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ARTICLE

Agribusiness 4.0: methodology for choosing robotic milking systems

Agronegócio 4.0: metodologia para escolha de sistemas de ordenha robotizada

Antonio Zanin[1], Silvana Dalmutt Kruger[2], Jenifer Ferreira Gonzaga[3], Rosamaria Cox Moura Leite Padgett[4], Mauro Lizot[5]

[1]Professor na Universidade Federal de Mato Grosso do Sul - UFMS na Graduação em Ciências Contábeis (CPNA) e Pós-Graduação em Ciências Contábeis (ESAN), Campo Grande (MS), Brasil. E-mail: zanin.antonio@ufms.br
[2]Professora na Universidade Federal de Mato Grosso do Sul - UFMS na Graduação em Ciências Contábeis (CPNA) e Pós-Graduação em Ciências Contábeis (ESAN), Campo Grande (MS), Brasil. E-mail: silvana.d@ufms.br
[3]Departamento de Administração, Centro Universitário Unigran Capital, Campo Grande (MS), Brasil. E-mails: jenifg@gmail.com
[4]Programa de Pós-Graduação em Ciências Contábeis e Administração, Escola Superior de Administração e Negócios (ESAN), Universidade Federal de Mato Grasso do Sul (UFMS), Campo Grande (MS), Brasil. E-mail: rosamaria.leite@ufms.br
[5]Departamento de Administração Geral e Aplicada (DAGA), Programa de Pós-Graduação em Gestão de Organizações, Liderança e Decisão (PPGOLD), Universidade Federal do Paraná (UFPR), Curitiba (PR), Brasil. E-mail: mauro.lizot@unochapeco.edu.br

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Abstract: The objective of the article was to select a robotic system for milking and identify its benefits within the Agribusiness 4.0 concept. The study took place on a rural property that implemented robotization in dairy milking in 2021. The selection took place with the help of the Analytic Hierarchy Process (AHP) method, considering three basic criteria and three milking systems. The analysis considers the mechanized milking process (70 animals) with the implementation of robotization (increase in the herd to 107 heads). The results show, among the benefits of robotization, the reduction in demand for manual activities, contributing to the reduction of direct labor and cost reduction, considering that the robot controls consumption and productivity per matrix. In general, the results shows benefits in aspects related to the feeding of dairy cows, control of animal health and welfare, productivity and labor. It is noteworthy that investments made in technology, as recommended by Agribusiness 4.0, contribute to operational improvements (labor demand) and productivity, which can benefit rural producers' satisfaction with dairy farming.

Keywords: milk production, multicriteria methods, robotization, dairy milking, Agribusiness 4.0.

Resumo: O objetivo do artigo foi selecionar um sistema robótico na ordenha e identificar seus benefícios dentro do conceito do Agronegócio 4.0. O estudo ocorreu em uma propriedade rural que implementou a robotização na ordenha leiteira em 2021. A seleção ocorreu com auxílio do método Analytic Hierarchy Process (AHP), considerando três critérios básicos e três sistemas de ordenha. A análise considera o processo de ordenha mecanizada (70 animais) com a implantação da robotização (aumento do rebanho para 107 cabeças). Os resultados mostram, entre os benefícios da robotização, a redução da demanda por atividades manuais, contribuindo para a redução da mão de obra direta e redução de custos, considerando que o robô controla o consumo e a produtividade por matriz. De uma forma geral, os resultados mostram benefícios em aspectos relacionados com a alimentação das vacas leiteiras, no controlo da saúde e bem-estar animal, na produtividade e com a mão-de-obra. Ressalta-se que os investimentos realizados em tecnologia, conforme preconiza o Agronegócio 4.0, contribuem para melhorias operacionais (demanda de mão de obra) e de produtividade, o que pode beneficiar a satisfação dos produtores rurais com a atividade leiteira.

Palavras-chave: produção de leite, métodos multicritério, robotização, ordenha leiteira, Agronegócio 4.0.

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1 Introduction

According to the United Nations (2019), the world population in 2050 will be 9.7 billion. However, the expansion of agricultural land is restricted and to meet this demand, Brazil must increase 40% of its production (Massruhá, 2020). With the high demand and the same amount of land, which cannot be expanded, technology has become an indispensable factor in increasing productivity (Vieira Filho, 2010, Silva & Cavichioli, 2020).

