DIGITAL AGRICULTURE IN DAIRY FARMING: CONNECTIVITY DIAGNOSIS AND BARRIERS TO TECHNOLOGY ADOPTION IN AN AGROTECHNOLOGICAL DISTRICT

Mateus da Mata Melo[1], Caroline Mendonça Nogueira Paiva[1], Athila Leandro de Oliveira[1], Fernanda Nunes Maciel[1], Gabriel Costa Siqueira[2], Maria Fernanda Rodrigues Borges[1], Gabriela Sabrina Rezende Furtado[1], Paulo Henrique Montagnana Vicente Leme[1].

[1] Federal University of Lavras (UFLA), Brazil.

[2] Embrapa Digital Agriculture – CNPTIA, Brazil.

A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

Abstract.

The integration of digital tools and communication systems has underpinned a profound transformation in global production chains, aiming to optimize farm operations through technological innovation. Within this context, the present study forms part of the Semear Digital project, coordinated by Embrapa, and is grounded in the premise that digital inclusion constitutes an indispensable strategy for the sustainability and competitiveness of contemporary dairy farming. The primary objective was to diagnose connectivity conditions and analyze the factors that drive or constrain technology adoption among farms located in the Agrotechnological District (DAT) of Ingaí (Minas Gerais). This research is justified by the urgent need to overcome the gap between the potential benefits of digital technologies—such as improved herd management and the transformation of data into strategic decision-making—and the persistent barriers faced in rural areas, including inadequate infrastructure and low levels of digital literacy. The study aims to provide evidence-based guidance for productive strategies that integrate digital technologies in order to enhance the competitiveness of small- and medium-scale producers and improve the quality of life of rural households. The study adopted an exploratory and descriptive design, employing a mixed-methods (quantitative–qualitative) approach. Twenty-nine small- and medium-scale dairy farmers were interviewed using a semi-structured questionnaire comprising 114 questions, complemented by direct on-farm observation. A multidisciplinary research team brought together specialists from diverse fields to incorporate multiple perspectives on the production process. The findings indicate a predominantly family-based and intergenerational activity profile, with all respondents identifying as male farm managers (100%). Most participants were over 50 years of age (65.5%) and had completed only primary or secondary education (79.3%). Regarding drivers of digital technology adoption, producers identified the pursuit of greater efficiency and improved quality of life as key motivations. Most already use mobile connectivity for financial management, marketing, and personal communication, with WhatsApp serving as the main technological gateway and technical assistance acting as a catalyst for the development of a measurement-oriented management culture. The use of WhatsApp for

commercialization, technical support, and financial management is characterized in this study as a form of "informal digitalization". Conversely, the main barriers to technology adoption include the high investment costs relative to the limited scale of production, chronic instability of the electricity supply, restricted internet coverage—often limited to the farmhouse—and discouragement stemming from the lack of interested successors to continue the family business. The study concludes that introducing advanced technologies would be premature without first "getting the basics right". Many farms continue to operate with manual tools and exhibit significant deficiencies in management, hygiene, and herd practices, including the absence of systematic record-keeping and a high incidence of mastitis. Therefore, a successful digital transition depends on prior process standardization and improvement, along with strengthened technical assistance services to foster digital literacy and data-driven management. The findings further suggest that digital transformation in the dairy sector requires adequate rural credit and infrastructure, targeted technical training in digital skills, and the modernization of the sector's public image to attract and retain younger generations in rural areas.

Keywords.
Dairy farming, Digital agriculture, Rural connectivity, Digital inclusion.

1. Introduction

The rise of Digital Agriculture has promoted transformations in agricultural chains, based on the integration of information and communication technologies to optimize production processes (Bolfe et al., 2020; Deichmann et al., 2016). In the context of dairy farming, the adoption of digital technologies, ranging from management software and monitoring applications to precision sensors and automation, presents itself as an indispensable strategy to increase operational efficiency, ensure economic sustainability, and meet the growing requirements of animal welfare and product quality (Kozina & Semkiv, 2020; Sangode, 2025).

It is observed that the digitization process in the field does not occur uniformly. The adoption of these innovations is permeated by a duality between benefits, such as the reduction of physical effort, the optimization of management time and the transformation of informal records into strategic data for decision-making, and adoption barriers. Among the barriers, the precariousness of connectivity and energy infrastructure in remote areas stands out to the high cost of acquisition and the need for digital literacy to operate complex systems (Drewry et al., 2019; Groher et al., 2020; Hassoun, 2023; Kaushik, 2024; Leddin et al., 2023; Malik, 2024; Neethirajan, 2023).

