PRECISION AND DIGITAL AGRICULTURE: ADOPTION OF TECHNOLOGIES AND PERCEPTION OF MAIN STAKEHOLDERS IN BRAZIL

AGRICULTURA DE PRECISÃO E DIGITAL: ADOÇÃO DE TECNOLOGIAS E PERCEPÇÃO DOS PRINCIPAIS STAKEHOLDERS NO BRASIL

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Abstract: Digital agriculture, in a challenging global scenario of population growth and resource scarcity, plays a fundamental role in the quest to eradicate poverty and mitigate climate change. Although a large proportion of Brazilian farmers have adopted digital technologies, challenges such as costs, limited connectivity, and a lack of vision about the benefits persist. The aim of this research was to understand the final criteria adopted to define the selection and usability of digital solutions. This study adopted a field research model with qualitative data collected through interviews to assess the adoption of precision/digital agriculture in Brazil. An online questionnaire via Google Forms was used to collect responses from farmers, service providers, and industry professionals. The data obtained were consolidated in a report and exported for statistical analysis, using absolute frequency and graphs as a basis. The research involved members of the Brazilian Association of Precision and Digital Agriculture, technical companies, distributors, cooperatives, and farmers. Among some results observed, the challenges of digital agriculture in Brazil, such as the need for technical training and the lack of clarity about costs and benefits, were highlighted. These challenges are crucial for guiding future investments in the area. In short, digital agriculture has the potential to improve the efficiency, productivity and sustainability of the Brazilian agricultural sector, making it more vibrant and resilient.
Keywords: Agriculture 4.0, Integrated technologies, Management, Connectivity, Usability

Resumo: A agricultura digital, em um cenário global desafiador de crescimento populacional e escassez de recursos, desempenha um papel fundamental na busca pela erradicação da pobreza e mitigação das mudanças climáticas. Apesar de grande parte dos agricultores brasileiros adotarem tecnologias digitais, desafios como custos, conectividade limitada e falta de visão sobre os benefícios persistem. Objetivou-se nesta pesquisa compreender quais os critérios finais adotados para definição da seleção e usabilidade das soluções digitais. Este estudo adotou um modelo de pesquisa de campo com a coleta de dados qualitativos por meio de entrevistas para avaliar a adoção da agricultura de precisão/digital no Brasil. Foi utilizado um questionário online via Google Forms para coletar respostas de agricultores, prestadores de serviços e profissionais do setor. Os dados obtidos foram consolidados em um relatório e exportados para análise estatística, usando frequência absoluta e gráficos como base. A pesquisa envolveu membros da Associação Brasileira de Agricultura de Precisão e Digital, empresas técnicas, distribuidores, cooperativas e agricultores. Dentre alguns resultados observados, foram destacados os desafios da agricultura digital no Brasil, como a necessidade de capacitação técnica e a falta de clareza sobre os custos e benefícios. Esses desafios são cruciais para orientar futuros investimentos na área. Em resumo, a agricultura digital tem o potencial de melhorar a eficiência, produtividade e sustentabilidade do setor agrícola brasileiro, tornando-o mais vibrante e resiliente
Palavras-chaves: Agricultura 4.0, Tecnologias integradas, Gerenciamento, Conectividade, Usabilidade

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INTRODUCTION

Agribusiness is considered one of the most important sectors of the world economy and has great growth potential to eradicate poverty and hunger and mitigate the effects of climate change. The predicted global scenario is critical: the world population will reach nine billion inhabitants in 2050, increasing the scarcity of land and water resources, per capita income levels and urbanization on the rise and decreasing increases in productivity in some countries (Massruhá, 2016; FAO, 2021).

Therefore, it is necessary to use precision/digital agriculture through integrated and intelligent technologies, which aim to rationalize resources, analyze real data and enable strategic decision-making in the sector, with a total focus on optimizing production.

