DIGITAL AGRICULTURE' IMPLICATIONS FOR SMALL FARMERS: EVIDENCE FROM COLOMBIA

A Dissertation

presented to

the Faculty of the Graduate School

at the University of Missouri-Columbia

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

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July 2023

The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

DIGITAL AGRICULTURE' IMPLICATIONS FOR SMALL FARMERS: EVIDENCE FROM COLOMBIA

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a candidate for the degree of doctor of philosophy.

and hereby certify that, in their opinion, it is worthy of acceptance.

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Professor Mary Hendrickson

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Professor Jere Gilles

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Professor Corinne Valdivia

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Professor Damon Hall

I stand

on the sacrifices

of a million women before me

thinking

what can I do

to make this mountain taller

so the women after me

can see farther

- legacy

Rupi Kaur, the sun and her flowers

I dedicate this research to all emerging scholars interested in conducting applied and engaged research, with the aim of contributing to a more inclusive and fair society, particularly for disadvantaged rural communities all over the world.

ACKNOWLEDGMENTS

Dissertations are researched and written alone, but they need a community to grow and eventually be born and see the light. I would like to express my gratitude to Mary Hendrickson, my thesis advisor, for her support, trust, and encouragement throughout this doctoral journey. I am truly thankful for her belief in my abilities and her continuous commitment to my academic growth. I also extend my thanks to Jere Gilles, Corinne Valdivia, Damon Hall and Stephen Jeanetta, the members of the thesis committee, for their insightful questions and valuable feedback. Their contributions have challenged me to delve deeper into my reflections and thoughts. I am grateful for their time and expertise.

I also extend my thanks to Fulbright Colombia and Pasaporte a la Ciencia for providing me with a scholarship to pursue my doctoral studies in Rural Sociology. Their assistance has been crucial in enabling me to further my education and research. Also, I want to express my gratitude to the Division of Applied Social Sciences, Cambio Center and the Center for Regenerative Agriculture for their support at different stages of the doctoral journey.

To my friends, both old and new, I am deeply appreciative of their unending support and companionship. Their presence and understanding have been a source of strength and motivation during challenging times. I am fortunate to have these people by my side, and I am grateful for their friendship. Lastly, I want to convey my deepest appreciation to my family and my partner. Their love, support, and understanding have been my rock throughout this roller-coaster journey. Muchas gracias.

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ABSTRACT

Digital agriculture proposes to revolutionize the processes of production, marketing, and consumption within food systems through the use of tools that collect, store, analyze, and share information digitally. While its proponents emphasize potential benefits, such as improved technical efficiency, resource allocation, and reduced transaction costs, the understanding of the risks and challenges associated with its implementation remains limited.

This qualitative study focuses on exploring the social and ethical implications of digital agriculture technologies and their specific impact on small-scale farmers. Digital agriculture operates at the intersection of technology and food systems, presenting a critical challenge due to the non-neutrality of technology intersecting with an already highly concentrated, centralized, and globalized food system. Understanding how these technologies can effectively serve resource-limited small-scale farmers and prevent further marginalization is urgent.

This study investigates the current state of digital agriculture technologies available in Colombia and analyzes the perspectives of Colombian promoters regarding the promises, dangers, and implications of these technologies. The review of the Colombian case reveals an emerging sector with a variety of digital products and services, driven by a mix of public and private actors, including startups, medium-sized enterprises, and large corporations. The perspectives of Colombian promoters predominantly align with an optimistic narrative, emphasizing the positive outcomes of efficiency and productivity for adopting farmers.

This thesis provides applicable knowledge for academia, practitioners, and the community alike. Its aim is to empower those with less power and agency, especially small-scale farmers, by shedding light on the broader implications of digital agriculture that must be taken into account. This work underscores the importance of addressing access to these technologies and implementing appropriate governance to ensure equitable distribution of benefits within the agricultural sector.

CHAPTER ONE: INTRODUCTION AND OUTLINE

Agricultural digitalization is inevitable; what is unknown is how dynamic and inclusive it will be.

ECLAC, FAO, IICA (2021:89). The Outlook for Agriculture and Rural Development in the Americas: A Perspective on Latin America and the Caribbean 2021-2022.

The newest agricultural revolution is happening today with promises to change organization and relations along each step of the agri-food system and ultimately "transform fundamentally" every part of it (Trendov et al., 2019: 2). The multitude of possibilities for digital agriculture is impressive. It includes farmers receiving specific technical advice on pests through mobile phones. Farmers deciding where and when to use fertilizers after considering data provided by sensors. Farmers assessing damages after natural disasters using imagery captured by drones. Farmers making choices on when to sell and to whom after considering marketplace data. Farmers fulfilling requirements for organic certification while using an app. Buyers verifying through blockchain that small farmers are properly receiving the premium price they pay. Consumers and farmers bargaining directly through marketplaces. Cooperatives using current and historical aggregate data on their members' farm productivity to understand the effectiveness of a specific intervention. While the benefits of this technology are widely recognized and promoted, its significant risks, albeit lesser-known, are also significant and should not be overlooked. This research is about the broader implications of these technologies for small farmers.

The mainstream narrative suggests that access to services provided by digital agriculture will improve efficiency, profitability, and sustainability through a reduction of transaction costs and an increase in allocative and technical efficiency (Schroeder, Lampietti & Elabed, 2021). In this view, data provided by digital agricultural technologies will allow for a better allocation of physical, natural, and human resources while reducing transaction costs for searching, contracting, monitoring, and enforcement. The narrative around digital technologies is optimistic. In high-level documents —published by the World Bank, the U.N. Food and Agriculture Organization (FAO), and the Organization for Economic Cooperation and Development (OECD)— these technologies are portrayed as a solution to tackle the global food shortage (Lajoie-O'Malley et al., 2020). In media coverage and social media, agriculture's digitalization is dominated by positive arguments and emotions (Mohr & Höhler, 2023; Ancín, Pindando & Sánchez, 2022).

Across the world, there is a skyrocketing interest in this sector; global investment went from $16.9 billion in 2018 to $26,1 billion in 2020 to $51.7 billion in 2021 (AgFunder, 2019; 2021; 2022). Nowadays, all kinds of public and private actors are actively promoting and financing the advancement of digital products and services. In developing regions, the increasing interest in these technologies combines efforts by several actors united by the transformative promise of digital agriculture. For example, since 2017, FAO and Telefonica —a multinational telecommunications company with headquarters in Spain— have worked together to leverage Telefonica digital technologies by farmers in Colombia and Honduras (FAO, 2017). In 2020, the Inter-American Institute for Cooperation on Agriculture (IICA) signed an agreement with Precision Agriculture for Development (PAD) —a non-profit organization co-founded by 2019 Nobel Prize for Economics, Michael Kremer— to use their proven model for mobile-phone-based agricultural extension across Latin America. In May 2022, the IICA organized a Digital Agriculture Week with Bayer, Microsoft, and the World Bank as co-sponsors; this was a space "to exchange and promote ideas and thereby accelerate the digital transformation of agriculture in the Americas." (IICA, 2022)

Despite a positive overall outlook on digital agriculture, concerns about these technologies' potential unintended consequences and impacts are arising. Multilateral promoters such as the World Bank Group (2019) have warned that digital technologies' benefits should not be considered a panacea. FAO (Trendov et al., 2019) expressed that to maximize opportunities and minimize risks in the development of digital agriculture, gaps in policymaking and regulation, the economic and gender gap, the skill gap, and the 'digital divide' should be addressed. Multilaterals also are concerned about the concentration of knowledge, power, and revenue in the hands of those who develop and own digital solutions and data and the potential for exacerbating existing inequalities (World Bank Group, 2019; Trendov et al., 2019; ECLAC, FAO, IICA, 2021).

Social movements advocate for a better understanding of the multiple implications of digitalization. For instance, the Nyéléni Forum on Food Sovereignty advocates for transparency in identifying the actors responsible for developing these technologies and their objectives. This initiative seeks to reveal who controls the technologies and, consequently, the right to utilize the generated data. Ultimately, the forum aspires to use this information to shape the governance and regulation of these technologies more effectively (Nyéléni Forum for Food Sovereignty, 2019). The *Campo y Agro* Working Group is asking if large corporations will control the digitalization process or if it will be governed in a more participatory manner (Via Campesina, 2021). They place the public interest and the welfare of the majority as top priorities. ETC Group —a non-profit organization monitoring the impact of emerging technologies and corporate strategies on agriculture— highlights the risks of concentration in this sector and the concern these new technologies could disenfranchise vulnerable people while strengthening people in positions of power (Mooney, 2018; ETC Group, 2022).

Social scientists have pointed out how paths of technologies could reproduce global asymmetries, the imbalances of power related to decisions on data ownership, and the lack of policy interventions on digital technologies implications (Rotz et al., 2019; Rotz et al., 2019a; Bronson & Knezevicj, 2016; Bronson, 2019; Carolan, 2017; Duncan, 2018; Marquis, 2020; Klerkx, Jakku & Labarthe, 2019).

These concerns lie in the problematic intersection between technology and food systems, where digital agriculture takes place. On the one hand, technology is never neutral; there are specific interests and intentions at all stages of the development process, including how it is developed, by whom, who will use it, and how it may be used. Digital technology's means and ends are value-laden (Bronson, 2022). On the other, digital agriculture technologies are being introduced into a food system that is highly concentrated, centralized, and globalized (Hendrickson, Howard & Constance, 2019). At this intersection, the concern is that introducing new technologies into an already unequal food system could further marginalize vulnerable farmers while reinforcing the power of those in privileged positions. Identifying and understanding the social aspects tied to these technologies is the first step to ensure that technologies will successfully serve small and limited-resource farmers.

Paying attention to these technologies' implications is urgent, especially when investments are skyrocketing and narratives surrounding them heavily showcase their positive potential. Even though the scholarship considering the dynamics and impacts of digital agricultural technologies is growing (Rotz et al., 2019; Rotz et al., 2019a; Bronson & Knezevicj, 2016; Bronson, 2018; Carolan, 2017; Duncan, 2018; Marquis, 2020; Eastwood et al.,2019) and advancing in the definition of a research agenda (Klerkx et al., 2019; van der Burg et al., 2019; Ingram et al., 2022; Bellon-Maurel et al., 2022), their empirical work has focused on North America, Europe, Australia and New Zealand, leaving the understanding of developing regions still unexplored. This dissertation responds to this gap and aims to offer a critical empirical view of the digital agriculture situation in Colombia.

This research highlights the importance of localized approaches, recognizes that these technologies do not have the same impact everywhere, and that the implications for different actors and regions vary in their urgency and importance. An understanding of where technologies are situated in, designed in, and how they unfold in specific interactions of power structures, market and institutional arrangements, science and society relationships, and rural development projects can lead to unraveling how and under which circumstances these technologies could fulfill their promise.

Research Aims and Research Questions

Through a qualitative inquiry, in this dissertation, I explore the empirical situation of available digital agricultural technologies in Colombia and what implications it poses to small farmers. This involves the following specific questions:

1. What is the spectrum of socio-ethical implications of digital agricultural technologies, and which are can be relevant for small farmers in the Colombian context? (Chapter two)
2. What is the current state of available digital agricultural technologies in Colombia and what are their potential implications for small farmers? (Chapter three)
3. What are Colombian promotors' views on digital agricultural technologies' promises, perils, and implications for small farmers? (Chapter four)
4. What must be considered in the Colombian context by multiple actors to ensure digital technologies support small farmers? (Chapter four)

Pragmatism and political economy lens

This dissertation is inspired by a commitment to research that advances academic scholarship, offers applicable insights to practitioners and the community, and is useful for those facing less power and agency. I used a pragmatic approach and a political economy lens in this research.

Pragmatism and political economy are significant traditions within the Missouri School of Rural Sociology. In its beginnings, under the intellectual leadership of William D. Heffernan, the Missourian School advanced on three fronts: a) research as a component of political action, b) fact gathering as a starting point for the construction of knowledge and political statements, and c) substantive democracy as the desired outcome of scientific investigation (Bonanno, 2008). In this sense, the Missouri School tradition inspires this work. I aim to support the problem framing on the implications of digital agricultural technologies, offering analysis and empirical evidence that can be used to understand and influence the trajectories of digital agricultural technologies in places such as Colombia.

Pragmatism is a philosophical view developed within American thought. Developed mainly by Holmes, Peirce, James, and Dewey (Snarey & Olson, 2003), it considers that ideas are not absolute truths looking to be discovered. Pragmatism simultaneously rejects positivism and anti-positivism because "to a pragmatist, the mandate of science is not to find truth or reality, the existence of which is perpetually in dispute, but to facilitate human problem-solving" (Powell, 2001, as cited by Pansiri, 2006). In this sense, the assessment of a theory is intrinsically tied to its ability to solve human problems. Prasad (2021) summarizes four principles at this philosophy's core. First is the idea that there are no fixed foundations to build on normative conclusions.

The world is encountered and known through an evolving, dynamic, and changing human experience and cognition. Second, although normative conclusions cannot be achieved, there is a need for provisional forms to solve actual problems that researchers should embrace. Third, these temporary forms should be judged by the specific communities affected by those problems. And four is the relevance of the practical consequences of the theory. For pragmatists, considering the practical implications of a theory is the only way to assess it.

A political economy lens is useful in the context of a pragmatist view. It offers a starting point to analyze social problems, paying attention to the structure and the historical, political and economic forces behind them. If we follow the Heffernan example of fact-gathering and building knowledge that reflects facets of problems shared by a specific community, political economy offers a container to start with. This interpretative lens runs through my research and defines my decisions on qualitative approaches and methods. A political economy approach presupposes that political and economic factors are interwoven; in this view, political institutions, laws, and power relations affect economic decision-making and outcomes, and economic conditions and development shape political structures and behavior. A political economy lens helps to "see technology not as benign or neutral but as a reflection of capitalism and an instrument of power" (Dauvergne, 2020, p7). Through this lens, I pay specific attention to identifying winners and losers —who is most likely to obtain disproportionate benefits and who is not—, and the social costs these technologies could impose on marginalized communities.

Several food and agriculture scholars have used a political economy lens to explore the implications of technological developments in agricultural contexts and called attention to specific aspects (Busch et al., 1991). In their view on precision farming, Wolf and Buttel (1996) pay attention to the structure of investments and the modes of production that benefit from technologies; they point out that these technologies emerged in a context where public sector investments in agricultural research, extension, and information transfers are decreasing worldwide, creating a space where private firms can shape the sector's development and trajectories. They bring to the forefront how precision farming benefits centralized agribusiness and supports a monocultural production practice.

Using the concept of Food Regime —a notion used in political economy explaining how the global food system is shaped by the interactions between various political and economic actors— Prause, Hackfort & Lindgren (2020) evaluate the promises of digitalization in the context of the third regime, a period signed by a more market-oriented system and a promotion of an increased liberalization of trade and investment in agriculture. They conclude that digitalization is happening along the entire agri-food system and is bringing into focus characteristics of a third regime, which allows agri-food companies to use data to increase control over farmers. Using a similar approach and promoting a dialogue between political economy and critical agrarian studies, Hackfort (2021) unpacks five patterns of inequality linked to digital technologies in agriculture, namely, i) control over technology deployment, ii) distribution of benefits, iii) sovereignty over data and hardware, iv) inequalities in knowledge and skills, and v) capacity to define and solve problems.

Using a political economy lens, Rotz et al. (2019) reflect on the digitalization process, and the winners and losers created. They warn that deploying these technologies would reinforce the current political and economic trends characterized by concentration, market integration, and value majorly captured by powerful actors. Their analysis shows data governance and technology production as the main challenges to be addressed. They also suggest that open, cooperative, and appropriate technology are potential pathways to advance fairness in the production of digital data.

Methods

To explore the empirical situation of available digital agricultural technologies in Colombia and their implications for small farmers, I used case study research as a qualitative approach. Case studies offer the possibility to address an event or entity with identifiable boundaries and provide an in-depth understanding of a specific context (Yin, 2009). Two main characteristics make Colombia an interesting setting for this research. First, digital agriculture is a relevant promise within the country, and the ecosystem of actors supporting it is flourishing, but without being the regional leader (Viton et al., 2019). Second, Colombia has a complex socioeconomic dynamic including a post-conflict setting, high inequality rates, and a profound rural-urban divide which offers a rich scenario to see tensions and clashes.

I adopted a broad definition of digital agriculture which encompasses "any form of information and communication technologies (ICTs) used in agriculture, either for automated or non-automated decision-making and practices" (Duncan, Abdulai & Fraser, 2021. p139). This includes a wide range of technologies, from basic mobile apps providing information to advanced systems that use data to control equipment. This definition was chosen because, in countries like Colombia, the promotion of digitalization in agriculture encompasses a broad spectrum of technologies, ranging from simple apps and text messaging systems to cutting-edge innovations like blockchain, virtual reality, robotics, and A.I. systems for soil analysis.

About Colombia

Colombia is home to 48 million people, has 32 departments —the equivalent of states in U.S.—, and in 2021, reported an estimated GDP per capita of 6,100 USD (World

Bank, 2021). It is internationally well-known for being one of the world's most biodiverse countries and the host of 10% of the global biodiversity (Hanson et al., 2009). In addition, Colombia created a Peace Accord that in 2016 ended an armed conflict that lasted 50 years.

Agriculture is vital to Colombia's economy, food security, rural livelihoods, biodiversity, and social and political stability. In 2020, the sector accounted for approximately 6.7% of the country's GDP, generated over $9 billion in revenue through exports, and employed around 16.7% of the labor force (World Bank, 2021b). Colombia's diverse agricultural production, including staple crops and tropical fruits, contributes to food security (FAO, 2021). Approximately 30% of the population resides in rural areas, where small-scale farming is predominant, with around 80% of farms being smaller than 5 hectares (World Bank, 2021a; FAO, 2018). Colombia, as the second most biodiverse country in the world, has committed to preserving its biodiversity through initiatives like the National Biodiversity Strategy and Action Plan (WWF, n.d.; Ministry of Environment and Sustainable Development, 2012). The importance of agriculture in achieving social and political stability is further highlighted by the 2016 peace agreement with FARC, which included provisions for rural development and land reform (Colombian Government & FARC, 2016). Promoting sustainable agricultural practices and supporting small-scale farmers is crucial for Colombia's long-term growth and development.

Small farmers in Colombia play a vital role in the country's economy, contributing significantly to food security and rural employment (FAO, 2019). Despite their importance, small farmers, typically operating on landholdings of less than 5 hectares, often encounter numerous challenges that hinder their productivity and competitiveness. Some of the most pressing barriers include limited access to credit, inadequate infrastructure, insufficient technological resources, and a lack of training and technical assistance. Furthermore, they are frequently subjected to volatile market prices and often have weak bargaining power due to their small-scale production (Roa-Clavijo, 2021).

Colombia is a country with unequal living conditions between its urban and rural populations. Historically, rural poverty has been higher than the urban and national average. In 2010, rural poverty was 50.8%, compared to 29.7% nationally and 22.9% in urban areas (DNP, 2011). The trend remained similar in 2021, with rural poverty at 31.9%, higher than the national average of 27.7% and the urban average of 21% (DNP, 2022). This poverty is reflected in the lack of access to basic needs such as housing, services, and education. According to the 2018 National Population and Housing Census, 14.28% of Colombians lived with unsatisfied basic needs, with the average for rural households being 30.48% compared to 9.53% for urban households (DANE, 2018). The poverty in the country is accompanied by inequality, as measured by the Gini coefficient, which was estimated at 0.523 nationally, 0.510 in urban areas, and 0.455 in rural areas in 2021 (World Bank, 2022). In the same year, 47% of the rural population was considered poor, 45.3% vulnerable, and only 9.0% middle class.

This poverty/inequality is one of the five interlinked challenges that face Colombia's food system, which also includes persisting hunger and malnutrition; expansion of the agricultural frontier as a threat to biodiversity; tensions behind the implementation of the Peace Accord signed in 2016, and its first point addressed in the Comprehensive Rural Reform; and the battle for food provisioning (Roa-Clavijo, 2021).