Inserted in this transition scenario, the present work is an integral part of the Semear Digital project, an initiative coordinated by Brazilian Agricultural Research Corporation (Embrapa) that aims to foster technological innovation and digital inclusion in the Brazilian rural environment. One of the pillars of the project is the development of Agrotechnological Districts (DATs), which function as hubs for experimentation and validation of technological solutions in real contexts. Within the scope of this initiative, the municipality of Ingaí (MG) was selected as one of these DATs, with a strategic focus specifically directed to milk production, an activity of paramount socioeconomic importance for the region.

The objective of this study was to diagnose connectivity conditions and analyze the factors that drive or constrain technology adoption among farms located in the Agrotechnological District (DAT) of Ingaí (Minas Gerais). By diagnosing the sociodemographic profile, infrastructure conditions and producers' perception of technology, this work seeks to provide subsidies for the creation of strategies that overcome structural barriers, promoting a digital transition that results in greater competitiveness and, above all, in the improvement of the quality of life of rural families.

2. Methodology

The research adopted an exploratory and descriptive character, with a quantitative-qualitative approach, in order to broadly understand the potentialities and challenges of the use

of technologies in rural properties. The team of researchers involved in the study was composed of administrators, veterinarians, zootechnicians and a forest engineer, allowing the integration of different critical views on the production process and enriching the analyses.

The selection of participants was carried out by random sampling in communities located in different regions of the municipality of Ingaí, ensuring geographical, socioeconomic and productive diversity among the respondents. One of the researchers worked as a veterinarian in the region and knew many producers in the region, which made it easier to identify possible participants. In all, 29 family and small and medium-scale rural producers were interviewed. All the producers interviewed work with milk production.

The data collection stage took place directly on the properties, with visits conducted between 9 a.m and 14 p.m. This period was chosen to respect the traditional milking times, which usually occur in the early morning and late afternoon. The interviews lasted an average of two and a half hours and were complemented with non-participant observation in management areas, especially the corral and adjacent facilities.

The data collection instrument consisted of a semi-structured script, based on a questionnaire with 114 open and closed questions. The content addressed questions about the socioeconomic profile of producers, characteristics of the property, production dynamics, level of digital literacy, connectivity infrastructure and perceptions about benefits, limitations and conditioning factors of technological adoption. This methodological structure allowed the capture of objective data on the productive context and perceptions of producers about their daily lives and the relationship with technologies in rural areas.

The data obtained through the questionnaire and observation were quantitatively analyzed through descriptive statistics using Microsoft Excel spreadsheets. The interpretation of qualitative information followed the approach of thematic content analysis, which enabled the mapping of trends, challenges and recurring perceptions in the reports of milk producers. To organize this material, word processing software and electronic spreadsheets (Word and Excel) were used. Finally, the data were structured into analytical categories and grouped according to the convergences identified in their productive realities.

3. Results

3.1. Description of the producer and production

Dairy farming in the region is predominantly family and generational, with producers who inherited the activity from their parents and grandparents, who make them use and persist in more traditional and less technical production techniques. The profile of the milk producers interviewed in Ingaí is characterized mainly by older producers with different levels of education, but predominantly from basic to technical level. All the producers interviewed were male. Among the properties visited, none had a woman as the main representative of the property, also indicating a gender issue already rooted in the practices of rural activities, culturally and historically marked by male predominance.

The sample is mostly composed of older producers, which reinforces the traditional and generational character of the activity, as 19 interviewees (65.5%) are over 50 years old. Producers between 18 and 39 years old add up to only five producers (17.2%), evidencing the challenges of rural succession mentioned in individual reports of producers. Regarding rural family succession, some producers have children, but their children do not show interest in continuing their parents' activities. The preferences of young people indicate the search for study and work in other areas or cities.

The educational level is quite fragmented, with a base of fundamental and technical training, in addition to a minority with high academic specialization. Among the producers, 21 (72.4%) have, at most, completed high school or technical education. The different levels of

education directly reflect on the way the property is managed: while producers with higher levels of education were more open to using computerized controls, those with more basic education usually manage them manually or store information in their memory, without taking physical notes or formal control.

Table 1 below presents an overview of the profile and productivity of the 29 producers interviewed.