Digital agriculture comprises and encompasses communication, information and spatial/temporal analysis technologies that allow rural producers to plan, monitor and manage the operational and strategic activities of the production system (Bolfe et al., 2020). Among the existing technologies, they can be grouped into three main categories: 1) data and collection systems, 2) decision support (DS) tools and 3) data-oriented equipment and input adjustments (McFadden et al., 2023).

The first category includes production data and soil monitoring equipment and different sensors and

images from drones, aircraft or satellites. DS tools include (electronic) maps or other georeferenced data visualizations, as well as smartphone applications and other sources of analysis with management and recommendations. The third category includes most guidance systems, automated section control systems and variable rate applicators, in addition to telemetry (Schwalbert et al., 2014; Molin, 2017; Bernardi et al., 2018; Huang et al., 2018; Bolfe et al., 2020; Castro et al., 2022).

Recent research conducted with 750 participants among rural producers, companies and service providers on trends, challenges and opportunities for digital agriculture in Brazil by EMBRAPA, SEBRAE and INPE revealed that 84% of Brazilian farmers already use at least one digital technology as a tool to support agricultural production. However, despite the broad potential for expansion and adoption in Brazil, approximately 67% of farmers are afraid of the amount to be invested. In addition, less than half use tools for buying and selling. Another major obstacle to the use of digital solutions is the lack of connectivity in the field, with more than 60% confirming this challenge (Agriculture, 2020).

Initiatives covering digital agriculture in the coming years are expected to generate approximately US$21 billion in business in the areas of Research, Development and Innovation (RD&I) in Brazil, according to estimates by the National Bank for Economic and Social Development (BNDES). A direct reflection of investment is noted in the number of startups present in agriculture, which jumped from 1,125 in 2019 to 1,703 in 2022 (Camargo, 2019; Figueiredo et al., 2022).

Despite the widespread use and growth of investment in digital agriculture, there is another limiting factor that influences access to information through technology: the final stakeholder, who may be a farmer, manager or technical sales or service manager, who requires access in a simple, agile and efficient manner (Oliveira et al., 2022). Studies state that it is necessary to adapt and improve the quality of the usability of interfaces, mainly by targeting tablets and smartphones, where the public has been growing and becoming heterogeneous (Magalhães and Romani, 2016).

Systems as a whole become complex and require alternatives that allow a satisfactory experience for users, as well as the benefits of monitoring and data processing for decision-making and autonomy in the agricultural domain in the palm of your hand (Schimiguel et al., 2004).

Today's computing solutions have interfaces with many types of data, different platforms (desktop, smartphone, and browser) and users with different levels of education. There are also different agricultural crops and different focuses (such as cultivar catalogs; pest, disease and weed identification manuals; information on climate and soil; and grain price quotes, inputs and freight), with a large amount of data to process, from different sensors, satellite images, and radars and from the users themselves. In the end, what we have is an excessive volume of information, poorly interpreted and without any practical use aimed at reducing costs or increasing productivity (Schimiguel et al., 2004; Oliveira et al., 2022).

The future of decision support systems in digital agriculture lies in researchers' ability to better understand usability challenges, including their applications in planning, management, climate change adaptation, and food waste control. Studies differ in various thematic groups of social sciences, such as stakeholder profiles, stakeholder skills, and agricultural labor; decision-making power; farm size; and data privacy and ethics (Massruhá, 2016; Magalhães and Romani, 2016).

Thus, the great challenge for organizations becomes finding the real profile of the stakeholder and identifying the practical obstacles to acquiring and using digital solutions. The aim is to extract the best strategy from the companies' point of view and the real importance of the tools and data sets at each stage, which are useful from the perspective of the stakeholders who act in the end customer service processes or as decision makers. Thus,

unnecessary and inefficient investments or even unused resources should be avoided. Thus, the objective of this research was to understand the final criteria adopted to define the selection and usability of digital solutions, seeking to answer the following questions: from the stakeholders' perspective, which digital tools and data sets are actually used, relevant and decisive at each stage of the production/sales process, in addition to their real value in terms of importance to the business.