The milk production chain, which is one of the main economic activities in Brazil, it is also no different (Ferreira et al., 2020), especially because dairy production plays a relevant social role, contributing to the generation of direct and indirect jobs, as well as income generation and optimization of rural family labor (Lizot et al., 2024).

Brazil ranks sixth in the world ranking of milk production. The states of Minas Gerais, Paraná, Rio Grande do Sul, Goiás, and Santa Catarina together produce around 74.42% of the volume of liters. In 2019, production reached 34.8 billion liters, according to data from the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária, 2020).

Despite the expansion of milk production and the volume produced, Vilela et al. (2017), associate problems such as climate change, lack of public policies and shortage of labor with the problems of the sector and highlight the importance of the use of technologies in production, which make it possible to increase production efficiency, and it leads to greater profitability of the activity. Gomes et al. (2018) point to factors such as a low level of knowledge and lack of technical assistance as a limiting factor for growth.

In this sense, the use of technology for the milking process (robotization) shows several advantages over mechanical or manual milking. In the search for better results, many producers adopted mechanical milking to replace manual milking, which limited production growth. In the same perspective, robotic milking proposes improvements and several advantages (Pacassa et al., 2022). The robotic milking system performs several activities without direct intervention of humans, including entry and exit control of animals, providing food during milking, cleaning, and sanitizing the udder and teats, placing and removing teat cups, diagnosing mastitis and post-milking disinfection, and washing the floor. It also generates informational reports on animal production and health (Botega et al., 2008; Maculan & Lopes, 2016; Feuz & Larsen, 2020).

From the advancement of the use of technology in rural properties, discussions, and the context of the advantages of Agribusiness 4.0 arise (Bassotto et al., 2023). According to Massruhá (2020), the scope of Agribusiness 4.0 covers precision agriculture and livestock, automation, and robotics, with an emphasis on the use of big data and the Internet of Things. The insertion of technologies such as artificial intelligence, robotics and constant data analysis can contribute to reducing costs and increasing productivity (Kagermann, 2013; Crews, 2019).

In this sense, milk production generates income and jobs, but can be more efficient in the financial management of resources, processes and performance, especially through the use of technologies (Fernandes et al., 2021; Bassotto et al., 2023). However, Embrapa (Empresa Brasileira de Pesquisa Agropecuária, 2020) warns that the robotic milking system must be well planned and adequate to the characteristics of each rural property and the rural manager's objectives. For the rural producer to make appropriate choices, given the complexity of the available alternatives, it is necessary to use robust methods to aid decision-making, in this regard, the use of multicriteria methods stands out (Lizot et al., 2021).

The literature highlights the use of multicriteria methods for problems solving for selecting alternative equipment or suppliers, such as Data Envelopment Analysis (DEA), which was applied to evaluate supplier performance (Weber, 1996; Weber & Desai, 1996; Weber et al., 1998, 2000) and the Analytic Hierarchy process (AHP) method, which was applied to evaluate supplier selection (Ghosh et al., 2012; Ajalli et al., 2017; Nirmala & Uthra, 2019; Chen, 2021).

Previous studies carried out the application of these methods of problem-solving for supplier selection, Total Cost Ownership (TCO)+DEA+AHP (Ramanathan, 2007), TCO+DEA (Garfamy, 2006), TCO+AHP (Bhutta & Huq, 2002), TCO+ BN (Bayesian Networks) (Dogan & Aydin, 2011) and TCO+MABAC (Lizot et al., 2021), which are focus on the rural environment.

The AHP is a tool to assist in comparisons that enable managers to find the necessary trade-offs to select the best equipment supplier's (Bhutta & Huq, 2002). The advantages of this method include greater simplicity, ease of use, and suitability for subjective data judgments (Knorr et al., 2023; Ramos et al., 2020). Another factor for applying AHP is that the problem analysed must have more criteria than alternatives (Lombardi Netto et al., 2021) and the criteria are numerically well-defined (Lizot et al., 2021).

