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Industry 4.0 In The Context Of Agribusiness: A Systematic Literature Review

Oscar Bertoglio[1], Simone Sehnem[2]
[1] *Instituto Federal Do Rio Grande Do Sul – Ifrs, Sertão, Rio Grande Do Sul, Brazil*
[2] *Universidade Do Oeste De Santa Catarina – Unoesc, Chapecó, Santa Catarina, Brazil*

Abstract:
This study presents a systematic literature review that examines how the Brazilian agribusiness is adopting Industry 4.0 technologies. The Scopus and WoS databases were utilized for this purpose. The results demonstrate that these technologies have the potential to enhance efficiency and productivity while also contributing to sustainability and competitiveness within the sector. Nonetheless, challenges exist, such as the lack of internet infrastructure in certain regions, the need for workforce training, legal and cybersecurity issues, resistance from farmers, and the requirement for investments. To overcome these challenges, an integrated effort among the government, academia, and the private sector is imperative. The study outlines an agenda of opportunities to stimulate the adoption of Industry 4.0 in agribusiness, including modernizing and evolving the sector, ensuring food security, monitoring and controlling production, traceability, and improving productive infrastructure. In summary, Industry 4.0 has the potential to make a significant contribution to the development of Brazilian agribusiness, but addressing the aforementioned challenges and promoting widespread awareness of the capabilities and benefits of Industry 4.0 is essential.

Key Word*: Industry; Technologies; Agribusiness; Connectivity; Efficiency*
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I. Introduction

Industry 4.0 and agribusiness are fundamental and interconnected domains in the current context [1], with the potential to enhance efficiency, productivity, and sustainability in agricultural production [2]. The adoption of emerging and innovative technologies such as the Internet of Things (IoT), artificial intelligence, robotics, and data analytics has transformed the agricultural sector, creating new opportunities for sustainable development [3]. It is important to conduct studies that bridge these two constructs due to the potential for integration between Industry 4.0 innovations and the growing demands of agribusiness [4], such as the need for increased resource efficiency and reduced environmental impacts [5] [6]. Research at the intersection of these domains can contribute to the development of innovative solutions for the challenges faced by the agricultural sector.

Existing gaps on this subject include the need to investigate the adoption and implementation of Industry 4.0 technologies in the context of agribusiness in different regions and cultures, as well as the identification of barriers and facilitators for such adoption [7]. Furthermore, there is room to explore the impacts of these technologies on the sustainability and efficiency of agricultural production, as well as the analysis of policies and strategies required to facilitate their implementation.

The social relevance of a study of this nature is attributed to the potential of Industry 4.0 technologies to enhance the quality of life for rural populations and increase agricultural production sustainably, thereby contributing to food security and poverty reduction [3]. The development of a new study on the relationship between Industry 4.0 and agribusiness is justified due to the constant evolution of technologies and changes in the demands of the agricultural sector. This research area is dynamic and requires up-to-date investigations that keep pace with emerging trends and innovations, as well as how they impact agribusiness [5]. Furthermore, understanding the social, economic, and environmental implications of these technologies is crucial for the development of public policies and business strategies that promote the adoption and sustainable diffusion of Industry 4.0 innovations in agribusiness [7]. In summary, the integration between Industry 4.0 and agribusiness is a relevant and ever-evolving research topic. Studies addressing this intersection are essential to address the challenges and opportunities in the agricultural sector while contributing to sustainability and food security. Based on this context, the following research question emerges: how does the Brazilian agribusiness internalize Industry 4.0 technologies? Based on this issue, the research objective is proposed: to analyze how the Brazilian agribusiness internalizes Industry 4.0 technologies.

