studies in the quantitative approach contributed to the design of IoT architecture for water consumption control, determining the detection system through sensors, water flow monitoring devices; network system and transport layer through wireless networks based on database information systems; Applying models of supervision of the necessary water in the fields, guiding the intelligent management of agriculture.

Second, studies in the qualitative approach reviewed information from IoT trends in times of pandemic to make decisions based on predictions of information data.

Finally, the information is based on the fourth industrial revolution 4.0, focused on digital transformation applied to processes to improve efficiency by discovering new business opportunities.

E. Certainty of the evidence

The evaluations of certainty or confidence in the body of evidence for each outcome evaluated are described item C, as a result that guarantees validity and reliability.

IV. Discussion

According to the information analyzed, it can be affirmed that although in the field of IoT applications for agriculture in Latin America during the COVID-19 pandemic extensive research has been generated, there is still a gap in relation to the publications that focus their attention on IoT and wireless sensor network. It is therefore very important that technology researchers design viable solutions to improve agriculture, which in the long term must be viable and sustainable.

However, Table 1 shows a very important database of documentary information that supports the formulation of possible solutions to improve agricultural production. According to the general objective of evaluating IoT application technologies for agriculture in Latin America during the COVID-19 pandemic

The results obtained in quantitative approach are based on experimental applications

[17] , [18], [19] and [22] agree on the research on the implementation of sensor design for automating irrigation in agriculture.

[20], [21] and [23] agree on the performance and performance evaluations of the communication platform, since it is very elementary for a good reading of the information base and control of the automatic system of agricultural production.

The qualitative results show the literature on the advances of industry 4.0 technology reviewing the technological trends [24] and [25] and intelligent architectures of automation by artificial vision [26], [27], [28] and [29].

The limitations in the review process There are articles that cannot be accessed for payment reasons obviously according to scientific research engines. Potential limitations of the study were the lack of laboratory to perform the relevant tests and/or simulations.

The overall result of valuing IoT application technologies for agriculture in Latin America during the COVID-19 pandemic and the most important implications of the results in practice are found in quantitative and theoretical research are in qualitative research showing future trends of digital technologies.

Implications of the results in the review, a great nutritional information is obtained with which, researchers with enough experience in the theory will be able to translate it into practice. In quantitative research, sensors generate the database for real-time decision making to optimize the irrigation process in smart agriculture.

V. Conclusion

The systematic review allows to know the proposed applications of IoT published in Latin America. Being research that used IoT in quantitative and qualitative approach in 57% and 43% respectively.

Evaluating IoT application technologies for agriculture in Latin America during the COVID-19 pandemic was very useful in all aspects and in all practical application. There is a concordance of the evaluation of IoT technologies for agriculture, managing to verify measurements of environmental factors to make decisions in agriculture. This allows future policy definition for the use of technologies in agriculture to obtain quality products at low cost.

All systematic review reports and highlights in the current situation the evaluations, proposals, and applications of IoT. The evidence collected should be available to all researchers internationally without any restrictions as a knowledge base for digital transformation and industry 4.0.

According to the revised information, it is identified that the fundamental purpose of monitoring the growing environment is to maintain the necessary humidity by automatically managing the irrigation system, according to how each type of crop plant requires. Therefore, read the behavior of the database in real time from anywhere in a simple way on a device that is the cell phone. Therefore, future research should use knowledge of IoT and ML that are under development for agriculture overcoming limitations and if possible, make large-scale applications.

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