Currently, digital technologies are considered an enabler of agricultural transformation in the Colombian political arena. In the National Development Plan proposed for 2022-2026 (DNP, 2022a), the Colombian government includes several angles within the pillar of Human Rights to Food for the promotion of digital technologies for the agricultural sector. In this national plan, digital technologies are considered tools for enabling more and best food production; facilitators for the betterment of supply chains, leading to more efficient and secure value chains, benefiting small farmers; and an instrument of logistics and infrastructure improvement to reduce losses of food production. Speaking specifically on the technological extension to small farmers, the Plan makes explicit the expectation of digital technologies as an agent of change,

> "Se debe incentivar el uso intensivo de datos y la adopción de tecnologías digitales para transitar hacia una economía agraria e industrial intensiva en conocimiento, que facilite procesos de reconversión productiva local y de trazabilidad del desempeño de las pequeñas unidades productivas"
>
> [The intensive use of data and the adoption of digital technologies should be encouraged to move towards a knowledge-intensive agrarian and industrial economy, which facilitates processes of local productive reconversion and traceability of the performance of small productive units] (DNP, 2022a p.120)

Data collections and Data analysis procedures

Data collection was conducted in three stages and included several data collection forms between spring 2021 and fall 2022.

In the first stage, I did a literature review to address question one —what is the spectrum of socio-ethical implications of digital agricultural technologies? This review was conducted using a snowball approach. Initially, I reviewed the literature reviews by Klerkx et al., (2019) and van der Burg et al., (2019); these were the most comprehensive reviews available. Klerkx et al., (2019) used a snowball method and searched with the word 'digital agriculture'. van der Burg et al., (2019) searched with the words 'smart', 'digital' or 'precision' and 'farming' (or 'agriculture') in combination with 'ethics'. The snowball was developed with three actions. First, I checked the authors cited in their literature reviews, focusing specifically on those whose research focuses on power, ownership, privacy, and ethics in the digitalization of agricultural production systems and value chains. Second, I used Google Scholar to identify articles citing these reviews. And third, I searched Scopus and Google Scholar using a combination of words such as "digital agriculture" AND "social implications" OR "social impacts" OR "ethical implications" OR "ethical concerns" OR "ethical issues" to find new sources. I analyzed this information using matrices aimed at finding patterns in the implications identified by the different authors. I chose Google Scholar because its reach is wider —including tech reports and grey literature— and allows for easier tracking of the authors who are citing a particular article. This was important as I employed a snowball sampling approach for conducting this search. The scope of Web of Science would be narrow to start this review.

In the second stage, I gathered information related to question two — what is the current state of available digital agricultural technologies in Colombia? I mapped the digital agricultural technologies currently available and the actors offering them. I employed a multi-pronged strategy which consisted of conducting web searches for various resources —including Google News, Crunchbase, and the databases of FAO, CGIAR, and IICA— participating in both in-person and virtual events focused on promoting digital agricultural technologies in Colombia and conducting informal conversations with professionals working in the field. I selected only technologies fulfilling two criteria: i) they offer any technology related to the definition of digital agriculture used (see annex 1), and ii) are available in the Colombian market regardless of their owners' place of origin; technologies that are still in the design stage were excluded. All technologies identified were organized in a matrix containing: name, objective, how it works, population target, name of the seller, type of company, key partners, and website. Using the framework elaborated from the literature review, I analyzed these technologies considering three aspects: types of service, types of data and types of expected outcomes. This source of information was useful to build a broad understanding of what is being offered in the Colombian context.

In the third stage, I conducted semi-structured interviews with entrepreneurs and promoters of digital technologies in Colombia to address questions three and four — what are Colombian promotors' views on digital agricultural technologies? (question 3) and what aspects must be considered to ensure digital technologies support small farmers (question four). Interviews were recorded (see interview protocol in annex 2), transcribed verbatim, and then coded inductively, using subquestions as a guiding framework —perceptions of technology deployment promises, complexities, uncertainties, and unforeseen impacts. With this bottom-up approach, I obtained themes by closely examining the interview transcripts and field notes, rather than relying on predefined theoretical frameworks (Elo & Kyngäs, 2008).

Organization of the dissertation

This work is presented in five parts, including this introduction. Chapter two reviews the literature on socio-ethical implications of digital agricultural technologies. It organizes and synthesizes the main concerns that social science scholars have identified theoretically and empirically. I present those aspects that are relevant in the context of developing countries. Chapter three offers a view of the composition of the products and services of digital agricultural technologies currently available in Colombia. I present a panorama of the type of technologies available in the market, their potential use and benefits for farmers, and the actors behind them. Chapter four explores the perspectives of Colombian promoters and entrepreneurs on the dynamic of digital agricultural technologies, their opportunities, complexities, and unforeseen impacts on small farmers. Drawing on twenty-three semi-structured interviews, I elicited their views on the role technology can play, their perceptions of the complexities and uncertainties of technology deployment, and their understanding of unforeseen impacts that technologies can have on small farmers.

In the last chapter, taking the insights presented in chapters two (literature), three (mapping of the technologies in the market), and four (perceptions of promoters), I revisit the main questions and arguments proposed, reflect on the current trajectories of digitalization in Colombia and outline areas for further research to ensure these innovations support, rather than marginalize, small farmers in Colombia.

Chapter Two: What Do We Know And Need To Know About The Social Implications Of Digital Agricultural Technologies For Small Farmers?

"If we can do something, such as push technological frontiers outward, then should we? And if we want to push those frontiers outward, then what do we gain and give up in doing so?"

James, H. (2018:1).

2.1 Introduction

Advocates and enthusiasts of digital agricultural technologies highlight the myriad benefits that these technologies offer. According to Schroeder, Lampietti, and Elabed (2021), digital agriculture can increase efficiency, profitability, and sustainability by enabling technical and allocative efficiency and lowering transaction costs. The argument is that digital technologies provide data that allows a more efficient allocation of resources, reducing the costs associated with searching, contracting, monitoring, and enforcement, resulting in increased profitability and a more sustainable environment. In this light, digital services offering weather or market information through an app could reduce the time used by farmers to obtain information and make decisions; or a blockchain-based platform could allow traceability across a value chain, facilitating communication, assessment, and contracting. For others, the impacts of these technologies are broader. Rolandi et al., (2021) used a broad spectrum to propose a theoretical grid with four impact domains —economic, environment, governance, and social—, fourteen areas of impact, and sixty-one outcomes of digitalization.

While both approaches indicate that digital technologies' potential outcomes are manifold and contribute to present digitization as an opportunity that willing people can seize, they are a limited lens to see the digitalization process. Both views —one heavily focused on efficiency and another on an extensive range of outcomes— lack consideration of the forces surrounding the implementation of digital technologies and their impact on social relationships across manifold aspects related to farmers' activities. These views seem to align with an apolitical view of technology, resonating with the old Value-Neutrality Thesis, which argues that technology is morally and politically neutral, neither good nor bad (Miller, 2021). This apolitical perspective, criticized by many scholars, fails to acknowledge the intricate network of power dynamics that influence technological benefits' design, utilization, and distribution or to identify the problematic intersection between technology and food systems. As summarized by Bronson (2022:p16) a view that understands technology as apolitical and free of politics and interests, "abstracts these technologies from the social means of their production."

Many voices, including social scholars (e.g van der Burg et al., 2019; Rotz et al., 2019; Hackfort, 2021), social movements (Nyéléni Forum for Food Sovereignty, 2019; Via Campesina, 2021; Mooney, 2018; ETC Group, 2022), and multilateral organizations (World Bank Group, 2019; Trendov et al., 2019; CEPAL, FAO, IICA, 2021) are discussing the potential risks and unexpected social consequences that digital technologies may bring to disadvantaged actors in agriculture and the food sector. They are concerned about how the process unfolds, who is leading it, and how the worst consequence could be a potential exacerbation of existing inequalities for the smallest farmers. However, the list of topics is too general to capture nuances, making it inadequate for informing political debates or guiding the actions of those shaping or contesting the process.

Considering this gap, this review essay aims to offer to applied scholars and practitioners a practical view to understand key questions on digitalization in agriculture and to organize the main socio-ethical implications that might be considered when promoting digital agricultural technologies. This essay presupposes the need to consider how power is expressed along digitalization and the importance of localized approaches;

it recognizes that these technologies do not have the same impact everywhere and that the implications for different actors and regions vary in their urgency and importance. It results from a review of academic and grey literature guided by these subquestions,

i) What is under the Digital Agriculture umbrella?

ii) What are narratives and assumptions on Digital Agriculture?

iii) What are socio-ethical implications of digital agricultural technologies?

iv) How to open possibilities for a different digitalization in agriculture?

v) What do we need to know?

This review essay was conducted using a snowball approach. Initially, I reviewed the literature reviews by Klerkx et al., (2019) and van der Burg et al., (2019); these were the most comprehensive reviews available. Klerkx et al., (2019) used a snowball method and searched with the word ‘digital agriculture’. van der Burg et al., (2019) searched with the words ‘smart’, ‘digital’ or ‘precision’ and ‘farming’ (or ‘agriculture’) in combination with ‘ethics’. The snowball was developed with three actions. First, I checked the authors cited in their literature reviews, focusing specifically on those whose research focuses on power, ownership, privacy, and ethics in the digitalization of agricultural production systems and value chains. Second, I used Google Scholar to identify articles citing these reviews. And third, I searched Scopus and Google Scholar using a combination of words such as “digital agriculture” AND “social implications” OR “social impacts” OR “ethical implications” OR “ethical concerns” OR “ethical issues” — “agricultura digital” AND “implicaciones sociales ” OR “impactos sociales” OR “implicaciones éticas” OR “preocupaciones éticas” OR “ethical issues”— to find new sources. I conducted a search for results in English and Spanish. I analyzed this information using matrices aimed at finding patterns in the implications identified by the different authors. I found in total 52 articles that were relevant to this research. Many of those come from fields as Social Studies of Science, Agriculture Innovation, and Ethics.

This paper is organized into three parts. First, it introduces what is included within the "digital agriculture umbrella", the narrative behind it, and assumptions behind some groups of digital technologies. Second, it organizes the socio-ethical implications in the academic literature in two interlinked groups: aspects preventing access and related to the design of these technologies; and elements related to the governance of these technologies. It closes with a discussion of what is missing and a need to know for advancing in a digitalization aware of its implications and responsible with it.

2.2. What is under the Digital Agriculture umbrella?

Agriculture 4.0, digital agriculture, e-agriculture, smart farming, FoodTech and Agtech are some names scholars and industry people use to talk about digital innovations in agriculture and food production. These names often overlap in their meaning, scope, and innovations included. Despite their differences in naming, in general terms, all these refer to the "digitalization of agriculture," a process under which all sorts of activities conducted to produce, commercialize, and consume food use at some point digital technologies (Klerkx et al., 2019).

Simply put, digital technologies are "tools that collect, store, analyze, and share information digitally, including mobile phones and the Internet" (World Bank Group, 2019). This broad definition of digital technologies allows the inclusion of previous approaches. For example, the information and communication technologies -ICT- included computers, the internet, mobile phones, radio, and television (Flor and Jimenez, 2015) and was formed under the umbrella of e-agriculture or ICT4D, mainly used to transmit information to farmers. Precision Agriculture includes technologies such as drones, autonomous vehicles, GPS guidance, robots, sensors, soil sampling, and automated hardware and software helping to have more control over farming activities. Smart farming steps forward and integrates new technologies such as cloud computing, the Internet of Things (IoT), and Geographic Information Systems (GIS), allowing the collection, integration, and visualization of data (Lytos et al., 2020). These technologies and the development of Big Data techniques and methods open the possibility of capturing massive volumes of data, varied, contextual, and accessed in real-time, and running advanced analytics useful for predictive modeling and decision-making, boosting productivity and efficiency (Wolfert et al., 2017). The complexity and sophistication of these technologies make them potentially "game-changing technologies that can dramatically affect the way food is produced, processed, traded, and consumed" (Klerkx and Rose, 2021). Using a broad definition, all these technologies have a place under the digital agriculture umbrella.

Categorizing the wide range of digital technologies used by farmers can include the degree of technological sophistication involved, their place in the commodity chain, or the specific service it offers to farmers. Using a lens focused on the level of technological complexity, Trendov et al., (2019), in a report by FAO, identified five segments of digital technologies in agriculture: (1) mobile devices and social media, (2) precision agriculture and remote sensing technologies, (3) big data, cloud, analytics and cybersecurity, (4) integration and coordination systems such as blockchain, financing and insurance systems, and (5) intelligent systems such as deep learning, machine learning and artificial intelligence. This approach acknowledges the variety of sophistication within these technologies but does not consider overlapping use when addressing specific digital products and services. Dashboards such as the Digital Agrihub —developed between Wageningen University and Research (WUR), GSMA, Grameen Foundation, and the Netherlands Advisory Board on impact investing— show how digital products simultaneously use several technologies. For example, the Tumaini Mobile

App, developed by the CIAT to identify major banana diseases worldwide, is accessed through a mobile application and uses machine learning, big data, cloud-based services, field sensors, and diagnostics equipment.

Paying attention to the place that specific technologies have along the steps of the food commodity chain, Prause, Hackfort, and Lindgren (2020) identified 280 specific products and services already available on the global market and grouped them into 20 categories. These categories include data-based insurance, precision agriculture equipment, farm robotics, digital marketplaces, and digital commodity chain traceability and transparency tools. This classification shows how technologies can be used across the value chain but does not reflect their dynamic nature.

Focusing on what specific digital technologies offer to farmers, Porciello et al., (2021) discussed nuances of four types of services, namely, advisory, farm tools, financial services, and market linkages. They used this classification in their scoping review to show the interactions between specific types of services and particular outcomes. For example, within digital advisory and extension services, particularly under general agronomy, they found seventeen studies offering positive evidence on changes and income and two showing negative changes. Within digital financial services and insurance, three studies showed positive changes in income and one with nil outcomes. The open dashboard where Digital Agrihub shares innovative digital agricultural solutions uses a similar taxonomy comprising five categories —advisory, market linkage and e-commerce, supply chain management, finance, and ecosystem support. This way of addressing technologies offers a structure to organize specific digital products and services that can combine technologies and deliver particular services to specific actors (e.g farmers, extensionists, consumers). This approach is more nuanced and valuable for conceptual and practical purposes and enables a localized conversation on how these technologies operate, and under which conditions can fulfill their promised benefits, and for whom.

Table 1 includes an overview of the digital products and services under the Digital Agriculture umbrella. The primary sources for this overview are the taxonomy used by Porciello et al. (2021) and the Digital Agri Hub (2022), and the digital products and services technologies portrayed in reports published by international organization

Table 1. Service types for Digital Agriculture

Service types	Service definition	Examples of digital products and services

Digital Advisory & Extension	Information delivered digitally to farmers on different topics looking to improve decision-making and increase in productivity and quality.
	Information includes:
	● General advisory information on agronomic best practices, Advisory on pest and disease management,
	● Recommendation tailored to agroclimatic conditions
	● Market prices
		● Mobile-based information services
		  ● specifically designed,
		  ● generic apps —e.g Whatsapp Groups
		  ● regular mobile features —e.g SMS
		● Web-based information service

Digitized Farm Tools	Products and services that facilitate the collection, synthesis, and interpretation of farm data, aiming to optimize farming practices and production.
	Farm data includes:
	● Crop extension, Crop health (e.g nitrogen prescriptions), Density of vegetation
	● Soil analysis, Farm' environmental parameters
	● Livestock health
		● Precision agriculture equipment (e.g sensors, drons, satellite images)
		● Farm management platforms doing data analytics
		  ● Mobile-based
		  ● Web-based
		● Farm robotics
		● Automated warehouses

Digital Financial Services	Digital products and services offering access to different financial services intending to improve farmers' yields and income. It can include: ● Digital payments, Digital transactions ● Credit, Credit scoring ● Insurance, Savings, Subsidies and Policy incentives	● Fintech for credit evaluation and payment services ● Data-based insurances
Digital Market Linkages	Digital services that facilitate farmers' access to transactional interactions along the food chain. It can include: ● Suppliers of agricultural inputs, Buyers in different markets, Service Providers	● E-commerce platforms ● Marketplaces
Supply chain management	Solutions along the food system helping different actors to facilitate flows of information. Information can include: ● Prices along a transaction ● Engagement of People, Organizations, Places or Things in an exchange	● Digital tools for traceability and Transparency (e.g Blockchain, QR code) ● Software for supply chain operations

Source: Author based on Porciello et al., (2021), Digital Agri Hub (2021), and products and services portrayed in Prause, Hackfort & Lindgren (2020), in reports published by international organizations such as InterAmerican Development Bank (Viton et al., 2019), GSMA (Phatty-Jobe, et al., 2020), FAO (Trendov et al., 2019), World Bank (Schroeder et al., 2021) and the open dashboard published by Digital Agri Hub (2022).

2.3 What are narratives on Digital Agriculture?

The narrative discussed by multilateral organizations and in news articles around digital technologies is mainly optimistic, technical, and holding the "feed the world" imperative. In general, the rationale is that digitalization is going to support efficiency, productivity and sustainability, three aspects required in a world expecting food demand to increase by 2050 linked to a new expected two billion more people in the world's population —up from 7.7 billion in 2019 (UN, 2019)— and currently suffering from food waste, production constraints due to climate change. Carolan (2017), in their interviews with farmers and regional food system entrepreneurs, learned that at the heart of their reasoning to promote digital technologies is the "feed the world" narrative, expressed in the concern to feed 9 billion people in the near future. In a similar vein, in a review of high-level documents published by the World Bank, the U.N. Food and Agriculture Organization (FAO), and the Organization for Economic Cooperation and Development (OECD), Lajoie-O'Malley et al., (2020) identified that in these documents these technologies are portrayed as a solution to tackle the global food shortage, accompanied by a possibility if increasing yields, incomes, and a reduction of harmful inputs.

In social media and materials published by international development organizations, these emerging technologies are presented as a means to achieve technical and practical outcomes. Analyzing how digitalization in agriculture is portrayed in German media, Mohr & Höhler (2023) evidenced that 59% of the arguments in their sample were pro-digitalization, 23% were contra, and 17% were neutral; the most frequent pro arguments are work facilitation, reduced fertilizer and/or pesticide use, environmental protection and sustainability, higher yields, and opportunities and possibilities. In a similar analysis covering tweets in English on the digital transformation of the agri-food sector, Ancín, Pindado, and Sanchez (2022) found that 80% of the sample showed a connection to positive emotions and a link with topics related to sustainability and climate change. In a critical discourse analysis on how precision agriculture and smart farming were portrayed on English spoken news and Twitter, Duncan et al., (2021:1190) concluded that "the PA [precision agriculture] discourse tends to not to be explicit about managing political changes or ensuring just food distribution, nor is it concerned with the types of foods that needed to be produced to ensure sustainable and nutritious diets". In a document analysis of materials published by international development organizations on digital agriculture for the African case, Abdulai (2022) observed that narratives were positive and focused on seven expected outcomes —bridging agricultural information and knowledge gaps, productivity gains and on-farm efficiency, food security, climate change resilience, employment opportunities, gender empowerment, and livelihoods improvements. His work highlights how the rhetoric of digitalization in this region continues on the path of the Green Revolution and that "the potential effects of digitalization, as presented in the narratives, extends, and entrench the pro-poor Green Revolution rhetoric of 'technology saviourism' in Sub-Sahara" (p.9).

This portrayal focused on the technology's technical aspects and promoting "feed the world" narratives rather than examining its political or social implications is not new. Similar positive claims were made about the Green Revolution (GR) and genetically modified (GM) crops (Brooks, 2005). As it is well-known, the GR technologies were presented as a strategy to improve food crop productivity growth through new pest-resistant seed varieties (Kilby, 2019; Pingali, 2012). Regarding GM, the proposition was that utilizing genetically modified crops resistant to pests would result in decreased input usage, heightened yields, and the establishment of more sustainable farming practices that necessitate less off-farm work (Dguidegue, 2019). Amidst the mainly positive narratives, several negative impacts were pointed out (Klepek, 2012; Shiva, 2016).