Table 1. Profile of the producers interviewed

ID	Age	Education Level	Total Area (ha)	Herd Size (head)	Milking Cows	Production (L/day)	Internet Access	Mobile Phone Signal
1	50–59	Completed Higher Education	27	16	5	65	Good quality (entire property)	Good and stable
2	30–39	Completed Secondary/Technical Education	18	20	15	250	Good quality (entire property)	Good and stable
3	40–49	Completed Secondary/Technical Education	23	30	21	220	Only at the farm headquarters	No coverage
4	40–49	Completed Primary Education	18*	50	35	470	Only at the farm headquarters	Partial / Unstable
5	40–49	Completed Secondary/Technical Education	60	15	12	110	Limited coverage	Partial / Unstable
6	60–69	Completed Primary Education	31	19	14	250	Only at the farm headquarters	Very weak/Nonexistent
7	50–59	Completed Primary Education	23.3	24	17	270	Limited coverage	No coverage
8	50–59	Incomplete Primary Education	55	30	18	180	Only at the farm headquarters	Very weak/Nonexistent
9	60–69	Completed Primary Education	12.4	27	24	300	Limited coverage	Partial / Unstable
10	50–59	Completed Secondary/Technical Education	28	65	24	370	Limited coverage	Good and stable
11	30–39	Completed Primary Education	25	40	30	500	Limited coverage	Fair
12	18–29	Completed Secondary/Technical Education	36	30	18	250	Limited coverage	Fair
13	50–59	Incomplete Primary Education	24	110	25	150	Limited coverage	Partial / Unstable
14	18–29	Incomplete Secondary/Technical Education	63	60	18	400	Only at the farm headquarters	Partial / Unstable
15	60–69	Completed Higher Education	12	8	6	70	Limited coverage	Fair
16	50–59	Completed Primary Education	12	20	13	170	No access	Good and stable
17	60–69	Completed Graduate Degree	28	52	42	650	Limited coverage	Good and stable
18	60–69	Completed Higher Education	100	65	52	1100	Good quality (entire property)	Fair

19	50–59	Completed Higher Education	80	50	27	450	Limited coverage	Good and stable
20	40–49	Completed Primary Education	40	90	45	1350	Good quality (entire property)	Good and stable
21	60–69	Completed Graduate Degree	7	26	18	NI*	Only at the farm headquarters	Fair
22	60–69	Completed Secondary/Technical Education	24	24	11	190	Good quality (entire property)	Good and stable
23	60–69	Incomplete Primary Education	3	18	11	100	Limited coverage	Good and stable
24	40–49	Incomplete Primary Education	21	30	14	100	Good quality (entire property)	Good and stable
25	60–69	Incomplete Primary Education	5	50	15	300	Good quality (entire property)	Good and stable
26	18–29	Completed Secondary/Technical Education	30	50	30	500	Good quality (entire property)	Very weak/Nonexistent
27	50–59	Incomplete Higher Education	91	45	22	250	Limited coverage	Good and stable
28	50–59	Incomplete Primary Education	8	30	40	150	Limited coverage	Fair
29	50–59	Incomplete Primary Education	52	40	20	300	Only at the farm headquarters	Very weak/Nonexistent

Source: survey data (2026).

Note: NI = Not informed

Most producers (n=28; 96%) have internet on their rural properties, but access is often restricted to the property's headquarters or has coverage limitations. They report difficulty in accessing corrals and pastures. Only eight (27%) of respondents report good quality internet throughout the production area. The telephone signal is another significant bottleneck for some producers, who report a non-existent, very weak or unstable signal. These connection issues make it difficult to use technologies in the field, such as cloud-based ones.

The properties visited are accessed, in part, by dirt roads. Although most classify them as good quality, producers report poor quality roads, especially in the rainy season, which can impact the logistics of milk collection.

Regarding electricity, the two-phase system predominates, but presents instability throughout the year. Producers reported frequent power outages, especially on rainy days and adverse weather conditions. The vulnerability of the network is evidenced by the use of generators by three producers to ensure milking and cooling in cases of power outages.

3.2. Factors Driving the Desire for Digital Technologies

The data collected indicate that technological adoption is motivated by the search for operational efficiency and improved quality of life. The following are factors that drive the adoption of technologies in the properties studied.

- *Connectivity:*

Producers have access to the internet predominantly via radio or 3G/4G mobile network.