The proposed study can generate several contributions, namely:

a) Identify specific Industry 4.0 technologies being adopted in Brazilian agribusiness and how they are being applied across different sectors and regions.
b) Evaluate the impact of these technologies on the productivity, efficiency, and sustainability of agricultural production in Brazil, considering economic, social, and environmental aspects.
c) Identify the main challenges and barriers faced by producers and other stakeholders in Brazilian agribusiness when it comes to adopting and implementing these technologies.
d) Analyze public policies and private sector initiatives that have been implemented to encourage and facilitate the adoption of Industry 4.0 technologies in Brazilian agribusiness and identify opportunities for improvement.
a) Propose recommendations and strategies to overcome the identified challenges and barriers and accelerate the internalization of Industry 4.0 technologies in Brazilian agribusiness, contributing to increased competitiveness and sustainability in the sector.

The study is structured into sections. Following this introduction, a section has been developed that focuses on Industry 4.0 and agribusiness. Subsequently, the methodological procedures are presented. Following that, the results, analysis, and discussion are provided. Following these sections, final considerations and references are included.

II. Industry 4.0 and Agribusiness

Industry 4.0 is characterized by the digitization, automation, and integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence, data analytics, robotics, and cyber-physical systems [8]. These technologies have transformed the way companies operate, enhancing efficiency, flexibility, and competitiveness across various sectors [9] [10].

In turn, agribusiness encompasses the entire agricultural production chain, including activities related to the production, processing, distribution, and marketing of agricultural products [11]. The integration of Industry 4.0 concepts and agribusiness can be understood as the application of advanced and innovative technologies in the agricultural sector to enhance efficiency, productivity, and sustainability of production [12].

The integration of these concepts brings several benefits, including the optimization of resource utilization, waste reduction, enhancement of the quality of agricultural products, and improvement in data-driven real-time decision-making [11]. Furthermore, the adoption of Industry 4.0 technologies in agribusiness has the potential to contribute to food security [5] and the reduction of environmental impacts [12].

However, the adoption of Industry 4.0 technologies in agribusiness varies between developed and emerging countries. In developed countries, the implementation of these technologies tends to be more advanced, with greater infrastructure penetration and access to financial and technological resources [13]. Conversely, in emerging countries, the adoption of these technologies may be slower due to challenges such as inadequate infrastructure, limited access to financing, and a lack of technical knowledge [2] [14].

Therefore, the theoretical foundation that integrates the concepts of Industry 4.0 and agribusiness underscores the growing relevance of technologies in the agricultural sector and the potential benefits for efficiency, productivity, and production sustainability. Furthermore, it emphasizes the need to address disparities in the adoption of these technologies between developed and emerging countries to promote inclusive and sustainable development.

Furthermore, the development and dissemination of innovative solutions tailored to local needs and realities can be crucial in promoting the adoption of Industry 4.0 technologies in emerging countries [2]. In this regard, cooperation between governments, the private sector, research institutions, and international organizations can be essential for sharing knowledge, technologies, and resources, as well as promoting the creation of policies and training programs that facilitate the transition to Agriculture 4.0. It also highlights the potential of advanced technologies to transform agricultural production and promote sustainability. By examining diferences in the adoption of these technologies between developed and emerging countries, it is possible to identify opportunities and strategies to foster more inclusive and sustainable development in the global agricultural sector.

III. Methodology

The systematic literature review is a research modality, which follows specific protocols, and seeks to understand the "state of the art" on a theme, through the analysis of a large number of documents [15]. Table 1 presents our study protocol, contemplating the three main stages, planning, execution and documentation.

Table 1 - Recommendation protocol for performing SLR

Protocol of the Systematic Literature Review		
Planning	**Execution**	**Documentation**
a) Justification of the need. b) Font selection c) Search strategy	a) Search sources b) Selection of articles c) Preliminary assessment of articles	a) Structuring - Article - Disclosure

d) Definition of Criteria -Selection -Extraction - Inclusion -Exclusion	d) Exclusion and Inclusion e) Data extraction f) Analysis	- Presentation