In this context, the motivation problem of the study arises: What benefits can milking robotization provide for a rural property, based on a choice involving multicriteria methods? To support the research question, the objective is to select a robotic system for milking and identify its benefits within the concept of Agribusiness 4.0.

The research objective is related to the assistance in choosing a milking robotization system for rural producers. The proposed methodology tends to facilitate the decision on the most suitable system, from the perspective of different decision-making criteria. The benefits of the robotization system that is more suited to the rural producer's reality are highlighted by the concrete results of the study and corroborated by theory.

This research is relevant due to the need to know how Agribusiness 4.0 contributes to identifying the benefits of the robotic milking system. Franco Neto & Lopes (2014), indicate the need for studies that show the characteristics of the robotic milking system, considering the increase in production, milk quality and system planning, as well as the economic viability of investments in the implementation of this technology. Like the study by Rose et al. (2016) and Singh et al. (2016), the present study also adds information to support decisions for agriculture.

The literature also highlights the importance of data and information management, which can benefit the management and decision-making process under a multicriteria approach (Ramasamy & Chowdhury, 2020; Lizot et al., 2021). Thus, it is expected to contribute to the literature on Agribusiness 4.0 in dairy farming and to assist rural managers in identifying the necessary conditions for maximizing the benefits of the robotic milking system. In addition, the aim is to cooperate with other stakeholders in the value chain such as government, industry, distributors and consumers by providing information on robotization in milking within the concept of Agribusiness 4.0.

This article is organized as follows: the second section presents a brief introduction to the topic. The third section presents the bibliographical research on perspectives of agribusiness 4.0 in the dairy activity. The fourth section presents the methodological development of the research. The fourth section highlights the main results and analyses. The last section presents the study's conclusions and suggestions, followed by bibliographical references.

2 Theoretical foundation

2.1 Perspectives of agribusiness 4.0 in the dairy activity

Industry 4.0 is considered the Fourth Industrial Revolution, due to the great presence of advanced technologies. The technology originates from the "Internet of Things", where equipment, sensors, cameras, and other equipment exchange information with each other in real-time (Wiendahl, 2012; Schwab, 2016).

The revolution came with technologies such as: Artificial Intelligence, Internet of Things, Big Data, 3D Printing, Cloud Computing, Machine Learning, among others, reducing costs and increasing production (Kagermann, 2013; Crews, 2019). Ustundag et al. (2018), point out technological advances that Industry 4.0 is based on: adaptive robotics; data analysis and artificial intelligence (big data analysis); simulation; embedded systems; communication and networking, such as industrial internet; cloud systems; additive manufacturing; and virtualization technologies.

Industry 4.0 has exceeded the boundaries of industries and has migrated to various sectors of the economy, such as the agricultural sector. The 4.0 concept allows for real-time information for decision-making and greater freedom in the decision-making process (Ustundag et al., 2018). With the concept of 4.0 in agriculture, Agribusiness 4.0 emerges, with better management connected to high technology, greater productivity and better conservation of the environment in agriculture and livestock activities (Braun et al., 2018; Esperidião et al., 2019; Fernandes et al., 2021).

Agribusiness 4.0 uses technologies such as sensor networks, machine-to-machine communication, cloud computing, and analytical solutions with high volumes of data taken from production for decision-making. As a result, it enables increased productivity, better use of inputs, reduced labor costs, reduced errors, less bureaucratic process and less impact on the environment, enabling the use of precision, automated and robotic agriculture (Massruhá, 2020).

The limitation of Brazil in using Agribusiness 4.0 among most rural producers is the high cost of investment, even though it's a crucial item for agricultural growth and development. It is also essential to train people who will use digital tools (Esperidião et al., 2019). However, boosting food production with fewer resources becomes an opportunity for Brazilian agribusiness, given the global demand for food (Pacheco & Reis, 2020), as well as adding advances in aspects of the development of sustainable production (Kruger et al., 2022).

Sanches et al. (2024), indicate that the prices of agricultural commodities impact the cost of products in production chains, being an aspect that producers are unable to manage. Oliveira & Silva (2012), indicate the importance of family farming, in the context of the milk production chain, as an activity that generates income, jobs, and contribute to the food security of families living in rural areas. However, there is a dependence on these small farmers on the actions of other agents, such as agribusinesses and transporters. Labor represents one of the main items in the formation of operational costs in dairy activities (Bassotto et al., 2022, 2023), so given the difficulties of retaining third parties to carry out the activity, robotization makes an alternative for the development of dairy production.