The use of the internet on rural properties is multifaceted, divided between activities related to the operation of the farm and personal well-being. Many producers use the network for financial and banking management, such as paying bills and accessing banking applications, reducing the need to travel to the city. Communication and entertainment are also highlighted, with the exchange of messages between family and neighbors and the consumption of movies, series and music.

In the context of commercialization, the internet is used to purchase inputs, such as feed and medicines, and to sell products such as calves, milk and cheese. In addition, it is an information and training tool, allowing access to meteorological data, news from the milk market and distance courses. Another relevant use is to support technical assistance, enabling interaction with technicians and veterinarians by sending photos and videos of animals and receiving milk quality reports.

Internet access in rural areas is centralized on mobile devices, with a predominance of cell phones as the main device and, in many cases, the only one used, given its versatility both at headquarters and in management areas where there is a signal. Television (Smart TV) appears as complementary equipment for entertainment and monitoring of specialized channels in the agricultural sector. The microcomputer or notebook is used by a minority, usually producers with higher education or who manage via spreadsheets and software, while tablets are only occasionally mentioned as auxiliary tools for consultation and leisure.

- *Social Media Presence:*

Producers have social media accounts, with WhatsApp being unanimous among those who have connectivity. A relevant finding is its use as the main digital input tool, working as a first step towards demystifying technology in the field and reducing producers' fear of using complex systems. WhatsApp is the main channel for negotiations, technical assistance and family communication, while Instagram and Facebook are used both for leisure and for following industry news. TikTok and Kwai, on the other hand, have a growing presence for quick video consumption and entertainment, and YouTube is often cited as a source of technical knowledge and educational videos about livestock.

- *Access to technical assistance:*

The presence of technicians is a key catalyst. Producers receive guidance from EMATER, SENAR (ATeG) and private veterinarians or those linked to dairy products. Some producers point out that the support of programs such as Balde Cheio or ATeG has introduced the culture of measurement and the use of spreadsheets. The Balde Cheio program, for example, was cited as transformative for introducing the culture of measurement and cost calculation, previously non-existent for the producer.

- *Perception of benefits:*

The producers interviewed place high expectations in the adoption of new technologies, viewing them as the path to the viability and longevity of their activities. The interviewees identify that modernization is not only aimed at profit, but also at improving working conditions, making activities safer and less exhausting.

The most cited improvements focus on reducing operating costs and increasing productivity, seeking to optimize the profit margin that is often considered minimal. In addition to financial gain, there is a strong desire to improve working conditions, aiming to make daily tasks more efficient, safer, and less physically exhausting. Technologies are also seen as tools to achieve greater control and monitoring of production, allowing management based on real data and not just assumptions.

3.3. Factors that hinder technological adoption

The main obstacles identified are economic and basic infrastructure:

- *Economic unfeasibility and scale of production:*

The cost of acquisition is the most cited barrier. Because they are small-scale producers and have informal and unqualified management, it was common to find producers who operate with narrow margins, where the profit after paying current expenses (feed and medicines) is not enough to make investments in production or to take on financing. Producers who produce on a small scale (e.g., 100 liters/day), see the investment in tanks or advanced milking as something unjustifiable.

- *Instability of electricity infrastructure and connection:*

The deficiency in the supply of electricity is a major bottleneck. Reports indicate properties that are without power for up to 5 days in the rainy season, which discourages the adoption of sensitive electronic equipment without additional investment in generators. Connectivity is also an issue. Although most have internet (via radio or mobile data), signal quality is often described as unstable or limited to headquarters, which precludes the use of technologies that rely on real-time data transmission in the corral or pasture.

- *Limitation of technical knowledge:*

The lack of familiarity with the concept of Digital Agriculture is common. Producers' views on digital agriculture are heterogeneous, ranging from ignorance to practical association with management and communication tools. Those who claim to know the concept often define it pragmatically, linking it to the use of digital devices (such as cell phones and computers) for property control, animal weight monitoring, and genetic improvement. There is also a strong association of digital technology with work facilitation and process accuracy, exemplified by the use of dairy apps to manage quality reporting, the use of GPS, and milking automation. However, a significant portion still has a vague view or admits to having never heard of the term, although many of these same producers already practice informal digitalization by using WhatsApp and banking applications for the marketing and financial management of their activities.