Paying attention to the narrative surrounding digital agriculture is crucial. Narratives matter: narratives and discourses construct aspects of the world and reflect values and worldviews (Fairclough, 2017). Far from being neutral, techno-optimism reflects specific values and imaginaries, is useful for specific outcomes, and is instrumental in constructing visions of futures, influencing regulations, modes of governance, and ways of public engagement (Bain, Lindberg & Selfa, 2020). As IPES-Food (2016) stated, the "feed the world" narrative is one of the factors serving the reproduction of industrial agriculture, characterized by industrial-scale feedlots supplied by crop monocultures and chemical fertilizers to produce an abundance of relatively cheap highly-processed foods; in a context of a concentrated food system, dominant actors in the current food system structure —big firms, large-scale retailers, and international organizations— exert discursive power while shaping knowledge, framing narratives, and influencing policy to adopt approaches favorably with their problem-framing.

Scrutinizing narratives around digitalization is pivotal to comprehending the potential implications of these technologies on small farmers. Adopting an excessively optimistic, uncritical, and apolitical stance toward digitalization can undermine our ability to hold businesses and institutions accountable.

2.3.1 What are assumptions on digital agricultural technologies by types of service?

A palpable linear optimism holds several assumptions in the description of how specific digital technologies can serve farmers. Three examples offer illustrations. Providers offering digital advisory usually indicate that smallholder farmers can use mobile devices to access several pieces of information —e.g weather forecasts, market research, and planting techniques— to make better decisions to improve productivity (see, for example, Development Gateway, 2021). This narrative assumes a direct relationship between reduced transaction costs and the possibility of making decisions based on information. It is vital to consider that not all farmers can make better decisions based on better information, as making different decisions requires mobilizing resources that may not be available or that require household or community agreements regarding labor and access (Yager et al., 2019).

Sellers of Internet of Things (IoT) devices, such as sensors placed on livestock to monitor their health, location, and behavior, indicate multiple benefits, including detection of illness, improved breeding, enhanced animal welfare and reduced labor costs. These promised benefits are not for every farmer, only farmers who manage large-scale livestock operations and have the capital to invest in the necessary infrastructure to support IoT technology, can use this technology and obtain benefits —e.g Vence (2023) is a virtual fencing, livestock management system for cattle designed operating only operations with over 500+ cattle. Marketplace promoters claim their platforms can connect farmers to multiple new buyers, offering better prices and flexibility while cutting out intermediaries. For example, Agri Marketplace, founded in Europe, connects farmers to industrial buyers across the globe, while Frubana is a Latin American company that promises to connect fruit and vegetable farmers with restaurants. However, not all farmers may have access to these connections. Farmers with market options located near roads and other infrastructure are more likely to participate in digital marketplaces and benefit from them.

In sum, despite the assumption of general benefits, not all farmers can use all digital products and services, or reap their potential benefits even with access. A small-scale producer with limited land may not see a significant improvement in access to better market pricing or weather information. This improved access may not translate into improved benefits, as their productivity challenges may stem not from inefficiencies, but rather from land size or market distance. As noted by Lioutas "digitalization of agriculture is also a function of farm size" (2021:2).

2.4 What are Socio-ethical implications of Digital Agricultural Technologies?

In the context of a bright narrative about digital agriculture coming from all corners, scholars are growing emergent literature analyzing these technologies' implications and unintended consequences (e.g., Rotz et al., 2019, 2019a; Bronson, 2022; Jakku et al., 2019; Hackfort, 2021; Fielke, Taylor & Jakku, 2020; Ayris & Rose, 2023).

Themes and categories often overlap and range across diverse scales of analysis. For instance, Hackfort (2021) unpacks five patterns of inequality linked to digital technologies in agriculture, namely, i) control over technology deployment, ii) distribution of benefits, iii) sovereignty over data and hardware, iv) inequalities in knowledge and skills, and v) capacity to define and solve problems. Ayris & Rose (2023) identified ten ethical concerns for agricultural robotics, including trust and data, health and safety, cybersecurity, employment, energy use, economics and performance, loss of farmer control, animal welfare, and connectivity. Ingram et al., (2022) conducted a prioritization exercise to identify priority research questions concerning digital agriculture in the UK; their results cover data governance, data management, enabling use of data and technologies, understanding benefits and uptake of data and technologies, optimizing data and technologies for performance, impacts of digital agriculture, and new collaborative arrangements. Ingram and Maye (2020) asked about the implications of digitalization for agricultural knowledge processes, farmers' knowledge and decision-making, and farmers' knowledge networks. Lioutas et al., (2019) identify key questions about using big data in farming, including data ownership and privacy. van der Burg et al., (2019) identify three themes in the current ethical discussion about smart farming: data ownership and access, distribution of power and impacts on human life and society. In a scoping study, McGrath et al., (2023) identify trends in the literature, including work-life balance on the farm, changes in skills, roles, and identities, and data ownership, power, and security.

A practical way to see this large spectrum of topics is by considering the intersection between salient factors related to who has access to these technologies; and factors associated with how these technologies are governed. The dynamics and possibilities happening in this intersection lead to different outcomes; changing how digital products and services are designed and governed can lead to different outcomes. Of course, these two, interactions and outcomes, do not occur in a vacuum but in a broader context, where the many facets of power have an influence. Considering how different facets of power influence digitalization is also a key component in influencing the trajectories of digitalization.

Roscigno (2011:353) explain power in terms of social relationships; in this view, power can be seen as "an unequal relation, or inequality, based on personal attributes, institutional positioning, and statuses that are defined, codified and acted upon within historical and cultural contexts." In his summary, power has a reciprocal and asymmetrical character, and the relative power of an actor is expressed in relation to and in interaction with. This unequal relation can be seen at different levels. Shackleton et al., (2022) summarize four theoretical approaches and illuminate how power can be seen. The actor-centered approach (e.g, Weber's tradition) conceptualizes power as a resource or capacity that actors (i.e., individuals, groups, or organizations) wield to impose their will on others, often resulting in zero-sum conflict and alliances; conflicts and alliances are essential channels of expression, research, and analysis for actor-centered power. In contrast, the institutional approach (e.g Ostrom's tradition) centers power on formal and informal rules, norms, and organizations and its possibility to shape patterns of social behavior and resource access. The structural approach (e.g Marxist tradition) takes a critical view of power by situating it within the broader political, cultural, and economic structures that constrain actor agency and reinforce social inequalities and injustices. Finally, the discursive approach draws on Michel Foucault's influential work to understand power as a productive force that shapes social norms and individual subjectivities through knowledge, truth claims, and narratives, with individuals and institutions acting as instruments of power. These four approaches are not mutually exclusive and can be used to provide a more comprehensive understanding of power facets.

The graphic 1 present the broader context, shaped by power facets, and the interactions between factors related to who has access to these technologies and factors associated with how these technologies are governed. Social outcomes from technologies can be identified at the intersection of these two factors and in dialogue with power facets.

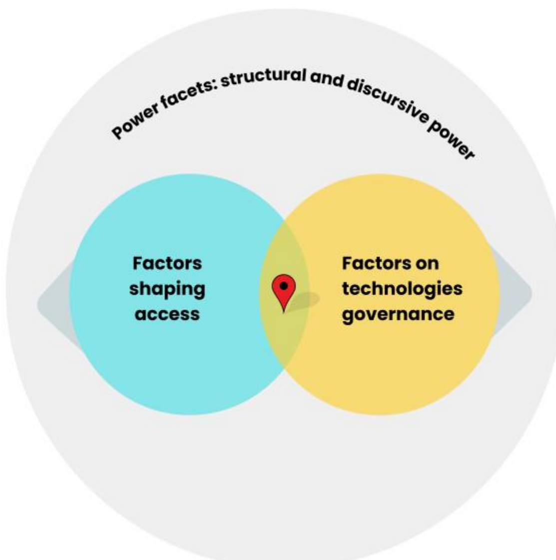

Figure 1. Dimensions shaping the digital technologies outcomes

2.4.1 Factors shaping access: Who is included and who is not?

The digital divide —generally understood as the unequal access populations worldwide have to the Internet and digital technologies— is one of the main concerns when discussing digital technologies' development. Reports published by multilateral organizations, including the World Bank Group (2019), Trendov et al. (2019), and CEPAL, FAO, IICA (2021), consistently highlight that a lack of infrastructure and related capabilities are one of the main reasons why farmers are not able to fully benefit from digital technologies. However, the question of who is included and who is not covers a complex and pluralistic range of aspects and requires a multilayered and intersectional perspective.

The gap in access

The first layer of the digital divide—lack of infrastructure to support digital technology access— is widely known and worrisome. For example, estimations regarding access to 5G cellular networks —the latest generation of mobile broadband allowing the fastest speed for data transfer— show that in 2025 access in the United States will be 55%, but for Low and Middle-Income Countries, it will only be 7%. The 2025 estimate for 4G is better at 52% for these countries (GSMA, 2020; 2020a). Data from the 2021 agricultural digitalization index (Schroeder et al., 2021) show this gap more dramatically. In the availability subindex, measuring the share of farmland in a country with mobile coverage, Israel scored 95.9, Australia 84.6, New Zealand 90.3, the United States 87.6, Honduras 42.9, Uganda 33,7, Mexico 33.6, Brazil 30.0, Argentina 26.3, Nigeria 22.3 and Bolivia 18.1. This well-known gap between North and South countries helps to say something that is not surprising; some countries are better positioned to unfold digital technologies and pursue their benefits; this unequal scenario results from historical processes and the history of the development project (McMichael and Webert, 2020).

Evidently, these gaps between regions are not limited to just the North and South, and differences in infrastructure availability do not solely cause them. Two examples illustrate the prevalence of multiple urban-rural gaps within developed and developing countries. In the United States, the percentage of rural Americans having access to or owning home broadband, or a smartphone, tablet, or desktop is consistently lower than suburban and urban Americans; only 72% of rural Americans have access to a laptop, while 80% of urban Americans own one. There are also differences among racial and ethnic groups. In the United States, black and hispanic adults are less likely than white adults to have a traditional computer or home broadband (Vogels, 2021; Atske and Perrin, 2021). In more dramatic contrast, in Colombia, the percentage of rural households owning a desktop computer is 5,9%, and a tablet is 1,6%, while it is 32,3% and 9,3%, respectively, in urban households. The reasons for not having these devices include high prices, 47% rural and 51% urban; lack of interest,32,5% rural and 33.8% urban; and lack of knowledge about its use, 18,7% rural and 12,3% urban (DANE, 2019).

While the lack of access is crucial, it is not the only gap worthy of attention when addressing digital technologies. The digital divide is a multifaceted phenomenon with three layers. First, differences in access and availability of information and communications technologies; second, sociodemographic factors influencing people's decision to use or not use available technologies; and third, an uneven capacity to benefit from the access and use of technologies (Ragnedda and Gladkova, 2020). A comprehensive view of the digital divide must consider inequalities in access, competencies, and capacities to obtain benefits.

The gender gap and data gap

Rijswijk (2022) note that in addition to this well-known gap in access, another two gaps are crucial when discussing digital technologies in agriculture, the gender digital divide and the data divide. The gender digital divide refers to the gender differences in access to these technologies; these differences reflect the many limitations women face in the offline world, including limited access to education, traditional gender roles, unequal distribution of resources —e.g land, credit—, limited access to infrastructure and laws limiting women's rights and opportunities. In this sense, the gender digital divide reflects an extensive social, political, and cultural process where women have unequal access to resources and opportunities.

The gender gap in mobile ownership and usage varies across regions. For instance, according to the Mobile Gender Gap Report 2022 (Shanahan, 2022), in Nigeria, as of 2021, the gender gap for mobile ownership[1] was 5%, with 92% of men and 88% of women owning a mobile phone. The situation was milder in Mexico, with a 2% gap, and chronic in Pakistan, with a 33% gender gap for mobile ownership. Similarly, the gender gap for mobile internet use was 35% in Nigeria, with 54% of men and 34% of women owning a mobile phone, 38% in Pakistan and 3% in Mexico. The ownership of different types of phones also varies by gender and has its implications since individuals who possess a smartphone are considerably more inclined to be knowledgeable about mobile internet and utilize it than those who possess a basic or feature phone. As reported in the same study, by 2021, 34% of women and 22% of men in Nigeria owned a basic phone, while 18% of women and 17% of men owned a feature phone; furthermore, 32% of women and 51% of men in Nigeria owned smartphones.

Cinnamon (2019) offers a nuanced view of this divide and argues that the data divide can be seen within three data divides, i) data access, ii) data representation inequalities, and iii) control over data flows. Data access refers to the extent data exist, is available, and is reliable. Data representation implies that when data is produced, choices are made involving specific worldviews. Finally, data control inequalities refer to those asymmetric relationships between those having data —collecting, storing, and mining— and those whose data is collected (Andrejevic, 2014).

The gaps in capabilities, motivations and opportunities

Paying attention to the level of single digital technology, McCampbell et al., (2022) developed and tested an approach to grasp individual factors for the specific case of phone-

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[1] In the Mobile Gender Gap Report, mobile ownership is defined as follows: “a person who has sole o main use of a SIM card (or a mobile phone that does not require a SIM) and uses it at least once a month” (2022, p17).

based digital tools for agronomic advice. This user readiness framework is built on behavioral sciences and considers three elements to define an individual's capacity to use a particular digital technology —capabilities, motivations, and opportunities. Capabilities are related to the individual's psychological and physical capacity to use digital technology; physical skills include, for example, the capacity to use a smartphone; psychological capabilities include e-literacy and the capability to understand interrelations between different phone functions. Opportunities refer to external factors —social and physical— making it possible to use digital technologies; social opportunities include farmer's mindset, social cues, cultural norms, and values; examples of operational categories are cultural norms on how men and women access technologies. Physical opportunities refer to having time, resources, or access to a location affording access; examples include time and financial resources to own and use a digital device and network availability. Finally, motivation is linked to 'all those brain processes that energize and direct the use of a digital technology'. These processes can be self-conscious and include the intention of using digital tools or beliefs about barriers or pressures. They can also be automatic, including impulses and reactions, such as the desire to become digitally connected. This approach offers an applied lens to consider the several interlinked social and individual factors preventing or promoting the use of a specific technology; it also helps to situate the role that infrastructure can play.

A multiscale approach to gaps

These gaps are not binary and interact among them at different scales. Rijswijk (2022) uses the conceptualization of Amartya Sen (2000) on social exclusion to offer a perspective beyond a dichotomic notion of inclusion/exclusion. According to this framework, there are unfavorable forms of inclusion, for example, when inclusion benefits are not evenly distributed because of deeply unequal terms of participation or when "the outcome of being included is then the same as being excluded". Along the same line, exclusion is not monolithic and can be constitutive, instrumental, active, and passive; Constitutive exclusion results from societal structures and norms that disadvantage certain groups, while instrumental exclusion is intentional exclusion used to achieve a specific goal. Active exclusion involves deliberate actions that exclude certain groups, while passive exclusion arises from inaction or neglect.

Rijswijk (2022) employs these various ways of inclusion/exclusion, three gaps —digital, gender, data—and three scales —single digital technology, a digital innovation package, and a digital agricultural system— to show how analysis varies across scales. For example, when analyzing a single digital technology, the most critical divide is access to data; there are possibilities for subordinated inclusion or constitutive exclusion. On the other hand, when referring to a digital innovation package, the most likely divide is data representation, while inclusion can be illusive, and exclusion could be constitutive and instrumental.

In sum, the question of who is included and who is not is far from being black and white; it is not a matter of choosing specific individuals or groups to "include" in a digitalization process. A key thing to remember is that many factors reinforce inequalities regarding digital technologies —access to infrastructure, gendered access, and access to have a voice on how technologies— and inclusion efforts can be empty or misleading to a false sense of participation.

2.4.2 Factors on technologies governance: Who governs technologies and how?

Broadly understood, governance in digital technologies revolves around how relationships and interactions are organized, structured, and regulated (Gorwa, 2019). Governance of digital technologies can include aspects such as data privacy, cybersecurity, intellectual property rights, accessibility, and regulatory compliance. It also involves addressing the technology's social, economic, and ethical implications and how it can impact different stakeholders.

When paying attention to the governance of single digital technologies, a large set of practical questions can be placed: who can make choices and how these decisions are made; who designs and who is consulted; who are users defined and approached; what is the rationale for making money; how farmers development is envisioned; what are the decisions on price; how future scenarios and potential economic, social and environmental implications are addressed; what are the definitions on data ownership and privacy and how are enforced, among many others. Answers to each of these questions reflect specific values and interests, and according to how these aspects of governance are defined, it empowers certain actors or disempowers others.

Below I summarize aspects of governance that present a practical opportunity for those who develop technologies to reflect on how their approaches are situated; and for users to hold those developers accountable.

Data and its challenges on ownership, access and privacy

Data is the blood of the digital economy. Data is used and generated on-farm and off-farm. According to Maru et al., (2018), in a report published by GFAR, GODAN, and CTA, there are four data streams for farming. Data created and compiled on the farm to be used solely on the farm makes up the first stream. It is denominated "localized data" and includes information on soil, seed, fertilizer use, sowing date, production practices, and water use. Data generated and acquired off the farm for use at the farm forms the second stream. This "imported data" includes market prices and climatic information analyzed and tailored for use on-farm by a third entity that owns, manages, and controls this data. Data generated and compiled on the farm for off-farm use comprises the third stream; it is called "exported data" and can be gathered by farmers or by using advanced tools. This on-farm data is typically processed, clustered, or merged with other information generated elsewhere, and various actors use it to make decisions. Governments can target services and subsidies; banks and insurance companies can offer targeted services and products; researchers can design and conduct specific projects. Finally, on-farm and off-farm data for use off-farm make up the fourth stream. It is called “ancillary data” and includes, for example, government statistical and research data on agriculture.

Each kind of data brings challenges and nuances. In the imported data, there are concerns about availability, accessibility, and usability. On the exported data —localized data shared with others—, privacy, ownership, and monetization are the pressing topics (Maru et al., 2018). This is an ongoing conversation in the political arena, and there are no final solutions yet. It is a topic worthy of consideration because, as stated by Schroeder et al., (2021:5) in a report published by the World Bank on the digital transformation of the agri-food system, “laws addressing the ownership of data from digital agriculture are frequently either missing or inadequate.”

Those with access to and ownership of data are in a different position to make choices and profit from this economy. Many critical scholars (van der Burg, Boggardt and Wolfert, 2019; Bronson, 2018; 2022) have raised questions about data ownership, access, and privacy.

van der Burg, Boggardt, and Wolfert (2019) show how data privacy, ownership and control are interlinked topics whose interaction exhibits risks and uncertainties. They reflect how farm data — localized data by Maru et al. (2018)— is commonly viewed as trade data rather than personal data; and how it is being produced and used in a context lacking of clear regulations and in an environment marked by unequal relationships. The authors illustrated these risks with two examples. Firstly, input suppliers such as seed providers may use data analyses to offer farmers different prices or terms based on their predicted yield or other data points, which could lead to potential price discrimination. Secondly, the presence of large companies such as Monsanto, which provides simultaneously smart farming technologies, data analysis algorithms, and recommendations to farmers while also selling inputs such as seeds, creates a situation where the company has privileged access to farmers' data, which can be exploited to gain an unfair competitive advantage.

Bronson (2018) offers more illustrations putting the lens on big data. This big data refers to large and voluminous amounts of data gathered from digital communication devices, organizing it into computer-stored datasets, which can be analyzed through computer algorithms. This data is not only localized data, but it covers all four steams of farming data and can include climate and weather data; soil data, including pH, nutrient content, and moisture levels; crop data, including yield, growth patterns, and pest infestation; livestock data, including growth rates, feed intake, and health information; machinery and equipment data, including usage patterns and maintenance history; market data, including pricing and demand trends; financial data, including input costs, labor costs, and profitability; satellite imagery and aerial drone data; social media and consumer data, including food preferences and purchasing behavior; and sensor data from IoT devices, such as moisture sensors or temperature sensors in greenhouses. Bronson (2018) stresses that big data can be sold to third parties to be mined with unknown goals, which can be more corporate and less societal. She is also concerned with large corporations accessing, owning and profiting from data that farmers help generate; she argues that this concentration can lead to a digital lock-in, benefiting larger corporations more and smaller producers less.