In dairy production, the use of robotic milking contributes to productivity. The "robot consists of a mechanical arm that performs all the tasks of the milking process autonomously" being a system that performs all the activity without human intervention. Then, generating reports with information such as milk quality, and animal health, among other information (Vilela et al., 2017; Maculan & Lopes, 2016).

The use of robotics in milking is encouraged by the economic return, originating from the efficiency of the process and the application of inputs (Oliveira, 2009). However, due to high deployment costs, robots are more used in developed countries, mainly in European countries (Salfer et al., 2017). In Brazil, the robotic system is in a few properties due to the high cost of imported equipment (Botega et al., 2008).

In this aspect, technical criteria are relevant and important for dairy farming. Ferreira et al. (2020) indicate that automated systems needs to demonstrate, among other information, diagnosis of the animal's health, individual production per animal and a high level of hygiene and cleaning. Pacassa et al. (2022), indicates that the manufacturer's experience, as well as installation and after-sales technical assistance are relevant factors. Complementing the technical criteria, there is also the assessment of milk quality, as well as the level of automation and the possibility of technological integration with other systems (Kruger et al., 2019; Almeida et al., 2022).

However, even with the high investment cost, the advantages of using the robotic systems are significant, highlighting the automation of the system, where the animal spontaneously presents itself for milking, where it is fed, thus performing the incentive. Remaining the manager, only the management of the animals, to avoid competition in the milking queue (Maculan & Lopes, 2016). In addition to the advantages of labour costs, and quality control, it provides the producer with a better lifestyle and increases milk production, by performing a higher frequency of milking (Salfer et al., 2017; Vik et al., 2019; Pacassa et al., 2022).

Dairy activity presents disparities between producing regions and characteristics that differentiate milk producers, mainly due to their technological standard, consequently, there are different levels of productivity (Almeida et al., 2022). In this sense, in addition to investing in technologies such as robotic milking, Brazil needs to improve the processing and marketing of milk, improving quality and acquiring more sustainable practices in the process (Vilela et al., 2017). Daneluz et al. (2022), indicate the importance of analyzing the performance of farms for their continuity, considering that young people expect a profitable business for the rural family succession process. Farmers make decisions based on perceptions related to their ability to access resources and manage risks (Singh et al., 2016).

Córdova et al. (2018) indicate the importance of monitoring the management of cow's milk productivity and animal welfare to evaluate the results. Also, the economic control of the activity becomes relevant to measure performance, assess financial viability, and correct adversities (Kruger et al., 2019, 2020).

2.2 Multicriteria methods applied to agribusiness

Multicriteria methods can deal with resource management problems in agriculture more realistically and efficiently. Hayashi (2000). Because these economic problems consist of multiple objectives, that most of the time conflict (Fontana et al., 2013).

Multi-criteria analysis is a methodology that evaluates alternatives and criteria for different stakeholder groups (Taefi et al., 2016). The main advantage of this methodology is the recognition of qualitative criteria, which are difficult to measure, in addition to providing integration between different areas, considering alternatives that can be selected or classified, to optimize the decision-making process (Thesari et al., 2021).

Some of these studies focus on prioritizing production activities, energy efficiency and resource reuse (Komeleh et al., 2011). Others use multicriteria decision models to allocate agricultural areas for planting (Kaim et al., 2018), and to optimize fuel economy in heavy trucks, using TCO as one of the tools for evaluation (Fries et al., 2018).

These previous studies did not discuss the use of such methods with the emerging theme of mechanization and Industry 4.0, in addition to the benefits and opportunities of applying each method used in the environment of agricultural activities.

3 Methodology

In this section, the methodological procedures adopted in this research are presented, being characterized in terms of descriptive objectives, and carried out through a case study and qualitative analysis. For the robotization systems evaluation, three equipment options were used (Lely, Delaval and Ordemilk), because they were the only equipment available by suppliers in the geographic region where the research was carried out.