Materials and methods

This work was developed on the basis of aspects applied in the evaluation of the adoption and future perspectives of precision/digital agriculture in Brazil. The model developed by Borghi et al. (2016) was used to evaluate the adoption of precision agriculture from the perspective of farmers and service providers.

On the basis of the bibliographical references and the practical experience of the project team in the Brazilian context, specific questions were established, addressing aspects with the possibility of multiple-choice answers about precision agriculture and digital agriculture technologies used in different application complexities, including in different sectors of agriculture and stakeholder profiles, in addition to the perceptions of benefits, challenges and future expectations of agriculture. The collection instrument used can be found in Appendix I.

Survey-type field survey. For Selltiz et al. (1987), descriptive research aims to understand a phenomenon without the intention of changing it to broaden the understanding of the object of interest in a specific period. The survey-type field survey evaluates a sample of a population through individual data collection, usually via questionnaires (Forza, 2002). For this work, an online interview tool called Google Forms, which has remained available for completion for four months since June 2023, was used.

The primary data obtained for each question (single choice, multiple choice) and their respective complete answers are consolidated in a report and later exported in csv and included in a spreadsheet. The aim is to generate statistics on the basis of absolute frequency data and graphs representing the relative frequency represented by the percentages of each of the variables associated with the research questions.

The survey was web-based and accessed via a link to be answered by technical professionals and support providers. The sampling frame used to select respondents was derived from lists of individuals from AsBraAP (Brazilian Association of Precision and Digital Agriculture) and stakeholders, technical representatives of companies, distributors, cooperatives, managers and farmers. Similar approaches to sampling respondents were used by Borghi et al. (2016) and Dieckman and Batte (2010). Each group was sent an email or a WhatsApp message explaining the objectives of the survey and the respective link to the web survey. On the basis of data previously published by other researchers involving surveys via mail or the web, approximately one-third of the invited participants provided feedback (Larson et al., 2008).

Preliminary Results

The survey covered the entire country, with a total of 107 questionnaires answered in full. Of these, 64 (59.8%) were from Central-West China, 11 (10.3%) were from Southeast China, 7 (6.5%) were from South China, 10 (9.3%) were from North China, and 4 (3.7%) were from Northeast China. Thus, 89.6% of the total sample was from people who work in Brazil or abroad.

Among the regions of Brazil, Central-West China and Southeast China stood out as those with the largest number of respondents in the survey, accounting for 70.1% of the interviewees. These regions are widely recognized for being home to highly productive agricultural areas and are considered pillars of the agricultural sector in the country. According to available data, both the Central-West Region and Southeast Region significantly contribute to the gross value of agricultural production in Brazil, with states such as Mato Grosso, Goiás, São Paulo, and Minas

Gerais being among the main producers (Luz and Fochezatto, 2022).

Among those who participated in the survey, 85.9% were involved in some way in the agricultural production chain; more specifically, they had direct contact with the field. In addition, the remaining 14.1% work in related activities, such as expertise, consultancy (administration, logistics, etc.), and students or teachers (Figure I).

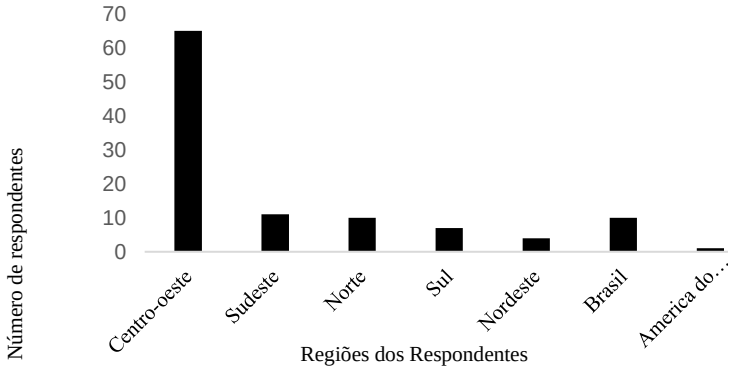


Figure I. Percentage distribution of research identification and profile by region of Brazil. Source: Original research results.