2.4.3 How to open possibilities for a different digitalization in agriculture?

Rose and Chilvers (2018), Eastwood et al., (2019), and Bronson (2019) have suggested that Responsible Innovation offers a way to foresee potential impacts and shape the trajectories of digital agricultural technologies. This approach —with roots in different research traditions, including innovation studies, science, technology and society studies, ethics and governance and regulation studies (Koops, 2015)— can be defined as 'a new approach towards innovation, in which social and ethical aspects are explicitly taken into account and economic, socio-cultural and environmental aspects are balanced' (Blok & Lemmens, 2015: 20).

According to the framework developed by Stilgoe et al., (2013), responsible innovation includes four dimensions, anticipation, reflexivity, inclusion, and responsiveness. Within this view, anticipation focuses on complexities and uncertainties, identifying possible future scenarios and potential economic, social, and environmental implications associated with digital agricultural technologies. Reflexivity refers to "holding a mirror up to one's own activities, commitments and assumptions, being aware of the limits of knowledge and being mindful that a particular framing of an issue may not be universally held." (Stilgoe et al., 2013: 1571). In this light, this includes an assessment of developers' motivations and assumptions; in practice, it might imply the creation and engagement of codes of conduct. Inclusion involves engaging a diverse range of stakeholders and incorporating their perspectives and concerns into the innovation process; it opens the participation to public and stakeholder voices on innovation' ends and means. Finally, responsiveness involves adapting the innovation process based on feedback and insights from stakeholders and the wider community and considers the capacity to change direction, react, and answer to societal needs.

Some scholars are using this framework to analyze specific cases. For example, Eastwood et al ., (2017) used it to assess a smart dairying project in New Zealand and to draw lessons that can be applied to smart farming more generally. Ayris & Rose, (2023) used it to frame the socio-ethical implications described in the literature on autonomous robots in agriculture. Legun and Burch (2021) used the anticipation dimension of this framework to analyze how apple orchard producers in New Zealand engage with the prospects of AI robotics. This dimension was useful for understanding how farmers' expectations and strategies are shaped by various factors and how they evolve over time. Bronson (2019) used this framework to analyze the views of technology designers and to elicit how inequity is present in the design of digital farming innovations. Building on the responsible innovation framework, Long et al., (2020) developed a tool that helps sustainability-focused start-ups in agriculture, food, or energy to identify socio-ethical issues systematically. McCampbell et al., (2022) combined Responsible Innovation, Human-Centered design, and a digital rights framework to analyze a pilot project using a digital extension to control and prevent a banana disease in Rwanda. Fleming et al., (2021) used this approach to frame a participatory foresight exercise with stakeholders in the Australian context; the four scenarios identified created a space for a conversation on the implications of digital technology development. Bellon-Maurel et al., (2022) used this framework to build "a research agenda to foster an agroecology-based digitalization of agriculture" at INRAE, a French national research institute for Agriculture, Food and Environment. These examples show the potential of a responsible innovation lens to open up conversations about digitalization's future and analyze current digital products and services.

2.5 What do we need to know?

Scholars and multilateral organizations are concerned about the potential exacerbation of inequalities and the consequence of power relationship shifts. These warnings derive from the interaction of the complex context where technologies are developed —the predominance of industrial agriculture, the concentration of power and the expectation of cheap food (IPES-Food, 2016), and how these technologies are being governed —by big and private actors using data as new means of control in a context of lack of public policy. Prause et al., (2020) warn that digital technologies deepen control and value extraction in the current organization of the food system, a third food regime (McMichael, 2009) characterized by neoliberal, free-market policies and the dominance of large corporations. These relevant warnings need to be considered to move forward on a path that can change how digitalization is occurring.

Through the blueprint that critical scholarship is building on digitalization in agriculture, we know that digital technologies pose several socio-ethical questions about their expected and unforeseen implications; also, we know that different scales —single digital technology, a digital innovation package, and a digital agricultural system (Rijswijk, 2022)— embrace specific challenges that need to be identified and analyzed. However, there are still many things that we do not know, and we need to promote agricultural digitalization that benefits small farmers worldwide.

Trajectories in different regions, types of production and types of crops

We need to know how digitalization unfolds in low and middle-income countries. As noted by Klerkx et al., (2019), McCampbell et al., (2022), Hackfort (2021) and McGrath et al., (2023), few critical studies on digital agriculture focus on these regions. Empirical work has focused on New Zealand, Australia, North America, and Europe. Only a few analyses consider empirical evidence on Africa and Latin America through a critical lens (see some examples on Abdulai , 2022; McCampbell et al., 2022; Steinke et al., 2022). This understanding of how digitalization is being promoted will need evidence across scales, addressing how it is unfolding in different types of production, crops, and farmers. In Latin America, for example, there is a growing ecosystem of digital technologies for agriculture that are being mainly described by multilateral organizations (Loukos and Arathoon, 2021; Viton et al., 2019; Sotomayor et al., 2021) and some scholars are analyzing with a lens of adoption and limitations (e.g Puntel et al., 2022; Silveria et al., 2022; Bolfe et al., 2020). But still, our understanding of what is occurring within countries, in specific products and across types of production is scarce. Latin American countries produce a diverse range of agricultural commodities, e.g coffee, cocoa, beef, bananas, and avocado, using different configurations of labor and in contexts with differentiated power structures, market and institutional arrangements, and rural development projects; because of this diversity an approach looking into particular cases is required.

This empirical evidence will help address and offer nuanced perspectives on the questions posed by van der burg et al., (2019), who propose to explore the advantages and disadvantages of different power distributions in relation to goals, distribution of burdens and benefits, sustainability of farms, autonomy of farmers and consumers, and the meaning of values such as fairness, justice, just distribution, transparency and trust.

Understanding the different stages of tecnological developments and its potential outcomes

The umbrella of digital agricultural technologies is extensive and covers many technologies, varying in complexity. Despite the hype, not all technologies are at the same level of market readiness or maturity across sectors —e.g, according to FAO (2022), while robotics, IoT and data analytics in livestock are closer to scaling, they are more at a prototype level in aquaculture. A deep understanding of the nuances —regarding what specific technologies do, in which crops, in which region, and what outcomes— would lead to better critics and more focalized interventions. Beyond a categorization, paying attention to the heterogeneity of agricultural technologies is needed, as Stræte et al., (2022:p9) exemplify, "what works well for technologies for goats follows different development trajectories than that for cattle, or round bales, for that matter".

Interactions of digital agriculture with ecosystemic challenges

Despite narratives on digital agriculture mention sustainability, this is more of a superficial connection since the discourse is overly focused on technical and economic benefits.

Considering that agriculture, food production, and deforestation are three major drivers of climate change (IPCC, 2019), it is imperative to understand how digital agricultural technologies impact environmental challenges, such as deforestation and consumption of natural resources. It is not the analysis of using digital technologies for environmental purposes, which is a different line of inquiry, but how the different types of digital agricultural technologies used in farming or livestock have measurable outcomes in environmental terms. Some work has been advanced by Green et al., (2021), but still much more is needed to explore through empirical cases.

More nuanced knowledge of how digital agricultural technologies operate will offer evidence to contest dominant narratives of the benefits of this digitalization and would inform sharper efforts of accountability on their development.

2.6 Conclusion

The aim of this review essay was to provide practical insights for applied scholars and practitioners who sought to understand the key elements of digitalization in agriculture. It covered a range of topics, including an overview of technologies within the digital agriculture umbrella, the narratives surrounding them, socio-ethical implications, and possibilities for developing a more inclusive and responsible approach to digitalization. The essay emphasized the important point that technology is never neutral. Factors such as who developed it, who used it, and how it was used were all influenced by the interests and goals of decision-makers, as well as the resources and possibilities available to those considered users.

Because digital products and services are neither neutral nor objective; conversely, they are embedded in power networks and arrangements, it is crucial to approach digitalization with a critical eye and a focus on inclusive and responsible development.

Chapter Three: Digital Agriculture In Colombia: What Is Available, By Whom, To Where Is It Leading?

3.1 Introduction

As in many countries in which the agricultural sector is essential for the economy and livelihoods, Colombia is interested in the potential use of digital technologies in agriculture. This is explicit in the National Developing Plan proposed for 2022-2026, where digital agricultural technologies are essential for creating technologically advanced supply chains, sustainable production systems, and e-commerce, supporting efficiency, security, traceability, and transparency in commercialization processes that benefit small farmers. In this Plan, these technologies are means to facilitate a “transition towards a knowledge-intensive agricultural and industrial economy, which facilitates local productive reconversion processes and traceability of the performance of small productive units." (DNP, 2022 p.120). Amidst the expectations regarding these technologies, it is unclear whether Colombia's current configuration of digital products and services is moving toward meeting these expectations. This study aims to provide an overview of the products and services of digital agricultural technologies currently available in Colombia and to examine their possible trajectories.

Digital agricultural technologies are anticipated to change relationships within food systems by affecting the production, distribution, and consumption processes (Trendov et al., 2019; Schroeder et al., 2021). Scholars have pointed out the positive, negative, and uncertain challenges and opportunities associated with digitalization, including, in general, the potential exacerbation of inequalities (Hackfort, 2021; Rotz et al., 2019, 2019a) and affectations along many factors, including trust, health and safety, sustainability and environment, regulation, data, employment, and economic impacts (Rose et al., 2021; McGrath et al., 2023). Despite the high expectations generated by digital agriculture and its many nuances, little empirical research has been conducted to understand how digital agriculture unfolds within countries, particularly developing countries (Klerkx et al., 2019; McCampbell et al., 2022).

Understanding the configurations of available digital products and services —actors involved, services offered, and types of target farmers— is crucial for both scholars and policymakers. By understanding the configurations of available digital agricultural technologies in Colombia, scholars can contribute to research and knowledge production that addresses the country's unique challenges and opportunities in agriculture related to rural inequality and the challenges of biodiversity conservation and climate change. Practitioners can enable better decision-making for promoters, prioritize conversations that need to occur based on the potential impacts of technologies, and make better investment allocations to inclusively and responsibly promote digital agriculture.

This study is situated in the growing literature on the social and ethical implications of digital agricultural technologies (van der Burg et al., 2019; Rotz et al., 2019; Bronson, 2022; Ayris & Rose, 202). To conduct the analysis, I used service types as the basis (Porciello et al., 2021). For each service type, I investigated the type of data involved (Maru et al., 2018) and expected results (Porciello et al., 2021; Rolandi et al., 2021). I also consider the potential patterns of inequality from the deployment of digital agriculture (Hackfort, 2021). This approach allows for a nuanced exploration of what technology does and the types of results that can be expected. In this way, the analysis captures specificity and informs scholars, civil society, policymakers, and entrepreneurs interested in participating in how digital agricultural technologies unfold in a particular territory.

This study contributes to the nascent literature on Latin America by examining the configuration of digital agriculture in a particular Latin American country. Currently, reports developed by multilateral organizations have mainly described the digital agriculture situation and offered insights into why it is relevant and how it is configured in different countries. For example, the Inter-American Development Bank and its Innovation Laboratory (IDB LAB) published reports describing the situation of the agtech entrepreneurial ecosystem. These include Viton et al., (2019), who offer a bird's eye view of the sector's size, innovations, and performance by country; according to this review, in 2018, 5 percent of the 457 start-ups in Latin America working on new agriculture technologies were in Colombia. It also includes the work of Loukos and Arathoon (2021), who offered market mapping, identification of trends, and recommendations for the digital agriculture ecosystem after examining 131 digital agricultural tools used in Latin America. Other studies have focused on specific technologies and countries. In a report by the IICA, Grasso (2022) explored the blockchain situation for Latin American agriculture and identified 29 blockchain solutions, including one from Colombia. Some studies offer insights into specific countries, such as Argentina (Munoz et al., 2021) and Honduras and Haiti (Strategic Impact Advisors, 2022, 2022a); however, a critical perspective that considers social implications is missing. In this sense, this study is an exploratory endeavor to critically understand what is available in the Colombian digital agricultural technology market.

This study presents a panorama of the types of digital products and services available in the Colombian market, their potential uses and benefits for farmers, and the actors behind them. These results arise from a mapping exercise conducted with secondary information, guided by the following sub-questions: (i) What initiatives currently promote digital agricultural technologies in Colombia? (ii) Which products and services of digital agricultural technologies are currently available in the Colombian agricultural context? (iii) What types of actors sell them, and to whom? (iv) What implications can be anticipated for small-scale farmers?

The remainder of this paper is organized into three parts. First, it introduces a framework to analyze the configuration of digital technologies available in the market, focusing on the specific type of service offered, potential outcomes, and particular social implications that could arise. Second, it provides a background of the Colombian case and introduces data collection and data analysis procedures. Finally, it discusses results of the current configuration of digital technologies in Colombia across five types of services: Digital Advisory & Extension, Digitized Farm Tools, Digital, Financial Services, Digital Market Linkages, and Supply chain management. The chapter concludes with a discussion of potential pathways derived from these configurations, their implications for small farmers, and aspects to consider for making this configuration more inclusive.

3.2 A Framework for analyzing digital agricultural technologies

To understand the configurations of digital agricultural technologies available to farmers in Colombia, I used service types as the backbone and added three layers: types of data, expected results, and patterns of inequality. Below, I introduce these elements:

Service Types and expected outcomes

Porciello et al., (2021), Digital Agri Hub (2021), and Loukos and Arathoon (2021) use a categorization of services offered by digital agricultural technologies. Service types allow for an understanding of the specific social relationships that may be affected by digital technologies, the actors involved, and the risks and uncertainties that can arise. The five types of services offered to farmers through digital products and services are i) advisory, ii) farm tools, iii) financial services, iv) market linkages, and v) supply chain management (Porciello et al., 2021). Each of these categories is broad and can contain subcategories that add nuances to each type of service (Loukos and Arathoon, 2021). Table 2 offers a summary of these service types and potential subcategories; I selected those subcategories that are particularly relevant to Colombia's situation.

Table 2. Service Types, subcategories, and expected outcomes for Digital Agriculture

Service types	Examples of Sub-categories of products and services	Definition of service type	Expected outcomes
Digital Advisory & Extension	• Weather forecasting and monitoring • Nutrient management and soil health • Pest and disease identification and management • Crop selection and rotation planning • Market information	Information delivered digitally to farmers on different topics looking to improve decision-making and increase in productivity and quality.	• Improved crop management and productivity • Access to expert advice and localized information • Enhanced pest and disease management • Better decision-making based on real-time data
Digitized Farm Tools	• Sensors for soil moisture, temperature, and nutrient levels • Precision planting equipment • Livestock and fishery management	Products and services that facilitate the collection, synthesis, and interpretation of farm data, aiming to optimize farming practices and production	• Increased efficiency in farm operations • Reduction of labor costs • Enhanced precision in planting, irrigation, and harvesting • Improved resource management (water, energy, and inputs)
Digital Financial Services	• Mobile banking and payment services • Digital credit and lending platforms • Microinsurance • Crowdfunding • Digital savings and investment platforms	Digital products and services offering access to different financial services intending to improve farmers' yields and income.	• Access to credit, insurance, and other financial products • Reduced transaction costs • Better financial management and risk mitigation • Increased investment in agricultural inputs and technology
Digital Market Linkages	• E-commerce platforms for ag inputs • E-commerce platforms for ag outputs • Mobile-based market information systems	Digital services that facilitate farmers' access to transactional interactions along the food chain	• Improved access to markets • Better price discovery and transparency • Reduced transaction costs in buying and selling • Enhanced market information and opportunities
Supply chain management	• Blockchain-based traceability systems • Digital inventory management • Quality control and certification platforms	Solutions along the food system helping different actors to facilitate flows of information	• Improved traceability and transparency of products • Enhanced coordination among different stakeholders • Reduction of post-harvest losses and food waste • Improved quality control and compliance with standards

Source: Author based on Porciello et al., (2021), Digital Agri Hub (2021), and Loukos and Arathoon (2021)

Types of data

According to Maru et al. (2018), agriculture has four distinct data streams. First, "localized data," consists of information generated and collected on the farm for exclusive on-farm use, such as soil composition, seed types, fertilizer usage, planting dates, farming techniques, and water consumption. The second is "imported data," which involves data gathered off-farm and applied on-farm. These data include market prices and weather information, which are analyzed and customized for on-farm applications by a separate entity that owns, oversees, and regulates the data. The third is "exported data," which includes data gathered and organized on the farm for off-farm utilization. These data can be collected by farmers themselves or through sophisticated tools, and are typically processed, grouped, or combined with other data from various sources, enabling different stakeholders to make informed decisions. Governments can direct services and subsidies, financial institutions and insurance providers can offer specialized services and products, and researchers can devise and execute targeted projects. Finally, the "ancillary data" comprised both on-farm and off-farm data used for off-farm purposes. Each data type presents several challenges. According to Maru et al. (2018), localized and exported data share challenges in privacy, ownership, monetization, and monopoly, and imported data have access challenges in terms of availability, accessibility, and usability. Table 3 illustrates the types of data that can potentially be found and used for each type of service.

Table 3. Data used by each service type in Digital Agriculture

Service types (Porciello et al., 2021)	Types of Data engaged Maru et al., (2018)	Challenges of data Maru et al., (2018)	Examples of data used
Digital Advisory & Extension	Localized Data	Sharing challenges	oil composition, seed types, farming techniques
	Imported Data	Access challenges	Weather information, market prices
Digitized Farm Tools	Localized Data	Sharing challenges	Fertilizer usage, planting dates, water consumption
	Imported Data	Access challenges	Weather information
Digital Financial Services	Exported Data	Sharing challenges	Production data, income data
	Ancillary Data		Credit scores, insurance risk assessments
Digital Market Linkages	Imported Data	Access challenges	Market prices, demand trends
	Exported Data	Sharing challenges	Product information, sales data
Supply chain management	Exported Data	Sharing challenges	Inventory data, shipment data
	Ancillary Data		Traceability information, quality certifications

Potential patterns of inequality

There are many social and ethical aspects to pay attention to when considering the impacts of digital agricultural technologies. Hackfort (2021) described five patterns of inequality linked to digital technologies in agriculture.

In the first one —inequalities in control over technology deployment— the main factors shaping it are the relevant role that big ag and tech corporations play to control technology development, technical lock-ins that limit farmers' options and the lack of interoperability —this inability of different systems, devices, or software applications to communicate, exchange, and use information effectively with each other hinders seamless data exchange and integration, limiting the potential for efficient decision-making and optimal resource management in agricultural practices. In the second pattern —the unequal distribution of benefits— the concerns are that innovation focuses on capital-intensive approaches that favor large-scale agricultural operations; the disparity in access to digital infrastructure exacerbates the divide between urban and rural farmers; and asymmetry in financial risks, where farmers face significant risks while technology providers gain advantages from utilizing data provided by farmers at no cost. In the third pattern, —uneven sovereignty over data and hardware— the concern is that technology providers dominate data storage, imbalances in bargaining power put farmers at a disadvantage, and private licensing agreements and legal restrictions that can prevent farmers from accessing their farm data and may even prohibit self-repair of hardware. In the fourth pattern, —inequalities in knowledge and skills— the worrisome elements are unequal digital literacy, a growing dependency on providers of big-data and the disadvantage that farmers with fewer resources can have to hire skilled employees. Finally, in the fifth pattern —unequal problem definition and problem-solving capacities— aspects causing concern are the relevance of productivist solutions to structural problems and the fixation on fixation on technological solutions detract from alternative approaches.