Planning:

a) Justification: The choice and delimitation of the topic are driven by the interest in uncovering research gaps that are potential and contribute to understanding the relationship between Industry 4.0 and Agribusiness. We recognize that questions related to Industry 4.0 and Agribusiness play a significant role in the development of economic and social contexts. We have transformed this expectation into central questions that shape the study, and thus defined: "What is the relationship between Industry 4.0 and Agribusiness? What are the main characteristics of the studies already conducted? What is the contribution of Industry 4.0 to the development of Agribusiness?
b) Source Selection: Considering the need to ensure feasibility for the study, we selected two databases, Scopus and Web of Science. These are comprehensive and reliable databases, ensuring the reliability of our searches.
c) Research Strategy: We defined as a constraint and boundary that the publications must be available in the two aforementioned databases, peer-reviewed, and published between the years 2019 and 2022. The search was conducted in December 2022.
d) Search and Selection Criteria: The search was conducted using the terms "industry 4.0" and "agribusiness," following the mentioned strategy. The returned articles were downloaded and archived for subsequent analysis. Next, the articles were compared to exclude duplicates, which was the first exclusion criterion.

Execution: The selection prioritized the set of criteria presented below. All other papers that appeared in the search were excluded and therefore met the exclusion criteria for this research.

a) Source Search: In Scopus: Business, Management and Accounting, articles and reviews, full papers, publications tagged as final, and articles in press. In Web of Science: Business and Management, articles and review articles. The search was conducted in December 2022 and considered publications between 2019 and 2022.
b) Article Selection: Articles that met the established criteria, namely those relating Industry 4.0 to Agribusiness, were selected.
c) Preliminary Evaluation: A first assessment was performed by reading the titles and abstracts. Duplicate articles were identified and excluded, as well as articles that did not align with the research objectives.
d) Exclusion and Inclusion: After the preliminary reading and the exclusion of the first block of articles that were not aligned in the title and abstract, a detailed reading of each remaining article was conducted. Some articles discussed Industry 4.0, others discussed Agribusiness, but did not establish a relationship between the two constructs. Nineteen articles remained, which were analyzed in detail.
e) Data Extraction: For each of the selected and read articles, relevant information for our study was extracted.
f) Analysis: With the extracted information, data coding and analysis were conducted.

Following the protocol described above, we ensured reliability and allowed for the possibility of replicability. Chapter 4, presented next, provides the presentation, analysis, and discussion of the results, covering the third stage of our protocol.

IV. Result

After classifying the articles, applying the inclusion and exclusion criteria as described in the methodology, and extracting and coding the data, we present the main results.

General aspects

We can say that there is no central theme or approach among the analyzed studies. Our readings have shown that publications range from general approaches to the relationship between the two constructs to discussions of specific cases where Industry 4.0 technologies were present. We also observed that studies, when directing their analyses to agribusiness, prioritize the 'upstream production' stage or the 'during production' stages. We did not find studies that address the 'downstream production' stage. Similarly, the studies prioritize general, theoretical analyses with little focus on applied/empirical issues, making it difficult to evaluate the actual results of the application of Industry 4.0 technologies to agribusiness activities. We also noticed that studies with an applied focus address productivity and efficiency gains from a technical perspective without demonstrating/proving economic gains. Therefore, it is not possible to assert that the applied technologies generate real economic gains. Specifically for Brazil, we did not find applied studies, despite all the progress the sector has been experiencing in the relationship between technology and agricultural production.

We observed the participation of a significant number of researchers involved in the studies, over 60. The analyzed studies were published in a dispersed manner across various outlets, with notable mentions including Open Agriculture Magazine (2), Production Planning and Control - Operations Management (3), and Agronomic Science Magazine, Special Agriculture 4.0 (2). We do not have a specific explanation for this dispersion, but we attribute it to the highly interdisciplinary nature of the topic, as well as being an emerging and not yet consolidated area.

Another observed issue is that the analyzed articles are distributed fairly evenly over the years, indicating that there has been no significant increase in publications over the period. There were 4; 5; 6; 4 articles for the years 2019, 2020, 2021, and 2022, respectively. In terms of nationality, Brazil stands out with 7 articles, followed by Indonesia with 4 articles and Greece with 2 articles. The United Kingdom, India, Portugal, Malaysia, Ukraine, and Hungary each have 1 article published during the period. It is worth noting that while Brazil prioritized theoretical/generalist studies, Indonesia presented articles focused on agricultural production.