When interpreting the results presented, it is important to keep in mind that they are associated with a sample survey, which implies the representation of only a portion of Brazilian farmers. As highlighted by Massruhá (2016), when analyzing the profile of farmers, it is essential to consider the diversity that exists in the sector, including regional and socioeconomic differences.

With respect to the age range of the participants, the majority, 61.7%, reported being between 26 and 35 years old, as reported by Pivoto et al. (2019) in their research on factors that influence the adoption of smart agriculture by Brazilian grain producers. These results are followed by 23.4% in the 36--45 age range and 9.3% in the 46--55 age range, demonstrating low adherence of audiences under 18 and over 55 years old (Figure IIa).

This age difference apparently has no relation to the length of time each professional in the responding sector has been working. Approximately 71.4% of the participants had been involved in agriculture for between 3 and 15 years, whereas 17.1% had more than 15 years of experience, as described by Bolfe (2020) in his research on farmers and profiles in Brazil (Figure IIb).

Among those who participated in the survey, different agricultural activities were reported, where 85.7% work in grain cultivation, 30.5% with fibers, 30.5% with sugarcane and 12.4% with coffee. In addition, the others involved work in activities such as growing vegetables and legumes, pastures and forages, among others (Figure IIc).

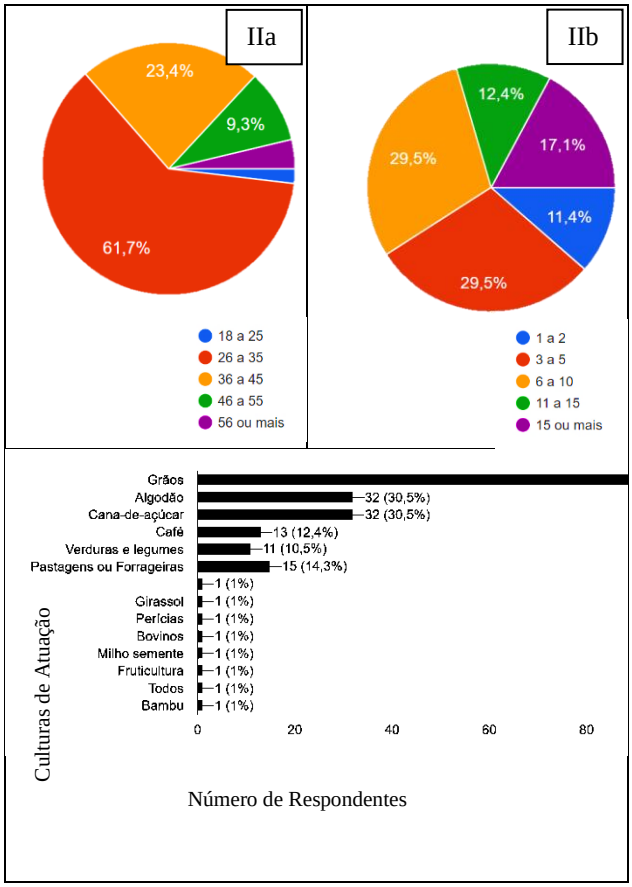


Figure II. Distribution of percentage of participants' age range (a), years of professional experience (b), and profile of performance by focus culture (c). Source: Original research results.

The results refer specifically to the sample of respondents to the topic worked on and cannot be generalized to all profiles and regions, as the heterogeneity