3.3 Context

Agriculture is vital to Colombia's economy, food security, rural livelihood, biodiversity, and social and political stability. In 2020, the sector accounted for approximately 6.7% of the country's GDP, generated over $9 billion in revenue through exports, and employed about 16.7% of the labor force (World Bank, 2021b). Colombia's diverse agricultural production, including staple crops and tropical fruits, contributes to food security (FAO, 2021). Approximately 30% of the population resides in rural areas, where small-scale farming is predominant, with around 80% of farms being smaller than five hectares (World Bank, 2021; FAO, 2018). The importance of agriculture in achieving social and political stability is further highlighted by the 2016 peace agreement with the FARC, which includes provisions for rural development and land reform (Colombian Government & FARC, 2016). Promoting sustainable agricultural practices and supporting small-scale farmers are crucial for Colombia's long-term growth and development. Historically, rural poverty has been higher than the urban and national averages. In 2021, rural poverty was 31.9%, which is higher than the national average of 27.7% and urban average of 21% (DNP, 2022). Table 4 presents an illustration of the general indicators for this sector.

Small farmers in Colombia face significant challenges in accessing infrastructure and other resources relevant to productivity, including low yields, insufficient resources to improve their main activities, such as irrigation systems, agricultural practices, and industrial machinery, and poor access to agro-climatic information. (Lopez-Barrera et al., 2022; Martinez et al., 2016)

According to Katz et al. (2021), in a report commissioned by the Ministry of Telecommunications and Bogota Chamber of Commerce, the adoption of mature digital technologies is still low among companies in the agricultural sector; only 57% of employees use the Internet for their work, and the sector has limited development in supply chain and distribution channels. For instance, only 24% of companies in the sector purchase inputs online and only 27% use the Internet for their sales. The slow digital transformation of the sector is due to several barriers and risks, such as resistance to change, limited budgets, lack of clear responsibility, and lack of resources. Moreover, the sector faces challenges such as poor broadband coverage in rural areas, lack of training in technological and administrative areas, and low adoption of advanced technologies, such as the Internet of Things, robotics, and artificial intelligence.

Table 4. Illustrative data on the agricultural sector in Colombia

Indicator	Value	Unit	Reference
Population	50,882,891	People	World Bank (2021)
Population in rural areas	24,8%	% of total population	World Bank (2021)
Rural Poverty (National Poverty Line)	42.5%	% of population	DANE (2020)
Rural Inequality (Gini Coefficient)	0.455	Index (0-1)	World Bank (2022)
Lack of Access to Basic Needs (Unmet Basic Needs Index) in Rural areas	30,48%	% of households	DANE (2018)
Electrical Coverage in Rural Areas	91.1%	% of rural population	UPME (2019)
Rural Population with Access to Meaningful Connectivity	4,6%	% of rural population	Alliance for Affordable Internet (2022)
Estimated Population with Access to Meaningful Connectivity	26,2%	% of total population	Alliance for Affordable Internet (2022)
Rural Population with Access to 4G	61.8%	% of rural population	MINTIC (2020)

3.4 Methods

This qualitative study examined the Colombian configuration of available digital agricultural technologies. It explores the following questions: (i) What initiatives currently promote digital agricultural technologies in Colombia? (ii) Which products and services of digital agricultural technologies are currently available in the Colombian agricultural context? (iii) What types of actors sell them, and to whom? (iv) What implications can be anticipated for small-scale farmers?

In this study, I used a broad definition of digital agriculture. Following Duncan, Abdulai & Fraser (2021. p139), here digital agriculture encompasses "any form of information and communication technologies (ICTs) in the agricultural field, either to make automated or non-automated decisions and practices". This can include anything from simple mobile apps that provide information to farmers to advanced automated systems that use data to control the equipment and devices. This broad term encompasses all the forms of digital technology used to improve the efficiency and productivity of agricultural operations. I made this decision because, in developing countries such as Colombia, initiatives promoting the digitalization of agriculture cover a large spectrum of digital technologies, including less advanced technologies (e.g., simple mobile apps, text messaging systems, soil moisture, temperature sensors, and human-operated drons) and cutting-edge innovations such as blockchain, virtual reality systems, robotics, and artificial intelligence systems for soil analysis, among others.

Searching strategy

I used a combined search strategy. I conducted web searches for different resources (see Table 5), conducted in-person and virtual participant observations in specialized events promoting digital agricultural technologies in Colombia, and had informal queries with professionals working there. During web searches, when possible, for the nature of the source, I used a list of keywords drawn from various lists of technologies (Prause et al., 2020; Trendov et al., 2019) (see Annex 1). During the search, I combined “agricultura digital” (Spanish for digital agriculture") and Colombia, and the name of technologies with Colombia and “productores” and “pequeños productores” (Spanish for producers and small producers"). The search was conducted between September 2020 and May 2022. An update was performed in March 2023.

Table 5. Sources used for searching

Type of resource	Name	Source characteristics or Search characteristics
General Search Engine	Google	Used the combination of keywords
Database	Crunchbase	It lists public and private companies, including early-stage start-ups. Search for companies within the food system in Colombia.
Database	FAO	FAO has a browser for all news, resources, and publications produced by FAO.
Database	CGIAR	CGIAR has a repository of agricultural research outputs produced by members.
News aggregator	Google News	Used the combination of keywords.
Event official Website	Expo Agrofuturo	ExpoAgrofuturo is an annual event with national scope gathering companies across the food system.
Database	IICA	The Inter-American Institute for Cooperation on Agriculture counts with a database of the projects funded by the organization
Twitter accounts	MinAgricultura	Colombian Minister of Agriculture
Twitter accounts	MinTIC	Colombian Minister of Information and Communications Technologies
Twitter accounts	IICA	Inter-American Institute for Cooperacion on Agriculture

During this search, I also identified initiatives with an active national scope during 2022 and the onset of 2023.

Data selection and organization

Initiatives were included if they are active during 2022 and the onset of 2023 and are completely focused on digital agriculture, or at least a major component. Digital products and services were included when fulfilling three criteria: i) fitting into the list of technologies, ii) having headquarters in Colombia or being marketed in the country by international companies, and iii) already in the market — I exclude technologies in the design stage.

All digital products and services identified were organized in a matrix considering the name, objective, how it works, population target, name of the seller, type of company, key partners, and website. Using the zoomed-in framework presented in the previous section, I analyzed these digital products and services considering three aspects: types of service, types of data, and types of expected outcomes.

Initially, 139 digital agricultural products and services that met three predetermined selection criteria were identified. To complete the analysis matrix, a thorough review of each organization's website, social media presence, and available news articles was conducted. In some instances, it was observed that only general information was present on the website, with no clear indication of the most recent update or current availability of the service. Under such circumstances, social media channels and news articles were examined in greater detail to determine whether the product or service remained in the market. Entries were removed from the results when the information was insufficient or when the product or service did not have a direct application for farmers. A total of 43 of the 139 initially identified entries were eliminated from the final analysis. The 93 digital products and services identified were illustrative, considering that Viton et al. (2019) found 23 digital products for Colombia and Loukos and Arathoon (2021) found 131 for Latin America.

Challenges and Limitations

This study primarily relied on information sourced from the official websites of each company and general news outlets. However, it is important to acknowledge that the content available on these platforms is directly generated by the respective companies themselves, with the purpose of conveying specific messages that promote the sales of their products or services. Consequently, while such information is valuable for obtaining a broad understanding, it may not sufficiently capture the intricacies underlying business decisions and the associated business models.

To gain a deeper comprehension of these aspects, it is recommended to conduct specific case studies that delve into the individuals responsible for decision-making processes, the methodologies employed, and the underlying rationale. However, given the scope of this research, these nuanced analyses fall outside its purview.

This study provides a non-exhaustive overview of digital products and services currently available in the Colombian agricultural market based on observations made during a specific time frame. Although digital technology is a fast-paced market, this review of available technologies allows us to identify patterns and trends in the current digital agriculture market and advance the conversation of their potential trajectories.

3.5 Findings

3.5.1 What initiatives currently promote digital agricultural technology in Colombia?

Although Colombia is not the Latin American leader in digital agriculture, it is among the top five countries, with most digital innovations unfolded in regional technologies (Viton et al., 2019). The interest in promoting these technologies seems mainly present at the national level, with public and private endeavors calling for the sector's development and looking for projects reaching farmers nationwide. Below is a panorama of projects with an extensive range in 2022 and/or unfolding by the beginning of 2023.

Promoting National Digital Extension

Public agricultural digital extension service: In October 2021, the public Rural Development Agency[2], started a pilot to offer a public agricultural digital extension service. This service was presented as a "strategy to expand coverage, supplement in-person services, and provide small-scale farmers with access to information, resources, markets, financing, and training" (EPSEA UTP and ADR, 2023: p4). The service combines WhatsApp with calls, text messages, podcasts, and videos (Agencia de Desarrollo Rural,2021). This initiative, executed by a public university, took a top-bottom approach, and defined the value chains to be considered and the users to reach at the local level based on regional dialogues with public entities and priorities written on the Regional Plans for Agricultural Extension and the Comprehensive Strengthening Plans per Producer. According to their indicators, the program included 57 value chains —12 livestock and 45 agricultural— in 30 of Colombia's 32 departments. The project targeted 187.981 farmers, of whom approximately 52% were women. At the end of 2022, the program was suspended, while waiting for guidelines to be offered by the new government, which started operations in August 2022. By February 2023, the future path of this service was still unclear. Still, the team was working on finishing knowledge management of the process, learning, and identifying good practices (A. Londoño, personal communication, February 1, 2023).

[2] Public entity under the branch of the Ministry of Agriculture and Rural Development in charge of managing, promoting, and providing financial support for agricultural and rural development aimed at transforming rural areas and executing programs with regional impacts.

Putting together open and public data for agriculture in Colombia

Two public entities, IDEAM[3] and AGROSAVIA[4], have been developing open information services to improve decision-making to enhance productivity and competitiveness. IDEAM developed the app "Mi Pronóstico" to offer access to real-time information on weather forecasts, satellite images, and early warning alerts (IDEAM, 2017). AGROSAVIA has seven open information systems that focus on different stakeholders and needs. For example, ViMaZ is a geospatial application that displays agricultural information for the Zulia irrigation district in a department; HornillApp helps users without specialized knowledge to estimate the dimensions and economic value of an efficient thermal panel for sugar cane production; Más Bienestar is a free application designed to evaluate and improve bovine well-being in specialized dairy systems; and M.A.P.A is a technological tool that helps increase local capacity for making decisions to improve crop system adaptation to climate change and climate variability (AGROSAVIA, 2023).

Digital technologies in the National Development Plan

In the National Development Plan proposed for 2022-2026, the Colombian government, ruled by Colombia's first leftist leader, includes several angles within the Human Rights to Food pillars to promote digital technologies for the agricultural sector (DNP, 2022). Their views on digital technologies are summarized in the following statement:

> "El uso intensivo de datos (monitoreo y seguimiento de cosechas y de producción, resultado de la adopción de tecnologías y cumplimiento de estándares, aceptaciones y rechazos de posibles compradores, entrada a segmentos de compras públicas) y la adopción de tecnologías digitales, permitirá transitar hacia una economía agraria e

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[3] Institute of Hydrology, Meteorology, and Environmental Studies, is responsible for producing and disseminating information related to hydrology, meteorology, and environmental studies.
[4] Colombian Corporation of Agricultural Research, aims to promote scientific knowledge and technological innovations in the agricultural sector.

industrial intensiva en conocimiento, que facilite procesos de reconversión productiva local y de trazabilidad del desempeño de las pequeñas unidades productivas."

[The intensive use of data (monitoring and tracking of crops and production, outcomes of technology adoption and compliance with standards, acceptance and rejection by potential buyers, entry into public procurement segments) and the adoption of digital technologies will allow for the transition towards a knowledge-intensive agricultural and industrial economy, facilitating local productive reconversion processes and traceability of performance of small production units] (DNP, 2022 p.121)

In other sections of this national plan, digital technologies are presented as tools for enabling more and better food production; facilitators for the betterment of supply chains, leading to more efficient and secure value chains, benefiting small farmers; and an instrument of logistics and infrastructure improvement to reduce losses of food production. Speaking specifically on the technological extension to small farmers, the plan makes explicit the expectation of digital technologies as an agent of change. The plan was presented in February 2023 and is currently undergoing a review by the Colombian Congress. Until May 2023, they had to study, analyze, and approve the document, which will then become a National Law.

Linking digital agriculture to climate action

Sustainable Agricultural Colombia is a 5-year project with funding of US$99,9 million, aiming to reduce the vulnerability of agricultural production to climate threats to minimize their impact on the competitiveness of the Colombian agricultural sector. This project, which began in November 2022, is financed through a combination of financial resources from the Development Bank of Latin America, the Government of Colombia, agricultural research institutions (Alliance Bioversity-CIAT, CYMMIT, and CIPAV), and agricultural producer associations in Colombia, as well as resources from both loans and concessional funds (grants) from the Green Climate Fund (Colombia Agropecuaria and Sostenible, 2023).

The main objective of this project is to enhance the resilience of agricultural production against climate-related risks, mitigate their negative impact on the competitiveness of the Colombian agricultural industry, and ensure consistent and high-quality food supply through the reinforcement of climate risk management. This will also contribute to reducing greenhouse gas emissions and harmful effects of agricultural production. It comprises three components: i) digital agriculture and climate services to modernize agricultural extension services with an emphasis on adaptation and mitigation; ii) genetic improvement, crop management techniques, technological options, and scaling to increase resilience and promote low-carbon agricultural development; and iii) innovative and inclusive business models through modernized innovation systems and a more committed financial sector. The project is anticipated to directly benefit over 619,691 individuals, comprising 194,871 rural producers and their respective families, and indirectly benefit approximately 347,996 producers. The project is targeting 8 crops, including rice, sugar cane and panela sugar cane, coffee, livestock, corn, musaceae and potato. The digital agriculture component aims to reach 126,394 farmers, 1,532 technicians, and nine crops across 139 municipalities (Colombia Agropecuaria and Sostenible, 2023). By March 2023, the project was completing its team and conducting regional workshops to socialize their aims and scope.

Agrifood tech innovation hub

Agcenter was launched in late 2022 in Medellin (Antioquia) as an agrifood tech innovation hub, "seeking to energize the ecosystem in Colombia, encourage ecosystem articulation through connections between actors, promote the development of global solutions for the sector, attract talent and investment, and accelerate agrifood entrepreneurship" (Agtech, 2023, para. 1). Agcenter aims to become a national and Latin American hotspot for companies, public entities, investors, and all-size farmers, to develop initiatives to accelerate digital innovations by startups, facilitate investment, and promote open innovation.

This hub was conceived by Ricardo Jaramillo, the founder of two initiatives focused on the agriculture sector, including a virtual marketplace where farmers could buy all kinds of agricultural inputs, and a company focused on the organization of specialized agricultural events. The idea was pitched and became a collective project led by the Antioquia government, a large private NGO promoted by leading companies in Medellin, and the largest public university in the department (S. Henao, personal communication, November 2, 2022). Agcenter started operations with an approved seed capital of USD 673.000 donated by the provincial government of Antioquia. By 2027, this hub aims to accelerate at least 200 startups, connect more than 300 to the corporate market, and have a fund with an increase of more than $70 million and an investment of more than $400 million, among other projects (Agronet, 2022). By March 2023, this hub had conducted its first business acceleration program and selected 25 companies across three topics: foodtech, agtech, and animaltech.

Initiatives promoting networking

Network for Extension workers

The Linkata is a network of extension workers and technical assistants in Colombia. It was created in 2012 by AGROSAVIA and the Ministry of Agriculture. Linkata aims to hold a space for interaction, discussion, and participation of the sector's technical assistants and extension workers, and to achieve and strengthen the service of technical advisory in the benefit of small farmers. Currently, the community comprises forty-four (44) groups that respond to the productive chains of the Ministry of Agriculture and Rural Development (Cruz and Perdomo, 2019). Today, this network contains more than 7.000 active members.

Creating a professional guild

In June 2019, a WhatsApp group called Agtech Colombia was created by civil society groups as a collaborative strategy for coordinating and implementing actions to develop the AgriFoodTech ecosystem. In its description, the group presents itself as an Agtech ecosystem group, home to representatives from the private sector, public sector, multilateral entities, civil society, farmers, associations, startups, media, financial and impact sectors, agribusiness associations, agriculture and food, and academia. The group hosts three working tables focusing on governance, technology and competitiveness, fair trade, and rural development. Since June 2022, I have joined the WhatsaApp group and have followed its evolution. By the end of March 2023, 265 people —including entrepreneurs, consultants, professionals, public servants, and a few leaders of farmers' organizations— were part of this group that shared news, relevant information, and specific questions on products and services, such as where to find drones or buyers to commercialize avocado. By March 2023, the group promoted a series of virtual and in-person meetings among their members, mainly those localized in Bogotá, Colombia´s capital, aiming to position and consolidate the Agtech Group "as an enabler for the use and diversification of technology in the Colombian rural areas, as a space for institutional influence with the aim of generating productive impact, food security, and economic development' (Agtech Group, 2023, p6). The group plans an in-person event in July 2023 to boost the work being developed in the working tables, define communication with the Bogota Secretary of Economic Development, and formalize their work as a professional guild with a strategic plan to guide their future actions.

Creating an annual space for gathering

ExpoAgrofuturo is a fair that takes place in Medellín every year and is an event focused on the agricultural sector, the most important for Colombia, and with projection to Latin America. This fair is "the place where supply and demand meet in all business segments and for all ecosystems of the sector" (Expoagrofuturo, 2023, para.2). For the past couple of years, ExpoAgrofuturo has promoted conversation and visibility of digital technologies in agriculture. Since 2022, the same organizers have been promoting Agstar as a platform to foster connections between different actors focused on integrating innovations in the agri-food sector. In its activities, Agstar holds start-up competition, a business roundtable, and conversations among sector experts.

Table 6 summarizes these initiatives.

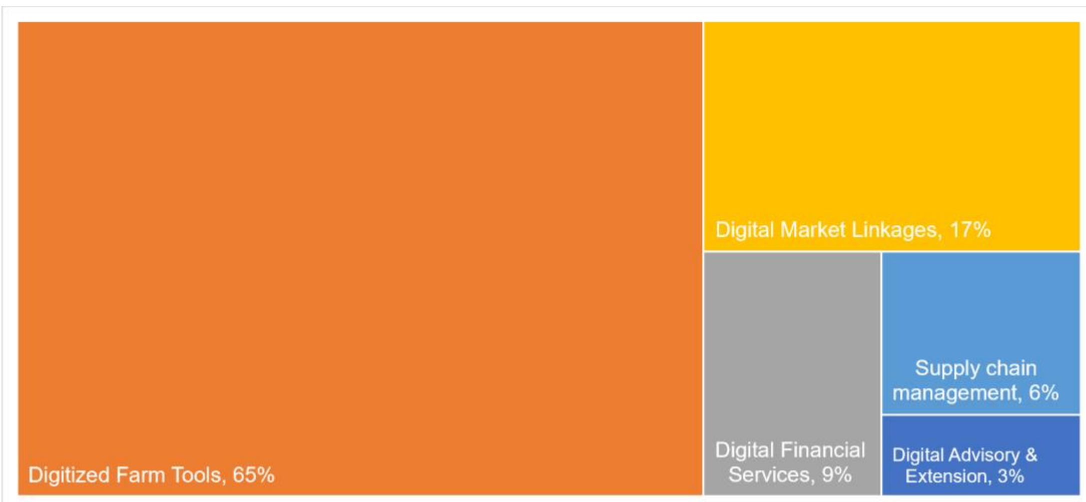
Table 6. Summary of Initiatives currently promoting digital agricultural technologies in Colombia

Initiative Name	Actors	Technologies involved	Service Type	Farmers targeted	Crops targeted
Public agricultural digital extension service.	Public	Whatsapp	Digital Advisory & Extension	All kind of producers	Livestock —including dual-purpose livestock farming, artisanal fishing, pig farming, ovine caprine, aquaculture, poultry farming— and crops —including coffee, potatoes, avocado, corn, banana, cocoa, sugar cane
Human Rights to Food pillar in the National Development Plan	Public	Unspecific	Digital Linkages with the market	All kind of producers	Unspecific
Sustainable Agricultural Colombia	Public and private	Unspecific	Digital Advisory & Extension	All kind of producers	Rice, sugar cane and panela sugar cane, coffee, livestock, corn, musacea and potato
Agcenter	Public and private	E-commerce, robotics, precision agriculture drons	Digitized Farm Tools, Digital Financial Services Market Linkages	All kind of producers	Unspecific
Agtech Colombia	Private	Unspecific	Unspecific	Unspecific	Unspecific
ExpoAgrofuturo	Private	Unspecific	Unspecific	Unspecific	Unspecific

3.5.2 Which products and services of digital agricultural technologies are currently available in the Colombian agricultural context?