- *Challenge of rural succession:*

Advanced age and the lack of interest of children (successors) shorten the investment horizon. Producer 29, for example, who has already won several awards, is discouraged in continuing to invest because his son has no interest in the activity. Other producers also share the disinterest of their sons and daughters or the absence of qualified successors as a challenge to continuity and investment in new technologies. The children of producers are getting involved in parallel activities and losing interest in rural succession. Some even have higher education in courses related to dairy farming, but do not show interest in continuing with their parents' activities.

- *A very critical point: techniques, routines and daily care applied to the herd and infrastructure:*

Among the deficiencies identified in the production process, the lack of basic hygiene and management care stands out as a critical obstacle, exemplified by the high incidence of problems such as mastitis, which compromises the health of the herd and the quality of the milk. During the survey, it was observed that many properties still operate with limited basic infrastructure, such as corrals with damaged structure, milking materials with compromised quality, procedures with poor hygiene and lack of understanding about diseases and animal nutrition.

The low technification and mechanization is evident in the widespread use of manual tools such as hoes, shovels, sickles and wheelbarrows, replacing more technical and modern agricultural implements, which increases the physical workload and limits production efficiency.

At the same time, management practices are equally deficient, with most producers performing calculations of production costs in their memory, without using physical or

computational resources, without formal records that allow a real analysis of profitability. The use of notebooks and physical spreadsheets for manual notes is not a rule, and formal control of crucial events such as childbirth and health history is rare. Often, the information recorded is fragmented and not used for strategic decision-making.

Given this scenario, it is justified that the implementation of digital agriculture technologies must be preceded by grassroots work. Before introducing complex software or hardware, it is necessary to train producers in improving basic hygiene and management activities, as well as in structuring simple and effective methods of herd management and control. Stabilizing these fundamental processes is the essential step in ensuring that technological innovations find an environment prepared to generate sustainable results.

4. Conclusions

The analysis of the data reveals that dairy farming in Ingaí is an activity deeply rooted in family and generational tradition, but that it faces a critical moment of technological and succession transition. The predominance of producers over 50 years of age and the low representation of young people suggest a scenario of vulnerability for the continuity of the activity, if there are no incentives for modernization that make the sector more attractive and less exhausting for the new generations.

The adoption of digital agriculture is held back by basic structural bottlenecks that transcend the will of the producer. The instability of the power grid and low connectivity in areas beyond the property's headquarters are factors that discourage investment in sensors and real-time monitoring. In addition, the high cost of acquisition and implementation is the most cited financial barrier, especially in a context where profit margins are compressed by the high cost of inputs such as feed and medicines.

The motivation for digitalization is not purely financial. Producers see technology as a means of recovering their quality of life. The desire for automated systems is driven by the urgent need to reduce physical effort and address the shortage of skilled labor, indicating that digital agriculture on small farms has a strong component of social impact and occupational health.

One of the most significant findings of this study is that the barrier to modernization in Ingaí is not only technological or financial, but structural and educational. It was identified that the introduction of digital agriculture tools on farms that still operate with rudimentary hand tools and lack basic sanitary controls would be premature and possibly ineffective. Therefore, this diagnosis shows that the success of the technological transition necessarily depends on a previous stage of sanitation of the production and management processes, establishing a solid foundation of good hygiene, handling and zootechnical bookkeeping practices before advancing towards full digitalization.

The study concludes that digital agriculture in Ingaí is at an initial stage of digitalization, with limited access to the internet and centered on the use of WhatsApp for marketing and technical assistance. Although the formal concept of Digital Agriculture is still unknown to a significant portion of producers, the perception of its benefits, especially with regard to efficiency and well-being, is largely positive.

For the digital transition in the dairy sector to be effective, it is essential to implement credit and infrastructure policies that facilitate access to financing and ensure the stability of essential services, such as the supply of electricity and connectivity via rural internet. In addition, it is necessary to promote targeted training through the strengthening of technical assistance, with the support of agencies such as EMATER and SENAR, to foster digital literacy and guide producers in the transformation of their manual records into strategic data for management. Finally, the modernization of the image of dairy farming through technology should be used as a strategic tool to focus on rural succession, aiming at the retention and engagement of young people in the countryside.

Digital agriculture, therefore, presents itself not as an end in itself, but as an indispensable strategy for the economic and human sustainability of dairy farming in the region.

Acknowledgments

The authors would like to thank Fapesp (Proc. 2022/09319-9; 2025/10367-6; 2023/18453-3; 2025/06048-2; 2025/10368-2; 2025/11085-4; 2025/25188-0) for the funding.

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