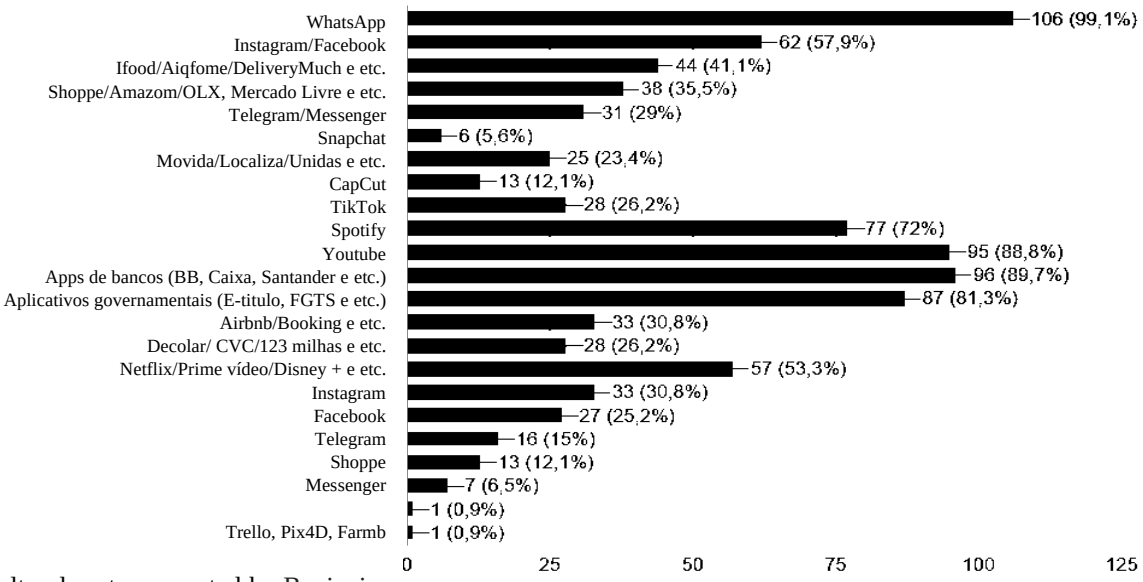


Figure III. Distribution of the percentages of different tools used daily by agricultural professionals (producers, technicians, managers, RTVs, etc.). Source: Original research results

of the agricultural sector, as noted by Buainain et al. (2014), must be considered when validating the results.

The survey results revealed that 88.6% of the interviewees had more than 3 years of experience in the activity, as observed by Carvalho and Godinho (2010) in a study on the profile of rural producers in Brazil. These data indicate that significant knowledge has accumulated over the years and that people with experience in the agricultural sector have participated (Figure IIb). Therefore, the results highlight the importance of the experience of the rural producers and employees in the sector interviewed, providing a solid base of knowledge and expertise to face the challenges of digital agriculture.

An analysis of the use of digital solutions by rural producers revealed that 84.8% of respondents actively use these technologies in their activities. These results are in line with the growing trend of adopting digital tools in the agricultural sector, confirming the relevance and practicality of devices such as smartphones, tablets and computers (Michels et al., 2019; Michels et al., 2020).

Among the digital solutions most used by rural producers, WhatsApp stands out, being used by 99.1% of respondents, as evidenced by Godoy et al. (2022) in their research on the use of communication technologies in rural areas. In addition, 89.7% of producers use banking-related applications, whereas 81.3% use solutions provided by government agencies. Other commonly used digital solutions are aimed at social media, commerce, and other purposes, opening a wide opportunity for the insertion of digital methods in the agricultural sector (Figure III).

These figures reveal great potential for adapting different services in the agricultural sector to digital platforms already used in agriculture. For example, technical assistance, input marketing, teaching of agronomic management techniques and crop diagnosis can be integrated and made available through these digital

platforms, as noted by Saiz -Rubio and Rovira-Más (2020) in their study on precision agriculture.

This digitalization trend in the agricultural sector represents an opportunity to optimize processes, improve efficiency and increase productivity, benefiting both producers and the production chain.

Digital agriculture has been driven by a number of innovative technologies that are transforming the agricultural sector. Recent studies by Silva et al. (2011), Godovskaya, M.A. and Medynskyi. (2010); Thompson et al., (2019); Saiz -Rubio and Rovira-Más (2020) highlight some of the main technologies used. Among them, we observed in this study that variable rate application was mentioned by 63.4% of the survey participants, followed by the use of drones for mapping, with 72.3%. In addition to remote sensing through satellites, which was mentioned by 46.5% of the respondents, it was also possible to note the use of e-commerce or Marketplace, with 37.6%. Other technologies mentioned include lidar and probes, telemetry and automation for the control of agricultural machinery, Internet of Things (IoT), embedded sensors such as lasers or light bars, flow application technologies and the use of GPS for guidance and monitoring of agricultural activities (Figure IV).