This empirical study identified 93 digital products and services of digital agriculture currently available in Colombia. Digitized farm tools had the highest available products and services (65%), followed by digital market linkages (17%). The three types of services with fewer digital products and services are financial services (9%), supply chain management (6%), and digital advisory and extension (3%). The segmentation of the identified digital products is shown in Figure 2.

Figure 2. Distribution of products and services found and categorized in types of service



<u>Digitized Farm Tools</u>

Sixty digital products and services were identified, offering several tools for collecting, synthesizing, and interpreting farm data; 97% of these services are provided by private organizations, including startups and small, medium, and large companies. Thirty-five of these products and services (58% of 60) are related to precision agriculture equipment and include a variety of sensors, drons, and satellite imagery. Twenty-four (40% of 60) are farm management platforms that generally allow farmers to analyze information gathered off-farm and on-farm using different tools. Only one (0,1% of 60) is focused on smart packaging.

Descriptions of precision agriculture equipment products and services are not specific to the targeted crop type. Some mentioned that they had been tested and used on particular crops, including coffee, banana, flowers, sugarcane, avocado, fruits, potatoes, grasses, citrus, and cannabis.

Farm management platforms vary in complexity and services offered. For instance, SimpleAgri, a Colombian company, offers medium-sized farmers and agroindustry services that enable the planning, scheduling, and execution of agricultural production systems. It focuses on costing, traceability, data collection throughout crop growth phases, and production and harvest quality management through recommendations from technical assistance visits to farms. SiomaApp, a Colombian company, offers the banana industry a mobile app, which is a precision agriculture ecosystem that can monitor the quality of georeferenced fieldwork using photographic records. Climate FieldView is a service provided by Bayer that allows the collection, transmission, and analysis of agronomic data from all farm tasks. Galápp is a service developed by a Colombian startup aiming to facilitate small farmers' capture of information on farms, including harvest, tasks, sanitary controls, input application, and sales; this app works without the Internet and is designed for small and medium farmers.

The service focused on smart packaging is called Nukak and was developed by the same company that launched SiomaApp. Nukak is a scale with an integrated control system that organizes the exact boxes for export. According to their brochure, using this digital product, an exporter can save $20,000 USD annually for a 100-hectare farm by avoiding an excess weight of 237 grams. Their main clients were the banana and palm companies.

Digital Market Linkages

Sixteen digital products and services offering a marketplace or e-commerce platform were identified. Ten (62% of 16) are digital marketplaces that bring together multiple sellers to offer buyers a broader range of agricultural products and services. The other six offer e-commerce platforms focused on direct sales from a single company that aggregates the production of small and medium producers.

Digital marketplaces have two types of connections: connecting farmers with input sellers and connecting farmers with buyers of their produce. In the first case, some services are free for buyers, while others are initially free for sellers but later charge a commission for sales. The inputs for purchase are seeds, fertilizers, farm equipment, and animals such as cows and horses. In the second case, the business model can vary. For example, SiembraCo employs an approach centered on virtual crop planting. This enables customers to finance the virtual planting of crops, and upon harvest, they can consume the produce, donate it, or sell it on the same platform. On the other hand, Comproagro allows buyers to communicate and buy directly from farmers their current produce.

E-commerce platforms also have specific nuances. Two platforms seem more specialized: Petalii sells superior quality floral products to national and international markets, and Mucho sells products related to the sustainable use of biodiversity. On the other hand, TuPlaza, Guineo, and Frubana commercialize the production of small-scale producers to urban centers, connecting them with households, restaurants, and neighborhood stores.

Digital Advisory & Extension

Three digital products and services offering farmers and technical assistants information on weather forecasting, pests and diseases, and market prices were identified. These products are provided by public, private, and nonprofit actors using different types of technologies to reach their users.

Cenicafe, the research branch of the National Federation of Coffee Growers[5] (FNC), provided Agroclima in 2011. This web-based agroclimatic platform delivers open information related to weather forecasting and identifies the most suitable months for coffee planting. This information is shared daily and includes current and historical data. This free service targets coffee growers of all sizes and utilizes historical data from the Cenicafe. AGROSAVIA offers Dr Agro, a mobile application sharing with extensionists workers, technical assistants, and farmers information for identifying pests, diseases and nutritional deficiencies in potato, cotton, tomato, mango, and rubber crops. It is based on scientific information reviewed and curated by AGROSAVIA and can be used without internet access.

AgrodatAI offers Don Tulio, a free WhatsApp chatbot that provides farmers with data on weather, prices, price forecasts, and best-selling prices for any product or location. Farmers can submit written inquiries, and the bot retrieves responses from public data. However, it remains unclear whether this information is accurate or reliable.

Digital Financial Services

Eight digital products and services offering some financial assistance to farmers were identified. These were created to facilitate farmers' access to financing through different operational models. One model is crowdfunding, where farmers structure their project and post it on the platform to look for micro-funding from other individuals; this is the model of Agrapp and Agroune, which facilitates the exchange between farmers and investors. Another model is the direct offer of customized financing services for farmers. For instance, Agricapital offers investments between USD 1.000 and 5.000 for rural young and women without credit scores, but with productive projects running. GrowBank provides a line of credit for agricultural

[5] Created in 1927, National Federation of Coffee Growers is a non-profit trade organization, internationally well-known within the coffee world, in charge of representing and defending the interests of Colombian coffee producers at the national and international levels.

activities after a thorough risk evaluation. The last model is supplied by Produce Pay, which offers funding up to 12 months before harvest and a marketplace to facilitate the sale of the produce.

AgRisk and IncluirTec offer financial companies and insurers risk assessment services tailored to the needs of farmers, supporting the emission of a rural loan within the offers of these companies.

Finally, the National Federation of Coffee Growers (FNC) developed Coffee Growers' Smart ID, a service that offers access to banking services to coffee growers members of the federation. This product is a savings account with access to ATMs for electronic payments that is also used to channel government subsidies.

Supply chain management

The six identified digital products and services provide platforms to support the interactions of several actors in one or more value chains. For example, Cultivando Futuro aimed to align supply, demand, and investment by creating Colombia's “largest supply calendar.” They expect to map what is being offered by farmers and what is being requested by consumers to generate data and provide access to details on how products are needed in the market. TraceCoffe, CoffeAgenda, and COLCO are value-chain-specific. TraceCoffee, a technology company founded by Colombians in Silicon Valley, offers traceability along the coffee value chain using the Internet of Things and blockchain to gather information at each production and commercialization step. CoffeAgenda, founded in Colombia, provides registers and monitoring for coffee during the productive process, post-harvest, and export. COLCO: The Colombian Cocoa Control System, developed by the British Embassy in Colombia, applies satellite technologies to support the interaction between cacao farmers and producers to improve quality and yield in the pre-and post-harvest phases of the cacao supply chain.

3.5.3 What types of actors sell them, and to whom?

National and international actors, including public, private, social, and international cooperation entities, constitute the providers of digital products and services for the agricultural sector in Colombia.

Digitized Farm Tools

All the companies in this category are private companies of varied size, including, startups, and medium and large companies. 56% of providers are Colombian; the remaining providers consist of international startups and large companies originating from Chile, Israel, Mexico, the United States, Germany, and Brazil. The available descriptions do not explicitly state whether the products are targeted at small-scale farmers; based on their features, these products and services appear to be geared toward farmers with larger land areas who require monitoring and evaluation of their agricultural processes more efficiently.

Digital Market Linkages

Eight out of the ten identified marketplaces services in this category are provided by national organizations, including startups and social companies; they are mainly located in major cities; only three out of eight were founded by entrepreneurs in departments such as Casanare, Boyacá, and Tolima, which are not very prominent as others where the major capitals are located. All have partnerships with different actors, including business accelerators, media outlets, international cooperation, large NGOs, universities, chambers of commerce and companies selling agricultural inputs. The other two marketplaces are provided by international companies, one from the United States (Agromovil with USAID and private foundations as key partners) and one from Brazil (Orbia with solid partnerships with Bayer and Yara). These marketplaces seem oriented to all kinds of farmers who know how to navigate these interactions mediated through digital platforms and are close enough to their potential buyers to sell the product in a profitable way.

Regarding the six e-commerce platforms, headquarters are all in major cities, and only one is oriented to national and international markets. All seem oriented to small farmers. For example, Petalli aggregates 50 small flower producers; and Mucho sells the produce of different farmers association.

Digital Advisory & Extension

The three primary technical assistance providers are of national origin. Agroclima is developed by Cenicafé, a research center affiliated with the biggest coffee association of farmers. Dr Agro is a product of Agrosavia, a public organization. AgrodatAI is a spin-off created by two private companies, one specializing in geographic information systems and the other in project design for agricultural chains. They all seem to target small and medium farmers with some internet access. Dr Agro is the only one available for use offline and focusing on technical assistants.

Digital Financial Services

Seven of the eight financial services identified are provided by national private companies, including startups. The other one (Produce Pay) is a US-based startup with a presence in Canada, the United States, Mexico, Colombia, Peru, and Chile.

Supply chain management

Approximately half of the services in this category originated from international sources. Two of them are associated with companies based in the United States, while the third pertains to an initiative developed through international cooperation from the United Kingdom. As for the national services, they are headquartered in various Colombian cities, including Bogotá, Jardin (Antioquia), and Popayán (Cauca). In this instance, it is not explicitly stated that these services are targeted towards small-scale producers, but rather towards producers in general.

3.6 Discussion and Conclusions

This qualitative study explored the configuration of digital agricultural products and services available in Colombia in 2022 and early 2023. The results showed that Colombia has an emergent and varied range of digital products and services for different processes required by producers, such as on-farm activities, market connections, financial services, supply chain management, and digital technical assistance. However, the distribution across these categories is uneven, with a higher prevalence of products and services focused on on-farm activities (65% of the total), followed by marketplaces and e-commerce platforms (17%), financial services (9%), supply chain management initiatives (6%), and, to a lesser extent, technical assistance (3%). Different private and public actors are the providers of these services, including startups and medium and large companies. The use of types of service allows a nuanced view of this configuration, evidencing the different stages of advance and emphasis within them.

Although there is a wide range of products within the category of digitized farm tools, including precision agriculture tools, there is a noticeable dispersion in offerings and a particular emphasis on those producers who are already engaged in production intensification activities or have sufficient production volumes to invest in these tools. Given the expected outcomes of using these technologies (table 2), it can be suggested that if these benefits are realized, such as increased efficiency, reduced labor costs, and improved resource management, they will be concentrated among these types of producers, potentially widening the gap with smaller producers or those with less access to resources. This is coherent with concerns being pointed by Rotz et al., (2019) and Duncan et al., (2021) who warn that these technologies can deepen the gaps between farmers.

An important issue for future research concerning this type of service is the lack of clarity on the policies surrounding the use of localized information by these technologies. The information provided on the websites of these organizations does not clearly demonstrate a stance on how they manage individual farmer data. This issue should be considered in future research since, as Schroeder et al., (2021) mention, "laws addressing the ownership of data from digital agriculture are frequently either missing or inadequate." (p.5). In the case of Colombia, data ownership in the rural sector is still a highly uncertain matter that needs to be further addressed to support and serve small farmers.

Marketplaces and e-commerce platforms coexist in the market linkages category, each presenting different power dynamics. On the one hand, marketplaces promote direct communication between buyers and sellers, yet this mainly benefits farmers with better access to resources and a closer connection to digital activities. The e-commerce model allows organizations to aggregate supply and sell it, preventing producers from managing customer contacts directly; the e-commerce approach seems to better serve producers who are more distant from the market or have fewer resources since the company assumes inventory and payment activities. However, it also highlights the need for better accountability from platforms offering these services to ensure transparency in their marketing processes.

In the financial services category, there was an interest in facilitating access to financial services for small producers. With a few exceptions, most platforms are oriented towards serving small producers, who have less access to credit and financing. Like the previous category, there are issues regarding data management that require further exploration, particularly on how each of these companies manages the data collected from their users and how this data is or is not used to make other decisions regarding access to resources or subsidies. The experience of the National Federation of Coffee Growers shows how a trade organization can develop a digital service to benefit its members by facilitating both the payment for coffee sales and access to public resources. This case is possible due to the leadership and significant role the Federation plays in the country. It is necessary to explore under what conditions other trade associations could also develop a financial service like this in partnership. Based on the information available on the websites of these organizations, it is difficult to determine the geographic coverage of these services. As the sector is primarily driven by startups, it is challenging to establish the continuity of these services over time, which resemble financial innovations aimed at accessing specific communities. Future research should analyze the success or failure of these startups and their business models in achieving national reach with their operations.

Although the mapping of products offering digital advisory indicates just a few services, the review of initiatives promoting digital agriculture shows a significant emphasis on digital extension, driven mainly by the public sector with the national digital extension system and the open information platforms being generated by IDEAM and AGROSAVIA. The existence of the Linkata network reflects that is a critical matter that counts with engaged actors but lacking a strategy combining this large number of actors in the Linkata network with the endeavors looking that digital technical assistance reaches a national scale in a coordinated fashion.

Finally, in supply chain management, the identified platforms are still in a very early stage, and the question remains open as to what types of actors will be able to access these services, which are highly focused on providing traceability and transparency throughout the chain. It is also important to note that several of these platforms were oriented towards coffee and cocoa, two very important crops for the country. On the one hand, coffee is a historically significant crop for the country, in which Colombia is an international reference. On the other hand, cocoa is considered the "crop of peace" and has gained great relevance in the country following the signing of the peace agreement, as many post-conflict initiatives have been dedicated to financing small producers for the establishment of cocoa crops.

Regarding the inequality patterns proposed by Hackford, several comments can be made. First, the first pattern of inequality focused on inequalities in control over technological development, particularly in the predominant role of large agricultural and technology corporations, does not seem to be fulfilled in the Colombian context, given that the actors driving the digital agriculture ecosystem are varied, and there is high participation of startups with a wide network of allies to develop their operations. Second, regarding the unequal distribution of benefits pattern, it is mainly evident in the category of digital tools for the farm, where innovations are primarily aimed at benefiting larger producers or producers better connected to the market. Third, regarding the pattern of Uneven Sovereignty over Data and Hardware, it is an uncertain issue. The country is in a very early stage concerning the management of data generated by producers, and a deeper analysis of current licensing agreements for the use of technologies, mainly focused on digital extension or supply chain management, is required.

Forth, in the pattern of inequality in knowledge and skills, there is a clear lack of skills to navigate the available information. For example, Doctor Agro, developed by Agrosavia, is aimed at agricultural extension workers with a higher technical preparation to navigate the information available on the platform. Finally, in the last pattern on Unequal Problem Definition and Problem-Solving Capacities, there is a prioritization of solutions focused on increasing efficiency and productivity. In the products and services reviewed, no reference was found to alternative approaches such as agroecology or regenerative agriculture. Only in the 5-year initiative driven by CIAT is there a concern for climate-smart practices.

This study faced a relevant limitation. Many of these companies' websites lack specific descriptions of their services, making it difficult to determine if they are active. It is also challenging to determine if the information is up to date; tracking their social media does not always yield recent updates to understand if they are still in operation. While this presented a limitation for this research, it also highlights how this sector operates; startups create a "minimum viable product" which, in the case of advisory & extension and market linkages categories, may be simply a website describing the service offerings. To overcome this challenge, future research must combine other search techniques and information triangulation methods, which may be more time-consuming and costly.

This study shows that Colombia has unique characteristics in its digital agriculture ecosystem and, therefore, should develop a research agenda that addresses them. It shows that, as indicated by some scholars (Klerkx et al., 2019; McCampbell et al., 2022), it is urgent to deeply explore the particularities of each configuration of digital agricultural technologies across developing countries. This understanding is essential to build relevant research agendas that respond to the country-level needs —as has been done in other countries (e.g Bellon-Maurel et al., 2022 in France)— but also to the issues that are more pressing in each country, for example the importance of digital financial services in reaching small-scale producers. These nuanced and critical views can empower stakeholders within each country to lead the type of digitalization that is most needed in the agricultural sector.

Chapter Four: The Promotors Of Digital Agricultural Technologies: What They Say About Its Promises, Perils, And Implications For Small Farmers?

Introduction

Digital agriculture is the application of different types of digital technologies in the agriculture field and across food systems. Known as Agriculture 4.0, e-agriculture, smart farming and Agtech, it conforms a broad sector promising to support global food systems, making them efficient, profitable, and sustainable (Schroeder et al., 2021). The implementation of this wide repertoire of hardware, software, and platforms (e.g sensors, drones, robots, blockchain, cryptocurrencies, internet of things, artificial intelligence, and the subsequent amount of data generated) is intended to change how farmers manage people, processes, animals and land; how producers, middlemen, traders and consumers relate among them; and how decisions on production and commercialization are made (Klerkx et al., 2019; Trendov et al., 2019).

Our understanding of how this emergent sector is evolving is still fragmented and biased to what is happening in developed regions such as the United States, New Zealand, Australia, and Europe (McCampbell et al., 2022; Hackfort, 2021). Understanding how digital agriculture develops in developing countries and what the perspectives of key stakeholders are essential to discern what is common and specific in the development of these technologies worldwide. In sum, these diverse views will reveal the different types and trajectories of digital agriculture.

This qualitative study explores Colombian promoters' perspectives on the dynamic of digital agricultural technologies, their opportunities, complexities, and unforeseen impacts, particularly for small farmers. The questions guiding this exploratory study are i) How do they envision digital agricultural technologies' role in Colombia? ii) How do they understand the complexities and uncertainties of these technologies' deployment in the country? iii) How are they considering the unforeseen impacts of these technologies? Answers to these questions offer insights to inform a conversation on how digital agricultural technologies are being designed, developed, and deployed and the potential trajectories of these technologies in the country. This study aims to contribute to the scholarship on the social implications of digital agriculture; exploring the views of promoters and entrepreneurs in Colombia, a population that has not been studied, offers a window to comprehend what is the situation in the country.

I am using a qualitative inquiry for two reasons. First, this approach directly explores narratives by digital agriculture promoters working in Colombia by identifying their perceptions, assumptions, motivations, and explicit objectives. Considering the lack of information available, semi-structured interviews enable the collection of details on the rationale behind these endeavors and elicit a response concerning the implications of their technologies. Second, this is a unique population within the spectrum of actors promoting and developing these technologies.

This paper continues to present the background and methods. Then I present the findings and discuss how aspects highlighted by the interviewees relate to the literature on narratives on digital agriculture and their expected outcomes.

4.2 Background

Narratives on digital agricultural technologies

The mainstream narrative surrounding digital technologies in agriculture is predominantly optimistic and technical, emphasizing the potential to address the global challenge of feeding the world as the population is projected to increase by 2 billion by 2050 (Lajoie-O'Malley et al., 2020). Digitalization is often portrayed as a solution to address global food shortages, enhancing yields and incomes and reducing detrimental inputs (Mohr & Höhler, 2023; Ancín et al.,2022).

However, this view on digital technologies is not the only one. In an analysis of social media and public websites, Glaros et al., (2023) identified three framings underpinning digital agri-food system transformations, namely Productivity through Precision (PtP), Enhancing Farmers' Rights through Technological Sovereignty (TS), and Traceability through Tech-Enabled Disruption (TTD). These three framings illustrate the different approaches that different actors can have over the same matter.

In the PtP, digital technologies are crucial in improving predictability and control at the farm level, ultimately contributing to higher global yields and sustainable profits for farmers. By leveraging digital data, farmers can refine their decision-making process, which can either complement or replace their intuition for determining optimal practices. This viewpoint underlines the need for individual farmers to embrace digital technologies to maximize yields and profits.