Theoretical/conceptual aspects

In the analyzed studies, it was not possible to identify foundational theories that underpinned them. The theoretical studies provide discussions from a general and broad perspective, always addressing Industry 4.0 issues in the traditional manner. This may indicate that we have not yet defined the desired direction in the research field, in addition to the highly heterogeneous characteristics of researchers in the area. Although we did not succeed in identifying foundational theories, we could observe a clear alignment when it comes to the concepts, categories, and pillars of Industry 4.0. Only two studies do not clearly present the concept of Industry 4.0 used - Iskandar et al. (2021); Kasimin et al. (2021). All other works base their discussions on the traditional pillars of Industry 4.0. Another aspect to highlight is that a significant portion of the studies that address traditional concepts of Industry 4.0 focus their analyses on the pillar of the Internet of Things - Kassab (2022); Ladasi and Shihab (2019); Queiroz et al. (2020); Sharmin et al. (2021). This observation may anticipate a conclusion of the study, focusing on the practical implementation of Internet of Things technology.

Regarding the categories of industry 4.0, the predominant form is in the digital category, followed by the physical category, and part of the studies address the two categories in an integrated way, as part of the same process.

Regarding the type of connectivity addressed in the studies, there is a prevalence of machine-to-machine connectivity, followed by people-to-machine and then product-to-machine. It seems that in this aspect of connectivity, the studies are still not sufficiently clear, most likely because the majority of them do not address applied/empirical situations. Here lies another important conclusion, that there is a need for more discussions/studies to demonstrate the delineation of each form of connectivity.

Concerning the pillars that characterize Industry 4.0, we found that most of the analyzed articles do not provide explicit indications of which pillars they are addressing. Some address them in an integrated manner, while others focus on the Internet of Things - Kassab (2022); Ladasi and Shihab (2019); Queiroz et al. (2020); Sharmin et al. (2021) - or on digitization - Kurniawan and Alvin (2019). It seems important to expand the studies to make it clear which pillars are most focused on by the agricultural sector.

Regarding the barriers to the adoption of Industry 4.0 technologies mentioned in the studies, five of them point to high costs as the main factor (without distinguishing between implementation costs or operational costs). Three highlight issues related to the lack or limitation of skilled labor, while one work mentions the lack of government incentives. These are relevant aspects that deserve further discussion to better understand this phenomenon.

Methodological aspects

The methodological treatment employed in the studies is an important factor to consider in a systematic review. It demonstrates how events were observed, how data were treated, and how the topic was approached. Among the most important aspects, we consider how data were collected and subsequently treated, as collecting and treating data differently could lead to observations that are not always suitable. We identified that the analyzed articles are relatively heterogeneous in terms of methodology, making it difficult to attribute a standard approach adopted in the studies. Some authors collected their data in the field, while others, such as systematic reviews and bibliometrics, collected their data from article databases. Others developed theoretical discussions, and their sources of data/information were extracted from secondary documents. The analyses, likewise, did not follow a standard method; each author made their own choices.

Regarding the focus of the study, whether theoretical or practical/empirical, it was observed that 63% of the studies had a theoretical focus, including literature reviews, systematic literature reviews, and bibliometrics. The remaining 37% referred to studies with an applied focus, emphasizing case studies or cluster analysis.

Aspects of results and implications

With regard to the results and implications presented by the authors of the studies, we found that many of them are aligned with our research questions, as described in the planning stage of the methodology, namely, to identify whether there is a relationship between Industry 4.0 and agribusiness. Some authors provide elements that establish cause-and-effect relationships, while others justify the difficulties in implementing models that align with and are suitable for Industry 4.0 premises.

Regarding the implications of the results of the studies for theory or practical situations, it was not possible to establish a common thread among them because most of them do not explicitly provide this information.