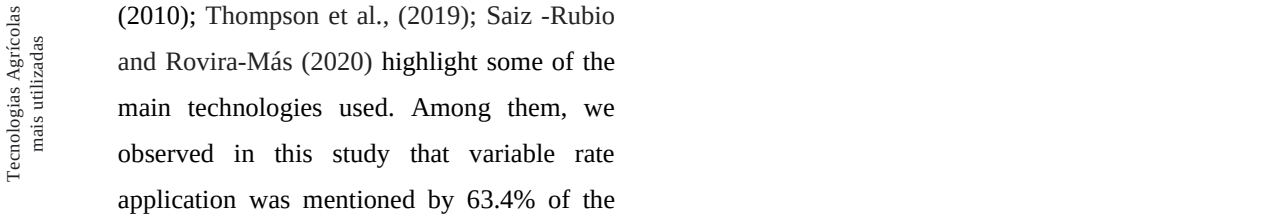
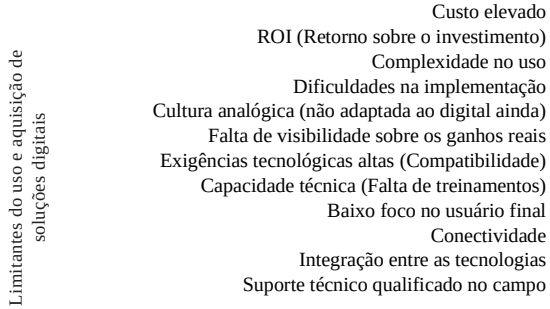


Figure IV. Distribution of percentages of digital agriculture technologies already used. Source: Original research results.

Another crucial point highlighted in similar analyses is the perception of 58.5% of respondents that current technical capacity and lack of training are the main obstacles to the adoption and integration of digital solutions for property (Silva et al., 2011; Borghi et al., 2016). These data reveal the need to offer adequate technical support and training to farmers to facilitate the use of digital technologies in the management of agricultural activities. In addition, the lack of visibility of real gains (48.1%) combined with the high cost of technological solutions (40.6%) limits the adoption process, in the view of respondents, since market fluctuations, adverse weather conditions and low knowledge of the subject significantly increase caution in making decisions about investment and need (Barbosa et al., 2019; Ferreira et al., 2022) (Figure V).



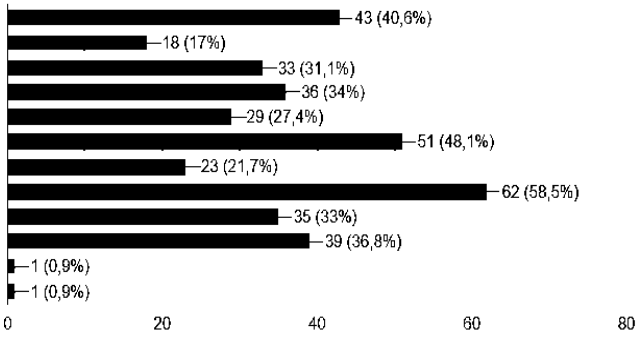


Figure V. Percentage distribution of the main limitations on the use and acquisition of digital solutions. Source: Original research results.

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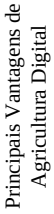


Figure VI. Distribution of the percentages of the main advantages provided by the use of digital agriculture technologies. Source: Original research results

Notably, the use of digital agriculture technologies can offer a series of significant advantages for agronomists, sales representatives and farmers in general. According to studies carried out by Martha Júnior (2020), some of the main advantages include greater efficiency in the application of agricultural inputs and enabling variable rate application on the basis of the specific needs of each area, resulting in resource savings and reduced environmental impact.