The TS framing highlights the potential challenges digital technologies pose to farmer autonomy while emphasizing the need for these tools to address diverse farmer needs and support agroecological practices. It focuses on the importance of governance structures, open and participatory processes in technology development, and sharing, to ensure equitable benefits distribution. By placing farmers and farming communities at the center of digital agri-food system transformation, this framing foster farmer autonomy, community organization, and legislative change, considering the needs of both individual farmers and farmer collectives.

Finally, the TTD framing aims to enhance supply chain transparency, improve market efficiencies, and meet evolving consumer demands. Industry news outlets and think tanks highlight the system-wide benefits of adopting digital technologies for transforming local and global supply chains. Technologies like blockchain and e-commerce platforms are emphasized in digital agri-food system transformation discussions. These digital solutions refine information delivery across value chains, enabling quick responses to disease and food fraud concerns, optimizing farmers' operations in real-time, and granting consumers access to quality and safe food information.

Implications of digital agricultural technologies

A growing body of literature identifies the expected benefits and aspects requiring further consideration when promoting digital technologies. In Table 7 I summarize these potential benefits and the questions that can support the identification and analysis of problematic aspects.

Table 7. Summary of potential benefits and aspects should be considered

Potential positive implications	Potential aspects to consider
Digital Advisory & Extension	
Improved crop management and productivity	• Who has access (Digital divide, Gender Gap, Data Gap) • Who can take advantage of technology (Gaps in capabilities, motivations, and opportunities) • What are data access challenges (availability, accessibility, usability) • What types of crops and productive systems are being promoted • Who makes decisions on how technology works
Access to expert advice and localized information	
Enhanced pest and disease management	
Better decision-making based on real-time data	
Digitized Farm Tools	
Increased efficiency in farm operations	• Who has access (Digital divide, Gender Gap, Data Gap) • Who can take advantage of technology (Gaps in capabilities, motivations, and opportunities) • What are data access challenges (availability, accessibility, usability) • Who is going to be affected by job losses and labor displacement • Is the offer concentrated in the hands of a few technology providers • What types of crops and productive systems are being promoted
Reduction of labor costs	
Enhanced precision in planting, irrigation, harvesting	
Improved resource management (water, energy, inputs)	
Digital Financial Services	
Access to credit, insurance, and financial products	• Who has access (Digital divide, Gender Gap, Data Gap) • Who can take advantage of technology (Gaps in capabilities, motivations, and opportunities) • Is the offer concentrated in the hands of a few providers • Is the performance of providers assessed by a public organization
Reduced transaction costs	
Better financial management and risk mitigation	
Increased investment in agricultural inputs and technology	
Digital Market Linkages	
Improved access to markets	• Who has access (Digital divide, Gender Gap, Data Gap) • Who can take advantage of technology (Gaps in capabilities, motivations, and opportunities) • Who makes decisions on terms and conditions • What are data sharing challenges (privacy, ownership, monetization, and monopoly) • Concentration of power in the hands of a few technology providers
Better price discovery and transparency	
Enhanced market information and opportunities	
Supply chain management	
Improved traceability and transparency of products	• How responsibilities, benefits and risks are distributed across stakeholders • Who has access (Digital divide, Gender Gap, Data Gap) • What are data access challenges (availability, accessibility, usability) • What are data sharing challenges (privacy, ownership, monetization, and monopoly
Enhanced coordination among stakeholders	
Reduction of post-harvest losses and food waste	
Improved quality control and compliance with standards	

Colombian digital agriculture

Colombia has an emergent ensemble of actors, public and private initiatives, and digital products and services promoting digital agriculture. An exploratory review found 93 products and services currently available (see chapter three). The current offer in Colombia is skewed toward digitized farm tools (65%), including sensors, drones, satellite imagery, and farm management platforms. Other services offering digital products are market linkages —e-commerce and marketplaces— (17%), financial services (9%) providing access to financing, supply chain management (6%), and digital advisory and extension (3%).

Initiatives promoting digital agriculture are diverse. They include the pilot of a public program to deliver digital extension service across the country using WhatsApp, information services on weather forecasts, satellite images, and early warning alerts, the inclusion of technologies as enablers for the rural sector in the National Development Plan proposed for 2022-2026, a 5-year and US$99,9 million project including digital technologies to reduce the vulnerability of agricultural production to climate threats, networks of extensionist workers, entrepreneurs and a regional agrifood tech innovation hub recently launched.

Despite the variety of initiatives and the numerous actors working in this sector, the country still lacks a common vision regarding the future direction of digital agriculture, the challenges it poses for the nation and aspects that must be considered to ensure that digital agriculture benefits the various groups of producers present in Colombia. A common vision would trace a common goal —equity along agrifood systems, environmental sustainability, food security, and climate change adaptation— and encourage collaboration among different stakeholders, enabling a better allocation of resources supporting research, innovation and dissemination of technologies. This exploratory study provides empirical evidence to advance in that direction.

4.3 Methods

This exploratory study examines the narratives of Colombian entrepreneurs and promoters on opportunities, complexities, and unforeseen impacts that digital agricultural technologies pose for small farmers. Specifically, it analyzes i) views on the role technology can play, ii) perceptions on complexities and uncertainties of technology deployment, iii) understandings of unforeseen impacts that technologies can have on small farmers.

I used a qualitative inquiry approach and conducted semi-structured interviews (Creswell & Poth, 2018) to explore perceptions, assumptions, motivations, explicit understandings, and objectives of digital agriculture promoters in Colombia. In this research, an entrepreneur is defined as someone who leads on a full-time basis, a commercial initiative — startup, organization, or project—developing and deploying a specific digital agricultural technology through the rationale of a business model. A promoter is a person or an organization contributing to the expansion of digital technologies by supporting or funding entrepreneurs, offering advocacy, developing knowledge, or unfolding initiatives to increase the use of these technologies in the agricultural sector. Due to the scope of this study, I only interviewed entrepreneurs and promoters with operations in Colombia.

Within the scholarship addressing digital agricultural technologies from a social standpoint, there is an interest in hearing the voices of actors participating in this field. In the North American context, Bronson (2019) conducted 22 unstructured interviews with designers of smart farming technologies to identify the values at the core of their practice; Carolan (2017) and Duncan (2018) conducted in-depth interviews (18 and 33, respectively) with North American farmers and retailers to understand farmers' perspectives on socio-technical changes derived from these technologies. In Europe, Van der Burg et al., (2022) conducted 33 semi-structured interviews with experts on A.I. robots for agri-food on their views on the values, ethical questions, and conflicts perceived. There is an evident absence of views from Latin

American entrepreneurs and promoters. This study contributes to this field by echoing these voices and perceptions.

Data collection

I used two strategies to identify people working in this sector. First, a desktop search looking into reports, news, and related events in Latin America; this process helped me understand the scope, size, and characteristics of this sector and to identify relevant actors. Second, I used a snowball strategy, starting with professional contacts working on projects focused on the development of rural areas. As an outcome of both approaches, I created a list of thirty potential interviewees that were sampled purposefully looking for promoters and entrepreneurs actively working in the sector. Specifically, I aimed to interview entrepreneurs with technologies in pilot phases or already in the market. For promoters, I selected those working actively to expand this sector. I sent direct emails to thirty and have a response from twenty-one.

Considering their leadership and board-level positions within their organizations, these actors can be considered elite interviews (Harvey, 2011). Elite interviewing is “the use of interviews to study those at the ‘top’ of any stratification system” (Jupp, 2006). Schedule these interviews was challenging, because these actors have busy schedules, and they don’t prioritize talking to unknown or previously unfamiliar researchers. I had to be persistent and use my networks to access to this person. Also, I had to find the most appropriate way to get to their inbox and transmit the objectives and relevance of this research. Finally, I spoke with co-founders, managers, and directors, all of whom identified themselves as experts in their respective fields. In some cases, certain interviewees extensively discussed their backgrounds and career paths, which had an impact on the duration of the interview. The interviews typically lasted between 45 and 60 minutes, but when such descriptions arose, the length extended to 90 to 120 minutes.

I conducted twenty-three semi-structured interviews with entrepreneurs and promoters of digital agricultural technologies based in Colombia between March 2021 and March 2023. Table 8 presents a summary of the interviewees. The interviews were in Spanish —the researcher's and interviewees' mother tongue. Two in-person interviews were conducted, and the rest were through virtual channels.

The interview protocol fostered a conversation around five open-ended topics: i) activities developed in the sector; ii) characteristics of technology being unfolded or promoted, iii) opinion on the relevance of digital technologies for agriculture in Latin America, iv) vision of digital technologies' future, vision of unintended consequences, and v) perceptions on ideas posed by responsible innovation frameworks. I included a question on the responsible innovation framework and its four dimensions —anticipation, reflexivity, inclusion and responsiveness— since this has been suggested by some scholars as a way to foresee potential impacts and shape the trajectories of digital agricultural technologies (Rose and Chilvers, 2018; Eastwood et al., 2019; Bronson, 2019). This ample approach has roots in different research traditions, including innovation studies, science, technology and society studies, ethics and governance and regulation studies (Koops, 2015). Responsible innovation can be defined as 'a new approach towards innovation, in which social and ethical aspects are explicitly taken into account (…) and economic, socio-cultural and environmental aspects are balanced' (Blok & Lemmens, 2015: 20).

Data analysis

I transcribed verbatim the recordings of the interviews and coded them inductively and deductively. First, I read each interview and start an open coding, allowing themes and categories to emerge from the data itself. Later, I did deductive coding, using as a lens my sub questions —views on the role technology can play, perceptions of complexities and uncertainties of technology deployment, and understandings of unforeseen impacts that technologies can have on small farmers. I analyzed each transcript and created descriptive labels for each topic. I organized all the themes under the structure of my sub questions.

Positionality

The impetus behind this study stems from my positionality as an engaged researcher, which has shaped the design, analysis, and interpretation of the findings. My academic background encompasses a synthesis of business management and social sciences, while my professional trajectory encompasses entrepreneurial endeavours and consulting engagements with large companies and private social organizations. This amalgamation of theoretical training and practical experience has fostered a pragmatist perspective (Creswell and Poth, 2016) that prioritizes the practical implications of my research. It also has provided me with access to a network of people in leadership positions working in agriculture and in market access for farmers. This network was crucial and opened the possibility to develop elite interviews.

Table 8. Interviewees description

Number	Role	Description of role and organization	City
P1	Director	Rural development leader in a major private NGO focused on rural development	Medellin
P2	Director	Director of an Innovation Hub focused on Agrifoodtech	Medellin
P3	Manager	Manager of the funding operations of the agricultural portfolio for a European Cooperation Program in Colombia	Bogotá
P4	Director	Director of a National Public Program offering digital agricultural extension	Pereira
P5	Senior Researcher	National Public organization focused on research for the agricultural sector	Bogotá
P6	Senior Researcher		
P7	Director	Director of Innovation and Technological Development in the Ministry of Agriculture	Bogotá
P8	Researcher	Researcher that developed a digital technology for the coffee sector	USA
P9	Director	Director of an Agricultural Engineering Program at a private university, with a focus on Agricultura 4.0	Medellin
P10	Founder and CEO	CEO of a coffee company using digital traceability	Medellin
P11	Director	Director of Public Policy at a Center promoting the Fourth Industrial Revolution	Bogotá
P12	Senior Researcher	International Research Center with headquarters in Latin America and working across the Global South. They have a line of work on digital inclusion for farmers	France
P13	Senior Researcher		Cali
E1	Co-founder and leader	Co-founder of an NGO offering digital technologies skills for rural communities	Bogotá
E2	Co-founder and CEO	Co-founder or a small private company developing a blockchain based technology to ensure traceability in the coffee sector	Medellin
E3	Founder and CEO	Founder of a small innovation lab focused on the rural sector	Medellin
E4	Project Leader	Leader of a technology project developing an app for farmers, developed by a major private NGO	Medellin
E5	Manager		
E6	Co-founder and CEO	Co-founder of a private company offering precision agriculture services	Pereira
E7	Founder and CEO	Founder of a private company offering a digital marketplace for farmers	Medellin
E8	Founder	Founder of a private company offering precision agriculture services	Bogotá
E9	Project Manager	Medium-sized social organization developing projects on technology for social change, including rural communities.	Medellin
E10	Project Leader		Medellin

P: Promoter . E: Entrepreneur

4.4 Findings

This qualitative research shed light on Colombian promoters' perceptions of digital agricultural technologies' opportunities, complexities, and unforeseen impacts on small farmers.

4.4.1 Views on the role technology can play.

Simple and sophisticated technologies are included in digital agriculture.

The interviewees shared a view that within digital agriculture there are many technologies varying in complexity. It includes less advanced or sophisticated technologies, such as Whatsapp and messages delivered through cellphones, sensors, drones, and tools to analyze soil health, weather, humidity, cloud computation, augmented reality, artificial intelligence, blockchain, and exponential technologies, among others. Two promoters from an International Research Center offered a structure to analyze these technologies; for them, a salient aspect of these technologies is that are useful for collecting, analyzing and disseminate information. In this sense, all tools supporting these aspects, regarding their degree of complexity can be included. In the collecting phase, there are active and passive ways for data collection. Active ways include the direct collection of farm information through tools such as apps, google forms or ODK forms. Passive ways include data collected by remote and non-remote sensors, capturing different types of farm information. In the phase of analysis, there are also a variety and degrees of sophistication, ranging from descriptive statistics to data analytics, big data, machine learning and artificial intelligence. Finally, in the phase of dissemination, they include all means useful for dissemination, including radio, email, web platforms, applications and text messages.

As summarized by one of these promoters from an International Research Center:

> Original – "Uno puede decir que todas las herramientas con sus distintas variedades de complejidad, que puedan colectar, analizar y diseminar, entrarían dentro de esto, desde lo menos sofisticado hasta lo más sofisticado" . P12
>
> Author translation – "One could say that all tools, with their different varieties of complexity, that can collect, analyze, and disseminate data, would fall under this category, ranging from the least sophisticated to the most sophisticated."

Although some actors focused mainly on on-farm technologies, others stressed that digital technologies could serve many purposes along value chains, beyond the farm.

The main benefits revolve around efficiency and productivity.

Five main themes were common to the interviewees when considering the benefits provided using digital technologies —efficiency, productivity, access to information to support decision-making, monitoring and traceability, and access to markets. Many explained a causal chain linking these benefits with an increase in income. For example, the Manager of the funding operations of the agricultural portfolio for a European Cooperation Program in Colombia, illustrated in this way:

> Original – "Con estos datos que se están dando un productor puede lograr mejorar su rendimiento, abrir mercado y de esta manera mejorar lo que llega a su casa en términos de ingreso" P3
>
> Author translation – "With this data that is being provided, a producer can improve their yield, open up new markets, and in this way, improve what comes to their home in terms of income."

In the case of traceability, it is presented by many as something requested and appreciated by the buyers and final clients, and as an enabler to enter new markets. Examples include coffee growers being able to share the stories behind the product, where and when was harvested, and by whom, which are appreciated by international and specialized customers. Others stressed that traceability also is useful for farmers to overcome information asymmetry. An entrepreneur selling blockchain-based technology to ensure traceability in the coffee sector (E2) indicated that he created this digital service because he realized that "farmers are not connected as an equal stakeholder (...) they are not receiving the same information that big coffee is using". He argues "with our platform, they're connected as equal stakeholders". For another entrepreneur, the founder of a marketplace, access to information is the first crucial step because it enables farmers to establish a direct interaction with actors with whom they would traditionally only have a mediated relationship through intermediaries.

> Original – "Lo primero es que (el productor) encuentre información, que parece muy básico, pero no tienen información. Entonces, al encontrar información, encontrar los proveedores, poderse contactar directamente con ellos, hacer las solicitudes de cotización directamente con los proveedores, pues yo creo que es el primer paso que le genera valor" E7
>
> Author translation –"The first thing is (for the producer) to find information, which seems very basic, but they don't have information. So, by finding information, finding suppliers, being able to contact them directly, and making requests for quotations directly with the suppliers, I think that is the first step that generates value for them".

None of the interviewees offered data or empirical evidence to illustrate how these benefits operate in particular settings, crops, regions, or type of farmers.

4.4.2 Perceptions of the current situation of Digital Agriculture in Colombia

<u>The sector is emerging and lacking coordination</u>

There is a common understanding that the digital agriculture sector in Colombia is emergent. Despite the various initiatives and pilot projects developed by public entities, private companies, international cooperation organizations, and research centers, participants indicate that there is a lack of concerted action or communication among the companies and different actors promoting the sector. Another participant more acutely indicated that “there is no such thing as a digital agriculture ecosystem in Colombia.”

In addition to the lack of coordination among the actors in the digital agriculture system, a lack of communication between public actors focusing on information technologies and those specializing in rural development was mentioned, as they seem to have different conversations but with a great opportunity for convergence.

A senior researcher from a national research center focused on agriculture noted that significant steps are being taken from the research side, as technology development and experiments are being carried out that allow the scientific offering of digital agriculture to be materialized for different sectors. Other promoters highlighted the work that has been done by the public sector to provide open information that is available for others to develop digital products and services, including databases on climate and workspaces for articulation among actors such as the agroclimatic tables; these tables bring together farmers, researchers, extensionists, representatives of government entities, non-governmental organizations, and other relevant actors in the agricultural sector, allowing them to exchange information and knowledge about climate and its influence on agricultural production.

A need for improving technical skills and knowledge about rurality.

There are diverse perspectives on the lack of technical skills or knowledge about rural areas. On the one hand, some promoters highlighted the lack of analytical skills among agricultural engineers and technicians, who are not being trained in universities to perform data analytics using, for example, flexible programming languages like R, Python, or PHP. With this deficiency, their role in supporting the interpretation of data for decision-making becomes very limited. On the other hand, there is a lack of integration between technological and agricultural knowledge. An entrepreneur stated that although there are experts in data science and experts in agriculture, there are no individuals who have knowledge of both topics leading to inadequate analysis of agricultural information. As stated by one entrepreneur,

> Original – "Yo diría que hay un problemita ahí escondidito, y es que mucha gente llegó a agricultura digital, pero nunca estuvo con lo anterior. Entonces, no solo en el manejo, sino en la interpretación de las cosas. Hay mucho mal manejo de la información, terriblemente malo." E8
>
> Author translation – "I would say that there is a little problem hidden there, and it is that many people came to digital agriculture, but they were never involved in the previous practices. So, not only in the management but also in the interpretation of things. There is a lot of mishandling of information, terribly bad."

In the same vein, a promoter pointed out that one of the characteristics of the sector is that many of the technological solutions are being designed by technology development companies in a top-down approach without considering the farmers who will ultimately be the users, their needs, and their conditions of use and access to the technology.

Large associations are crucial but their role is contested

Nearly half of the interviewees highlighted the importance of guilds and how sectors such as coffee, rice, cereal, legumes, sugar cane, and oil palm are in a better position for the development and implementation of digital agriculture technologies. On the one hand, it was noted that these guilds have a higher level of organization, which allows them to develop efforts more cohesively with research centers, cooperation entities, and the public sector. On the other hand, these guilds have large-scale producers who, having large extensions, have the need and vision to use these technologies to optimize their activities in the field.

However, other interviewees do not share such a positive vision of guilds as farmers' associations and federations. Two entrepreneurs noted that farmers organizations like associations and federations are managed politically. In the case of associations, one entrepreneur stated that they are managed by a small number of people, sometimes from the same family, as an exercise of power over resources. In the case of federations, another entrepreneur indicated that they have become marketers of products and inputs but are not bringing technological advances to their members or promoting technological development. Instead, they become an obstacle to the articulation between technological entrepreneurs, technology providers, and farmers.

4.4.3 Perceptions of complexities and uncertainties of technology deployment in rural Colombia

Upon investigating the particularities of the Colombian context that contribute to the complexity of the digital agriculture sector, the interviewees highlighted factors related to both the institutional support structure for the agricultural industry and the infrastructure characteristics, as well as the intrinsic features of the producers themselves.