We found that some technologies are more commonly used in the relationship between Industry 4.0 and agribusiness, with a highlight on the Internet of Things and the use of sensors in production activities. In studies authored by Brazilians, however, due to their more theoretical and generalistic nature, it was not possible to identify their direct application in agribusiness activities. Certainly, there are cases where Industry 4.0 technologies are being applied to Brazilian agribusiness, highlighting the need to study and report on the most commonly used technologies, whether in production or support activities. Examples include robotic milking in the cattle industry, automation in poultry and swine production farms, and water quality measurement sensors in fish production, among other Industry 4.0 technologies applied to agribusiness.

Regarding the impacts of Industry 4.0 technologies applied in the context of agribusiness, in specific activities, the reviewed studies report a cause-and-effect relationship, with technologies producing impacts on productivity and efficiency in agribusiness. However, specific situations demonstrating the implementation and measurement process, as well as the real quantification of gains from these adoptions, were not described.

Concerning efficiency indicators, the discussion always focuses on technical efficiency in a cause-and-effect relationship. There are no reports of improvements in economic efficiency where the marginal gain exceeds the marginal cost as a result of the adoption/implementation of Industry 4.0 technologies. In the examples mentioned earlier, such as robotic milking, automation in poultry and swine production farms, and water quality measurement in fish production, there is knowledge of the need for significant investments in adapting production facilities, but it is not precisely known whether the marginal gains outweigh the marginal costs of adopting these technologies.

Some studies identify costs as the main obstacle to the adoption of Industry 4.0 technologies, in addition to the lack of internet infrastructure and a shortage of qualified labor. As for the effects of Industry 4.0 technologies on agribusiness, the studies only highlight the results, while it would be necessary, for the sake of better understanding, to also examine the implementation and maturation process of these technologies. Long-term studies would be needed, given the time required to implement and monitor the development of these processes.

We would like to highlight one of the studies analyzed, which focused on a research project selection announcement with the theme of Industry 4.0 and agribusiness. The study is Brazilian and concluded that there were not enough resources to meet the demands of that research project selection announcement. This demonstrates that, unlike what happened in the third agricultural industrial revolution, there is no coordinated 4.0 movement among the government, funding agencies, technical assistance agencies, as well as private sector actors. Instead, there is a fragmented movement without catalyzing agents.

Discussion

Our findings suggest that there is a direct cause-and-effect relationship between Industry 4.0 and agribusiness, even though there is no standardized or homogeneous behavior across all sectors or stages of production within the agricultural sector. The reviewed studies demonstrate a conceptual understanding of the characteristics of Industry 4.0. It is an ongoing phenomenon, and as a result, discussions are consistently evolving. Additionally, our findings indicate that there has not yet been alignment among studies around key theories, which could potentially enhance the dissemination of the topic and unify studies around central themes.

The findings demonstrated a prevalence in the use of technologies related to the physical and digital forms, with connectivity occurring through machines and people. As a rule, the analyzed studies address the topic of Industry 4.0 through all its pillars, but they primarily focus their discussions on the Internet of Things (IoT) and digitalization..

Discussions addressing the relationship between these two constructs revolve around the argument that the application of Industry 4.0 technologies leads to increases in productivity and technical efficiency. A study conducted by the Inter-American Development Bank (IDB) concluded that the adoption of these technologies could result in an increase of up to 40% in agricultural productivity, along with reductions in operational costs and improvements in product quality. Thus, this aligns with what we found in the reviewed articles.

A study conducted and published by McKinsey & Company [16] highlights that the application of Industry 4.0 technologies could potentially increase agricultural productivity by up to 70%, while reducing costs by up to 25%. According to the study, the adoption of the Internet of Things (IoT) and sophisticated data analysis would assist farmers in enhancing efficiency by reducing the use of resources such as water and fertilizers. It would also improve precision regarding planting and harvesting timing.

Industry 4.0 can bring several benefits to sustainability in agribusiness, with a focus on reducing the use of agricultural inputs, improving the efficient use of natural resources, and producing healthier and safer food. It is important to emphasize that the application of Industry 4.0 in agribusiness should be guided by a holistic and integrated perspective, as it encompasses biological, social, and environmental aspects [17].