Furthermore, the use of drones for mapping and monitoring agricultural areas has proven to be a valuable tool to assist in the early diagnosis of diseases, pests and water stresses, providing preventive action and greater precision in management (Massruhá, 2016; Saiz -Rubio and Rovira-Más, 2020; Castro et al., 2022).

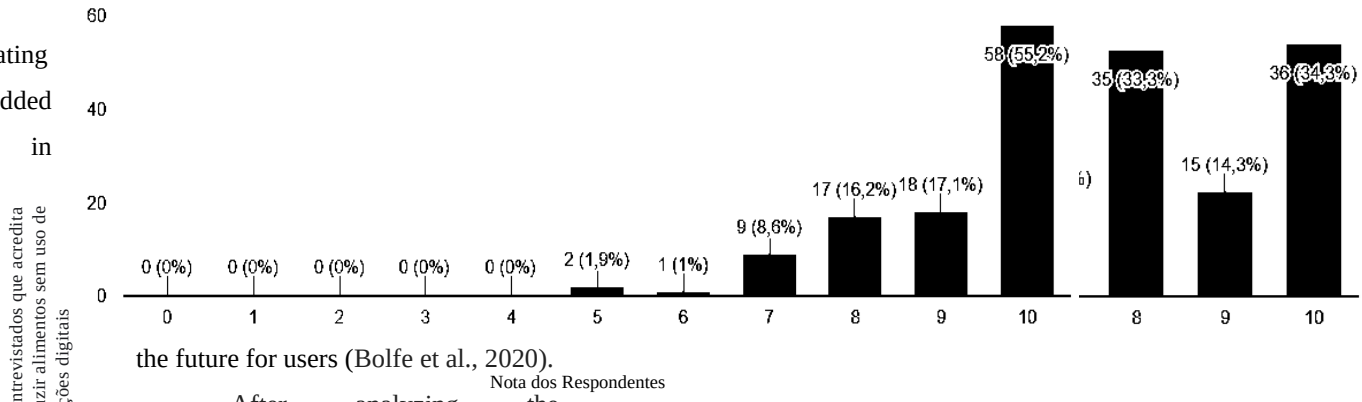
In short, digital agriculture technologies represent an important evolution for the agricultural sector, offering benefits such as greater efficiency, precision in management, reduced costs and environmental impacts, in addition to facilitating market access and improving control of agricultural operations (Bernardi et al., 2028; Thompson et al., 2019). These advantages directly impact the work of agronomists, sales representatives and farmers, promoting more sustainable, efficient and profitable agriculture.

This behavior can be observed in the questionnaire responses, where 27.1% placed the increase in productivity as the main advantage in using digital solutions, followed by savings on inputs with 26.2% and improved management with 18.7% (Figure VI).

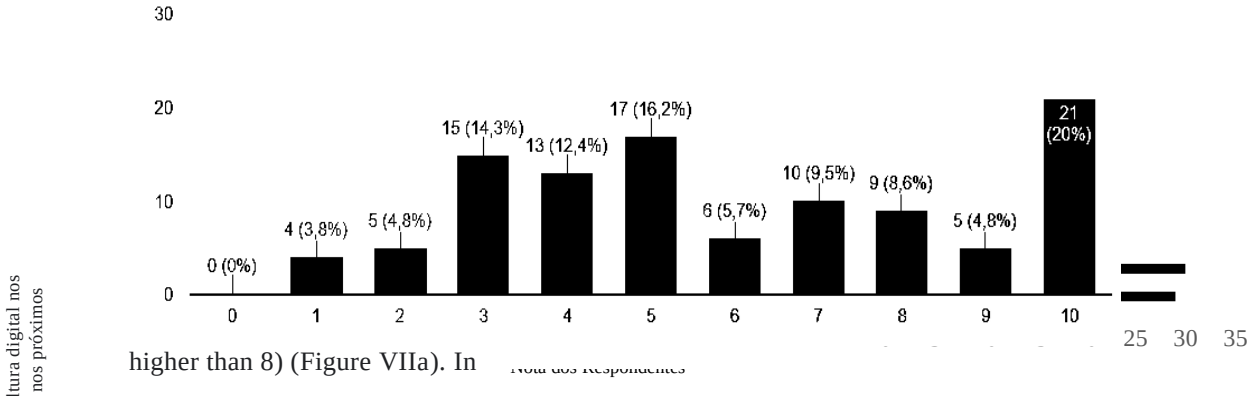
This proportion of responses about gains and advantages is in line with the distribution of results when the suggested question addressed the level of knowledge in digital agriculture on a scale of 0--10 (0 being nothing and 10 being a lot), and most of the interviewees scored above 5. Only 21.1% of the scores were below 5. In addition, 78.9% reinforce the recommendation on the use of digital solutions in agriculture.