A weak technical assistance system

Entrepreneurs and promoters concurred that the country possesses a rather frail technical assistance system. It is noted that the existing agricultural technicians are insufficient to meet the farmers' needs, due to the limited number of technicians available, the geographic dispersion of the country's producers, and the characteristics of the access routes to the farms. Others indicate that a problematic issue with technical assistance is its close association with “casas comerciales” —commercial establishments selling agricultural inputs. This relationship creates a situation in which the advice provided by technical assistance is not entirely autonomous but is instead influenced by the sales requirements of these commercial establishments.

Lack of digital infrastructure

All interviewees mentioned the barriers to accessing technology that exists in the country. On one hand, there are challenges in accessing the internet in various parts of the country, which limits the implementation of many of these technologies. On the other hand, this situation compels technology promoters to adjust their products and services so that they function offline or in accordance with connectivity limitations.

Furthermore, there is a discussion about the deficiencies in the ownership of technological devices, such as smartphones. Many of the producers in Colombia only possess low-end mobile phones (commonly referred to as “Teléfonos flecha” —feature phones), which have limited memory and constrain the possibility of interacting with more sophisticated applications that are entirely online or require substantial storage space on the phones.

Lack of education and risk aversion in small farmers

The majority of entrepreneurs pointed out that the educational backgrounds of small-scale producers limit their access to and engagement with technology. First, their low level of schooling was mentioned; most possess the ability to read and write at a very basic level, if at all. Second, the lack of technical education was highlighted, as evidenced by their unfamiliarity with soil fertility conditions and the behavior of pests or diseases, which impacts their productivity. Third, four of the interviewees indicated that the producers have a high aversion to change, and therefore resist trying new technologies. According to one entrepreneur, these characteristics explain why agribusinesses manage to utilize digital technologies while small-scale producers do not.

> Original – "Todo lo que no sea agroindustria es un sector muy atrasado por múltiples factores. Uno, por temas de escolaridad, el hecho de que no sepas escribir y leer, pues no te permite hacer uso de esta tecnología. Dos, porque no hay educación de Buenas Prácticas Agrícolas (BPAs), si tú tampoco sabes BPAS nada haces con estas plataformas. Estas plataformas están diseñadas para que tú, montes BPAs, por lo tanto, sigas ese plan de acción si tú no tienes una educación técnica de cultivo tampoco haces nada. Tres, si no tienes una educación de costos financiera no haces nada; y cuarto, el manejo de tecnologías hoy en día todo el mundo cree que la tecnología es un WhatsApp y la tecnología no es solo un WhatsApp." E8

> Author translation – "Everything that is not agribusiness is a very backward sector due to multiple factors. One, is education issues; the fact that you don't know how to read and write, does not allow you to make use of this technology. Two, there is no education on Good Agricultural Practices (GAPs); and if you don't know GAPs, you won't be able to do anything with these platforms. These platforms are designed for you to implement GAPs, therefore, you must follow a plan of action, and if you don't have technical education on cultivation, you won't be able to do anything. Three, if you don't have financial education on costs, you won't

> be able to do anything; and fourth, the management of technologies nowadays, everyone believes that technology is WhatsApp, and technology is not just WhatsApp."

A combination of problems: low productivity, high costs, generational gaps, middlemen

All interviewees pointed out various interrelated factors that describe the structural problems affecting small-scale farmers, who, on average, own one or two hectares of land. These issues include low productivity, lack of technical knowledge, high input costs, youth migration from rural to urban areas, the absence of an agricultural policy with an agri-food system focus, and intermediaries who dictate the terms of exchange. All these factors interact and amplify each other, leading to significant disparities between various producer groups and considerable complexities and challenges when developing digital products and services. For many of the interviewees, this combination of problems represents the primary obstacle to the development of digital agriculture in the country. As described by the Founder of a small innovation lab focused on rural sector,

> Original – "No hay un proceso de productividad alta, porque se crean sofismas idea de lo que es bueno en la tierra, claro, hay unos conocimientos técnicos, campesinos, indígenas tradicionales, muy positivos, pero también la naturaleza del país, la violencia, desarraigo, los bajos precios, el alto costo de los insumos, la alta intermediación, los altos circuitos, los malos precios de compra hacen que el producto se encarezca que no sea competitivo." E3
>
> Author translation –"There is no process of high productivity, as misconceptions arise concerning what is beneficial for the land. Of course, there are positive traditional technical, peasant, and indigenous knowledge systems, but the country's nature, violence, uprooting, low prices, high input costs, significant intermediation, extensive circuits, and poor purchase prices all contribute to an increase in product costs, rendering them non-competitive."

4.4.3 Understandings of unforeseen impacts that technologies can have

The perspectives on the unanticipated consequences of technology in Colombia were diverse among the interviewees. Three distinct outlooks were identified: technology as neutral, no discernible impacts yet, and the consideration of multifarious implications.

Technology is neutral

A promoter from the public sector highlighted that negative implications arose from the manner in which technology was utilized, as the technology itself was neutral. In their words,

> Original – "Yo diría que las tecnologías todas *per se* son buenas, es el uso que se le dé a esas tecnologías las que pueden causar problemas." E3
>
> Author translation — "I would argue that all technologies, per se, are inherently beneficial; it is the application of these technologies that can potentially lead to problems."

In a related context, albeit from a distinct perspective, a promoter asserted that technology embodies a black box, possessing the potential for both beneficial and detrimental applications.

No impacts yet

Four promoters and one entrepreneur conveyed that they did not discern any unfavorable impacts arising from the utilization of technology. The promoters noted that they might potentially recognize such implications during the implementation of their pilot projects or as these initiatives underwent scaling up.

Multifarious implications

The remaining promoters and entrepreneurs acknowledged one or more facets that could give rise to undesirable consequences. Among these are the monopoly on access to information, issues related to data ownership and privacy, the loss of knowledge on the part of producers, and asymmetry in the capacity for action among different groups of producers.

Monopoly on data or access: Numerous promoters mentioned that the primary concern is the possibility that certain actors could exercise a monopoly on information or access to technology. This concentration of information or supply would result in small producers being unable to reap the benefits, as the prevailing intention would be to "conduct business at the expense of the producers."

Data privacy and ownership: Promoters from the private sector and international cooperation emphasized the importance of data and the current lack of awareness regarding its relevance and potential applications. One promoter pointed out that the rural population does not comprehend the value that information can hold, which is why they still share data on production costs and productivity, without understanding how other actors might exploit this information. The same promoter indicated that certain sectors, such as the flower industry, recognized the importance of data and were thus more cautious when sharing it. Another issue pertains to data ownership: interviewees note that there is no clear consensus on how this ownership should be established or through which mechanisms it should be protected.

Data bias: One researcher identified bias in data representativeness as one of the main issues concerning data. This promoter illustrated that feeding a model with a limited dataset results in a representation bias, causing the recommendations to be unbalanced and skewed by the content of the training dataset used by the application. In this case, reflexivity on the part of developers is required to ensure that this bias is overcome.

Loss of knowledge: Four promoters indicated that they perceived a risk of the loss of ancestral and traditional knowledge that might not be compatible with technified practices. In this regard, the concern is that technology could promote alternative forms of knowledge that displace ancestral knowledge or render certain manual labor unnecessary, thereby resulting in the loss of manual labor techniques.

Asymmetry in the capacity for action among different groups of producers: Interviewees highlighted various aspects that fell within this category. One entrepreneur, the co-founder of an NGO that offers digital technology skills, pointed out that a significant risk is that new players entering the market that provide technological products and services to small producers become new intermediaries and capture more value than they actually offer to small producers. This entrepreneur noted that she observed some individuals charging for the use of technologies that are free, such as Google Maps. This situation is reinforced by small producers' lack of knowledge about technologies and their uses. A promoter leading rural development in a large NGO expressed concern that technological solutions may widen the gaps between those who have access to information and those who do not, consequently increasing market asymmetries and exacerbating exclusion within the supply chains.

4.4.4 How to ensure digital technologies benefit Colombian small farmers

When the respondents were queried regarding the elements that ought to be addressed to enhance the digital agriculture ecosystem in Colombia in such a way that it could benefit small-scale producers, they indicated the following.

Promoting collective action

The associativity among stakeholders was the first aspect mentioned by more than half of the respondents. This associativity encompasses both producers, insofar as improving their associativity increases their collective bargaining power, and the promoters themselves, including trade associations, international cooperation agencies, and research centers, which are currently undertaking efforts independently and have not yet converged on a common work agenda.

Facilitative Public Policy

The participants concur with the importance of a public policy that promotes and supports the sector; however, they are not in favor of developing regulations that would constrain its growth. Instead, they mentioned the significance of fostering a public policy that bridges the gap between supply and demand and provides producers with the necessary infrastructure to utilize digital agriculture technologies.

Promoting Technical Assistance

Four promoters underscored the significance of enhancing the extension team that supports the producers. One of them discussed the importance of returning to the writings of the extension itself, which combined professionals from various disciplines to achieve comprehensive support, mindful of the social, environmental, and productive dimensions that surround the lives of producers.

Boosting business models reaching small farmers

The promotion of business models that primarily aim to include small-scale producers is related to collective action among stakeholders who promote and develop technologies. Currently, technological offerings are mainly geared towards large producers who have the capacity to afford the prevailing prices of digital services and products. Some respondents highlighted the need to develop innovative business models that cater to the requirements and payment capabilities of small-scale producers. One entrepreneur emphasized that small producers should be approached through institutional means, that is, with the support of local governments and regional administrations, to create conditions that enable access for small-scale producers.

Offering services according to the actual needs of small farmers

Another aspect highlighted concerns regarding the use of the digital technology currently available in the country. In this regard, it is not necessary to adopt cutting-edge technologies but to seek the optimal combination of low-cost technologies and offline services that are presently accessible and can benefit the largest number of producers.

4.5 Discussion and conclusions

This study aimed to explore the perspectives of promoters and entrepreneurs in digital agriculture in Colombia regarding their views on the current situation, complexities, and unforeseen aspects that affect the development of the sector. The findings of twenty-three interviews with various stakeholders reveal that the respondents hold a broad vision of digital agriculture, considering a wide range of technologies, from simple ones such as WhatsApp to sophisticated ones such as machine learning, artificial intelligence, and blockchain. There is also a consensus among respondents regarding the primary benefits derived from these technologies, including efficiency, productivity, access to information as support for decision-making, traceability monitoring, and access to markets. The respondents indicated that the digital agriculture sector in Colombia is emerging and still lacks coordination among its actors. This is in line with the studies about digitalization in agriculture in Latin America, that show that Colombia market is growing but still is far from the regional leaders is not the regional leaders — Brazil and Argentina.

Participants reflected on the contextual conditions that drive digital technology advancement in the country, including lack of technical skills, the contradictory role of large producer associations, the lack of digital infrastructure, and various problems affecting the rural sector, such as low productivity, high input costs, generational gaps, and the role of intermediaries. These factors, which mainly affect small producers, suggest that, in this emergent sector, small producers may not receive the best benefits expected from these technologies.

Examining these results considering conceptual discussions on digital agriculture, it was found that the promoters' vision in Colombia is closely related to the predominant and most optimistic narrative of the positive results in efficiency and productivity that can be achieved by producers using these technologies. Reviewing the framing suggested by Glaros et al. (2023), it is found that the visions of Colombian promoters align mainly with the first framework called Productivity through Precision (PtP) and to a lesser extent with Traceability through Tech-Enabled Disruption (TTD), focused on transparency in the chains to increase market efficiency. There was no evident link with the framing focused on Enhancing Farmers' Rights through

Technological Sovereignty (TS). This is relevant because TS framing cares about governance structures, open and participatory processes in technology development, aspects lacking in Colombia, and crucial to promote equitable digitalization.

Regarding the implications of the technology that should be considered, this study finds three different perspectives regarding its impacts. At one extreme, some view technology as being morally and politically neutral. The next group has not yet identified the impacts, which indicates a lack of anticipation and reflexivity, two of the principles of responsible innovation. In the third group, a varied range of factors should be considered when implementing technology. These factors include data monopolies, data access monopolies, data privacy, data ownership, data biases, potential loss of knowledge, and asymmetry in the capacity for action among different groups of producers. It is interesting to note that these factors are all associated with power, as they present unequal relationships based on attributes, status, or position in the social structure. Concern for data or access monopolies indicates the existence of income inequality and actors with the capacity to hoard resources. Concern about the loss of farmers' knowledge is associated with the possibility of imposing research agendas and technological developments that privilege forms of production more typical of larger producers or technified agriculture. These three perspectives demonstrate that digital agriculture promoters do not correspond to a monolithic group; on the contrary, there are diverse nuances and perceptions regarding the role of technology and the factors that must be considered for its promotion. It is crucial to acknowledge these diverse perspectives to facilitate discussions and collaborative efforts towards promoting digital agriculture in the country. Understanding the perception of what technology is and can do is vital for achieving a certain level of accountability in this regard.

The findings of this study show that while there is common and widespread optimism about digital technologies in agriculture, which is shared at an international level, nuances can be observed when reviewing the perceptions of promoters within the same country that respond to the specificities of each territory. For example, in the interviewees' comments, the role of agricultural input vendors is highlighted as a key actor because they are very close to the producer, but at the same time with an accompanying agenda that may be influenced by their sales objectives. In particular, this aspect responds to the characteristics of Colombian agriculture, the high intermediation rates, and the difficulties that producers face in accessing information. In this sense, promoting responsible and inclusive digitalization in Colombia requires a deeper understanding of the unique challenges surrounding the agricultural sector, the views and interests of their actors, and the potential and limitations of the current rural public policy.

Chapter Five: Concluding Remarks

Through this qualitative study, I explored the literature on the social and ethical implications of digital agriculture technologies, as well as the empirical situation of what was happening in Colombia. I chose to conduct my research on this topic because I believe it holds significant conceptual potential in terms of uncovering what these new digital technologies are capable of and understanding the implications and unintended consequences they may have for both agri-food systems and the livelihoods of small-scale farmers worldwide. I also believe it is an urgent matter from a practical standpoint, as it is mobilizing a wide array of actors, both familiar and unfamiliar with the agri-food sector, and is driving various types of public and private actions that will affect the livelihoods of people who dedicate their lives to food production and ecosystem protection.

The literature review presented in chapter two allowed me to develop a framework that acknowledges the non-neutrality of technology, the central role of power, and its manifestation in both the factors that shape access and those involved in the governance of technologies. This applied framework recognizes the importance of understanding the different types of services offered by digital technologies and the various moments associated with their design, access, and governance. This categorization acknowledges the diverse social relationships in which producers are embedded and offers practical utility for analysis and intervention by scholars, practitioners, and other stakeholders interested in promoting digital agriculture that benefits all actors, including the smallest and least resourced.

Applying this framework to the reality of Colombia (chapters three and four), I found a variety of actors, initiatives, and ways of doing things unfolding in this Latin

American country, which warrants the construction of a research agenda focused on the country's characteristics, its equity challenges, and the emergence of the digital agriculture ecosystem. Through conversations with promoters and entrepreneurs of digital agriculture, I identified three current ways of approaching the implications of technology: technology is neutral, no implications have yet been identified, and there are many implications, ranging from the risk of monopoly, privacy and data ownership, algorithmic bias, and asymmetry in the capacity for action among different actors. This finding suggests a need in the literature to understand how different actors construct these visions of social implications and how conversations on accountability, monitoring, and assessment can be fostered among digital agriculture promoters with different visions of its implications and possibilities.

This research analyzed secondary information from digital agriculture promoters and entrepreneurs, as well as data from 23 elite-interviews. One aspect brought to light by this research, conducted through the lens of political economy, is the indispensable consideration of the relationship between structural dynamics that engender inequity and constraints in accessing resources, and the actual capabilities of technologies. Thus, it becomes imperative to challenge the apolitical narrative that posits technology integration as inevitably yielding heightened efficiency, productivity, and profit for all. This narrative merely perpetuates existing structures and reinforces the simplistic notion that technology alone generates changes divorced from material and institutional contexts. Such a view of digitization hampers our ability to perceive that access, in and of itself, is insufficient. It is important, but insufficient. Transforming information access into tangible efficiency or productivity requires paying attention to other factors, such as market access, property rights, land size, production types, extant capital, as well as individual capability and motivation. These days, teeming with misinformation and excessive wide access to superficial information, the critical need to discern information sources and cultivate the capacity to discriminate amidst the deluge of daily information bombardment has become abundantly clear.

We must challenge and reshape this narrative to engender a dialogue about the structural and agency-level conditions requisite for advancing toward a form of digitization that spurs transformation and reaps benefits for historically marginalized communities. This endeavor will enable us to expand our imaginative horizons and foster alternative institutions, incentives, and business models.

Another salient finding arising from this study pertains to the importance of employing a lens of specificity when assessing the offerings of digital agricultural technologies. Not all digital technologies serve identical purposes for all individuals, nor do they possess equal potential for reshaping the status quo within diverse communities. In certain circumstances, when material and relational conditions are favorable, mere access to new information can engender positive transformations. In contrast, the ability to effectively act upon novel information necessitates additional material changes, such as access to credit or access to a better-linked network. This plethora of tangible possibilities underscores the need for comprehensive case studies that enhance our understanding of the potentialities and limitations of technology across varying contextual landscapes.

Based on this exploratory research, I identify two elements that are still missing from our understanding of digital agriculture and merit in-depth exploration. First, a perspective exploring links with the environment. Currently, the conversation on digital agriculture technologies is developing separately from the conversation on digital technologies addressing environmental issues (e.g., deforestation control, fauna and flora inventories). One possible avenue for further investigation is to understand the collaborative spaces and tensions that arise from these technologies, both those more oriented towards productivity and those focused on reducing environmental impact or conducting inventories of environmental features. Secondly, there is a need for research that critically and practically addresses the specific challenges posed by particular digital products and services. The problem-solving sociology perspective can serve as a source of inspiration to advance in this direction.

In a context where investments in digital agriculture are continuously growing, along with interest in its potential outcomes, this research demonstrates that it is urgent to have a better understanding of the particularities of Latin American and African countries. It is important to know the actual and concrete offerings of various digital agriculture services in these countries, as the current literature is insufficient for analyzing the implications these technologies will have in these nations. The concerns that exist in developed countries such as the United States, Canada, and Australia are not the same as those pressing in these countries. Considering the real implications for people's lives that the promotion of digital agriculture services and products may have, it is necessary for applied research to serve better decision-making and understanding of the institutional arrangements, power relations, and resources at stake in each location.

As an applied researcher, I harbor the belief that a remarkable opportunity lies before us to reshape the trajectory of digitization within the realm of agriculture. The present investigation was undertaken with the purpose of offering organized and lucid concepts, as well as evidence, capable of nourishing the ongoing conversation amongst those dedicated to leveraging digitization as a deliberate means of enhancing the livelihoods of rural producers.

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VITA

Jenny Marcela Melo Velasco was born in Bogotá, Colombia (1982) and grew up in Cali, where she finished high school education with an emphasis in gerontology. She graduated from the Universidad del Valle in 2005. In this public university, she obtained a degree in Business Management. Since the beginning of college, Jenny has been interested in understanding how to promote inclusion and fairness using the business sphere of influence. This interest guided her professional path as an applied researcher and practitioner.

Between 2009 and 2011, with the support of a scholarship from the Organization of American States, Jenny studied a Master's in social sciences at the Universidad Nacional de La Plata (Argentina). After returning to Colombia, she worked as an independent researcher and consultant in different places in Latin America, conceptualizing and executing knowledge management processes, combining academic and practitioner perspectives for all-size companies, developmental organizations, NGOs, and small farmers' organizations. In 2018, with the support of a Fulbright-Pasaporte a la Ciencia scholarship, Jenny started a PhD in Rural Sociology at the University of Missouri. She is now specializing in rural settings, particularly in understanding and practically promoting inclusion and fairness for small farmers through market exchanges and the implementation of technology.

Starting in 2021, Jenny co-founded Huella Delta, a social enterprise supporting rural organizations to establish fair and inclusive links with the market while advancing conservation goals. Huella Delta has worked in Colombia, Peru, and Mexico. She is proudly the first generation to obtain a doctoral degree in her whole family, achieving this milestone in 2023.