Similarly, a study published by Al-Shahrain et al. [18], which assessed the challenges and opportunities of Industry 4.0 for precision agriculture, concluded that the use of precision technologies would reduce input wastage, increase productivity, and contribute to promoting sustainability in agribusiness. Furthermore, the study conducted by Wenguo et al. [19], evaluating the application of Industry 4.0 technologies in precision irrigation systems, found that data analysis could significantly enhance crop production efficiency while ensuring interoperability and the safety of the technologies employed.

Another study [19] aimed to assess the application of Industry 4.0 technologies in precision agriculture for the cultivation of fruits and vegetables. The authors concluded that these technologies could significantly improve resource efficiency and productivity while reducing negative environmental impacts associated with agricultural production. However, they emphasized the challenge of implementing these technologies and considering the social and psychological impacts of adopting Industry 4.0. Similarly, Zhahg et al. [20], in their systematic review evaluating the use of Industry 4.0 in precision agriculture for cereal cultivation, concluded that it is possible to enhance resource efficiency, increase productivity, and reduce environmental impacts. They highlighted the challenge of overcoming technical and operational deficiencies related to the internet of things and data analysis.

Regarding the challenges reported in the reviewed studies, Souza et al. [21] also identified that the main challenges include the need for increased investments and workforce training to enable agriculture to achieve its goals of increased productivity and efficiency.

Maes [22], in their work "Digital Agriculture in the United States and Europe: A Comparative Study of Approaches and Trends," concluded that, "although there are significant differences in the approaches and trends of digitization in the agricultural sector in the United States and Europe, both regions are investing significantly in the digitization of the agricultural sector. However, tracking strategies and priorities vary among countries and regions, with the United States emphasizing efficiency in agricultural production and Europe giving more importance to sustainability goals."

Regarding the application of Industry 4.0 technologies in Brazilian agriculture, Moreira et al. [23] argue that there is a need for more research in the field of application within the Brazilian context. Oliveira and Oliveira Jr. [24] also highlighted the need for adequate connectivity infrastructure, a qualified workforce, and the creation of a conducive environment for the adoption of innovative technologies. These conclusions align with what we have observed and pointed out in our study.

It is important to note that, due to the complexity of the topic, its emergence, and the rapidly evolving technological changes, we will continue to make discoveries on one hand, but there will always be limitations on the other. We have listed some of the limitations that we consider important and that should be taken into account in discussions. The first limitation relates to the low number of studies published for the analyzed period that met the selection criteria, making it challenging to analyze the impacts of Industry 4.0 technologies on the agribusiness sector. Additionally, the characteristics of the available studies should also be considered. The majority of these studies approach the topic from a general and theoretical perspective, often relying on simulations, with a limited number of practical/applied studies in the agricultural context. Furthermore, not all areas or stages of production are covered by studies, such as downstream processing stages.

An important limitation observed in the analyzed studies was the lack of standardization among them. Because they did not originate from the same theoretical framework, the results do not necessarily allow for an inductive analysis of other situations. Finally, it is possible that the review did not include all relevant sources, such as institutional reports, conference materials, or non-indexed articles that did not pass the selection criteria.

Based on these observations and considerations, along with the awareness that we are dealing with a dynamic phenomenon, we suggest the need for a research agenda that relates Industry 4.0 to agribusiness, especially in the Brazilian context. This can help accelerate the adoption of these technologies, contributing to increased competitiveness and sustainability in the agribusiness sector. We have summarized these propositions in Table 2.