Given the lack of knowledge among participants on the subject, studies indicate that tools such as geographic information systems, remote sensing, applications and online platforms benefit agricultural planning, efficient communication between farmers and buyers, supply chain management and real-time monitoring through sensors and IoT devices. These technologies have a positive impact on property management, productivity and strategic decision-making,

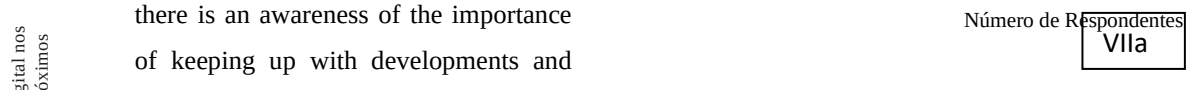
thus generating high added value in the future for users (Bolfe et al., 2020).



After analyzing the recommendation of using digital solutions in agriculture on a scale ranging from 0--10 (0 being none and 10 being very much), 81.9% of the respondents believed in the direct impact of digital agriculture on their businesses in the next 5 years (a score higher than 8) (Figure VIIa). In addition, 88.5% in the next



However, when participants were asked about the possibility of producing food without the use of digital solutions, a reduction in the score given was observed (Figure VIIc). This finding indicates that although digital agriculture is not yet fully necessary in the current scenario, there is an awareness of the importance of keeping up with developments and overcoming obstacles related to digitalization. However, its low dependence on food production does not yet make it an indispensable tool in the current scenario, such as seeds, chemicals, fertilizers, etc.



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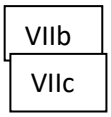

Figure VII. Scale distribution of the impact of digital agriculture on business in the next 5 years (a); scale distribution of the impact of digital agriculture on business in the next 10 years (b); scale distribution of respondents' perceptions of whether it is possible to produce food (grains, etc.) without using digital solutions (c). Source: Original survey results.

CONCLUSION

Considering the diversity of the agricultural sector and the regional representation of respondents, the results of this survey suggest a growing interest in and recognition of digital agriculture in Brazil. The sample collected demonstrated that the adoption of digital solutions is already underway, mainly in the Central-West and Southeast Regions, and that the age range of those involved varies considerably.

The data reveal a positive trend in the use of digital technologies, with WhatsApp standing out as a communication tool widely adopted by farmers. In addition, the research indicates that there is potential for the expansion of digitalization in several areas of agriculture, including technical assistance, agronomic management and trade, taking advantage of the digital platforms already in use.

However, there are also challenges that need to be overcome, such as the need for technical training and the lack of visibility of the real benefits and costs associated with the adoption of digital technologies. Raising awareness of these challenges is crucial for guiding future developments and investments in digital agriculture.

In summary, this study reinforces the growing relevance of digital agriculture in the Brazilian context, offering a promising vision of the advantages that this technological transformation can bring to the agricultural sector.

As farmers and industry professionals adopt and adapt to these solutions, digital agriculture has the potential to significantly improve the efficiency, productivity, and sustainability of agricultural operations in Brazil, thus contributing to a more dynamic and resilient sector. Additional studies are needed to understand this issue in other regions of Brazil in greater depth.

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