Table 2 – Schedule of opportunities for advancement

Share	**How to do it**	**Strategic Stakeholders**
Typology of technologies	Stratify the typology of industry 4.0 technologies that are used in agribusiness in the scope of agriculture, livestock, innovation ecosystem in agribusiness.	University researchers
Evaluation of the impact of I4.0 technologies on agriculture	Via experimental research	Farmers, researchers and government

Mapping the potential of generating sustainability of I4.0 in agriculture	Via case studies and action research	Researchers Farmers Startups
Mapping of Industry 4.0 application initiatives in agribusiness activities.	Through case studies	Researchers Students
Technical and economic feasibility studies from the implementation of I4.0 technologies	Through Research and Extension projects	Researchers, Students, Farmers.
Evaluate the social impacts on employment (positive and negative) from the adoption of I.4.0 practices in production sectors.	Comparative empirical studies.	Researchers Government
Evaluate the process and maturation time of initiatives to implement I. 4.0 technologies	Institutionalized Research and Extension Projects	Universities, Researchers, Government
Expansion of precision agriculture	Via dissemination of technologies using sensors, drones, GPS and monitoring systems to collect real-time data on soil, climate, crops and animals. This contributes to making decisions about planting, irrigation, fertilization and harvesting.	Federal government Farmers
Dissemination of automation and robotics technologies	Autonomous agricultural machines and robots for planting, pesticide spraying, harvesting and soil analysis. It increases the efficiency of agricultural operations and reduces the need for labor.	Farmers Agricultural enterprises
Spread of IoT	Via sensors and connected devices to remotely monitor and control different aspects of agricultural production such as plant health, soil moisture, temperature and irrigation. Assists in resource management.	Farmers Agricultural enterprises
Professionalization of management through the adoption of big data and data analysis	Use of large volumes of data from different sources to improve decision making and optimize production. Artificial intelligence and machine learning tools employed to perform data analysis and provide valuable insights to farmers.	Farmers Agricultural enterprises
Spread of vertical farming and hydroponics	These technologies make it possible to optimize resources such as water, energy and space, as well as reduce the environmental impact of agricultural production. They are important for urban areas and regions with limited space and natural resources.	Epagri Cooperatives Associations
Traceability and blockchain	They are used to improve traceability and transparency in the agribusiness supply chain, ensuring the quality and safety of food products.	Associations Cooperative Industries

Implications for Strategic Stakeholders

The results and discussions of our study yield theoretical and practical contributions that can be directed towards key stakeholders in the agribusiness sector. In our view, the primary beneficiaries of these findings include researchers in the field, government organizations, funding agencies, financial institutions, various levels of government, as well as producers and any economic agents professionally involved with agribusiness. We outline some ways in which stakeholders can benefit from the findings and discussions:

a) Identification of trends and best production practices - these findings are valuable for both producers and researchers, as well as other private stakeholders, as they can provide guidance for their modes of operation. Similarly, they help identify new opportunities for the implementation of Industry 4.0 technologies, with an understanding of the potential and challenges reported in the literature.
b) For the government, in particular, the findings and discussions regarding possibilities, types of technologies used, and challenges encountered can provide insights for the development of public policies to support the sector. These policies can promote the practice and adoption of Industry 4.0 technologies. More specifically, based on the discussions and reports from the reviewed articles, the government can choose stages that are already more familiar and suitable for adopting these technologies.
c) For private stakeholders in agribusiness, studies of this nature allow them to identify opportunities for investment in innovation and to discover technologies that are already available and have undergone real-world testing. This enables stakeholders to keep their businesses up-to-date and competitive.
d) For students and researchers, the results and discussions have identified knowledge gaps (some of which were mentioned in the agenda of possibilities) that can contribute to future studies, especially empirical research, as this was one of the relevant findings.
e) For municipal or state-level public officials, this study can contribute to reflections on the difficulties faced and reported by those who have implemented Industry 4.0 practices. This can guide actions or resource allocation and help agribusiness stakeholders promote economic and social development. Examples of this could include the implementation of workforce training courses and improvements in internet infrastructure.

V. Conclusions

In conclusion, this systematic review identified a range of emerging trends and technologies related to Industry 4.0 in the context of agribusiness, including the Internet of Things, digitization, artificial intelligence, and automation. The analysis of the results indicated that the implementation of Industry 4.0 technologies can bring several benefits to the agricultural sector, including increased productivity, improved efficiency, and contributions to sustainability. It also has the potential to impact cost reduction and better management of natural resources, and this technological innovation is crucial for addressing the challenges posed by population growth and climate change.

The results of the systematic review also highlighted the importance of public policies and incentives to promote the adoption of Industry 4.0 technologies in the agricultural sector. Furthermore, the findings pointed out the need for adequate training for those working in the agricultural segment, who, in collaboration with universities and the government, can drive innovation and competitiveness in the sector.

Regarding the categories of Industry 4.0, the review found that the prevalent categories are physical and digital, and connectivity is achieved through machines and people. It was also observed that the Internet of Things, along with digitization, were the most frequently mentioned by authors. The results showed that Brazil had the highest number of studies published on the application of Industry 4.0 (within the defined search criteria) in the agricultural sector from 2019 to 2022. This demonstrates that the country has significant potential to lead both the adoption of these technologies, given the importance of Brazilian agribusiness on the world stage, and the development of new research. However, it is important to highlight the challenges to be overcome, especially in terms of infrastructure and implementation costs. It is essential for the public sector and private stakeholders to work together to make this practice successful, contributing to the economic and social development of the country. The fact that the country had the most published works also suggests a growing interest in the use of Industry 4.0 technologies in Brazilian agribusiness.

One limitation identified was the scarcity of applied and empirical studies. Most of the reviewed studies focused on theoretical and technical issues. Furthermore, no studies were found that addressed economic gains. This lack of empirical evidence and economic analysis may limit the decision-making capacity of managers and investors regarding the adoption of Industry 4.0 in agribusiness. Therefore, it is important to encourage more applied and empirical research in this area to provide more robust evidence to guide the successful implementation of these technologies in the agricultural sector.

In summary, the implementation of Industry 4.0 in the agricultural sector has the potential to bring economic, social, and sustainability benefits. However, it requires infrastructure, training, and access to financing to become feasible in the context of agribusiness. In a vast country like Brazil, where asymmetries are evident, these challenges are complex and can lead to social exclusion and territorial impoverishment for less privileged individuals. They contribute to increasing income inequality and wealth generation for enterprises with production potential, technological investment, and technical preparation of employees to handle the technological arsenal of Industry 4.0.

Some opportunities for improvement and expansion of these Industry 4.0 initiatives include:

a) Democratization of access to technologies: Ensure that small and medium-sized farmers also benefit from Industry 4.0 technologies through digital inclusion policies and access to credit and financing.
b) Strengthening cooperation and knowledge exchange: Increase cooperation among research institutions, universities, companies, and farmers to share knowledge and promote the adoption of innovative technologies and practices.
c) Investment in research and development: Increase investment in research and development to create technologies adapted to the specific needs and conditions of Brazilian agribusiness.
d) Development of specific policies and regulations: Create clear and appropriate policies and regulations for the use of emerging technologies, such as drones and biotechnology, ensuring safety and promoting innovation.
e) Increased awareness and outreach: Conduct awareness and outreach campaigns about Industry 4.0 technologies and their benefits in agribusiness, both nationally and regionally, to increase acceptance and adoption of these technologies by farmers.
f) Strengthening governance and coordination: Improve coordination among different government agencies, companies, and civil society organizations involved in promoting and implementing Industry 4.0 technologies in Brazilian agribusiness.
g) Monitoring and impact assessment: Implement monitoring and evaluation systems to measure the impact of public policies and private sector initiatives on the adoption of Industry 4.0 technologies in agribusiness, identifying areas of success and opportunities for improvement.
h) Encouraging the adoption of sustainable practices: Promote the adoption of sustainable practices in the use of Industry 4.0 technologies, such as integrated natural resource management, reduced use of chemical inputs, and mitigation of greenhouse gas emissions.

i) Integration with production chains: Foster the integration of Industry 4.0 technologies with the production chains of Brazilian agribusiness, creating synergies and promoting efficiency throughout the value chain.

By enhancing and expanding these public policies and private sector initiatives, Brazil can maximize the benefits of Industry 4.0 technologies in agribusiness and contribute to the sustainable development of the sector, improving the productivity, efficiency, and competitiveness of rural producers.

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