Interviews were helded with dairy producers on 13 rural properties. The properties are located in the same macro-region, in three municipalities in the state of Santa Catarina (São Lourenço do Oeste, Novo Horizonte and São Bernardino) and two municipalities in the state of Paraná (Vitorino and Renascença). The study case was carried out on a single rural property, which already had a fully installed robotization system, located in the city of Herval D'Oeste in Santa Catarina. The study aimed to analyze the benefits provided by robotic milking, which maintains the dairy herd in the compost barn system.

Data collection took place in July 2022, through a visit with the application of the decision matrix to define the weights and a semi-structured interview with the dairy farm manager. Subsequently, a visit was made to the facilities of the rural property to learn about the production stages, the milking process and care with the development of the dairy activity.

The rural property of study, is located in the West of Santa Catarina and has been working with milk for approximately 22 years, being its main activity. It is a small property with 25 hectares. For the herd's feeding, it has another 25 leased hectares for corn silage and hay production.

The labor is family, being carried out by the couple and another 20-year-old son. Eventually, third parties are hired to help make hay and corn silage (for animal feed). The analysis makes it possible to identify the steps implemented in the dairy activity based on the robotization of milking, considering the information stored by the system (robots), regarding milking, cow feeding, productivity, and calendar, as well as presenting the synthesis in the form of a Table of the advantages perceived by the manager from the implementation of robotization in the rural property. To define the priorities for choosing equipment, as well as the attributes sought by the decision maker in their choice process, three criteria were used: Technical, Financial and decision-making. For a complementary understanding, the criteria matrix was described to help in the description of the factors analysed in the decision. Table 1 shows the factors analyse in each criteria.

Table 1 assists in the analysis of the relevant factors linked to the criteria defined based on the literature. The methodological foundations for the development of the decision model to select the milking robotization system, are organized into phases that describe the entire organizational scheme of the multicriteria method. First, the weights will be determined, according to the opinions of rural producers.

The model presents a multicriteria methodology to select milking systems, considering the fundamentals of AHP selected in the literature and adapted to the reality of Industry 4.0. The research design is shown in Figure 1.

The AHP method is a multicriteria methodology that aims to select or choose better alternatives in a process with different evaluation criteria, allowing the comparison of quantitative and qualitative criteria (Maêda et al., 2021).

To tabulate data, normalize and calculate the consistency ratios, the Excel spreadsheet was used. Subsequently, the Super Decisions® software was used to carry out the general AHP hierarchy calculations, to provide greater credibility to the decision-making process.

Table 1 - Auxiliary information to the criteria

Criteria	Lely System	Delaval System	Ordemilk System
Technical	Experience of more than 75 years in the market, operating in about 40 countries	135 years of experience, operating in more than 100 countries	Experience of about 24 years, operating in Brazil, has 13 branches
	Digitally automated control	Precision livestock	Automated system
	Evaluation of milk quality per animal at each milking	Robotic arms perform the repetitive tasks of cleaning, preparing, treating, milking, and spraying	The robot arm completes the entire milking process
	Analysis of cow health, rumination, and feed efficiency	Animal health diagnosis	
	Individual cleaning and sanitizing	Each teat is individually cleaned and stimulated to improve productivity	Process steps are monitored using sensors and measuring devices.
	Technical assistance	Technical assistance	Individual cleaning and sanitizing of ceilings
	Measurement and evaluation of production per animal	Measurement and evaluation of production per animal	Technical assistance
Financial	Analysis of productive performance per animal	Analysis of productive performance per animal	Measurement and evaluation of production per animal
	Capacity of up to 65 cows per robot	Milking capacity of 70 heads per robot	Capacity of up to 60 cows per robot
	Capacity of 2,000-2,500 litters of milk/day	Capacity of 3,500 litters of milk/day	Capacity of 2,500 litters of milk/day
Decisive	Management of consumption per animal: the robot milks each cow according to its potential, monitoring the amount of feed per animal		
	Quality control: the robot controls the quality of the milk in the tanks, avoiding waste or contamination of daily production		
	Technical follow-up per animal: complete pregnancy analysis and heat detection		
	Human activities: reduction of manual activities and reduction of third-party labor demand on the rural property		
	Profitability: increased profitability of the dairy activity and return on investment		

Source: Prepared by the authors (2023).

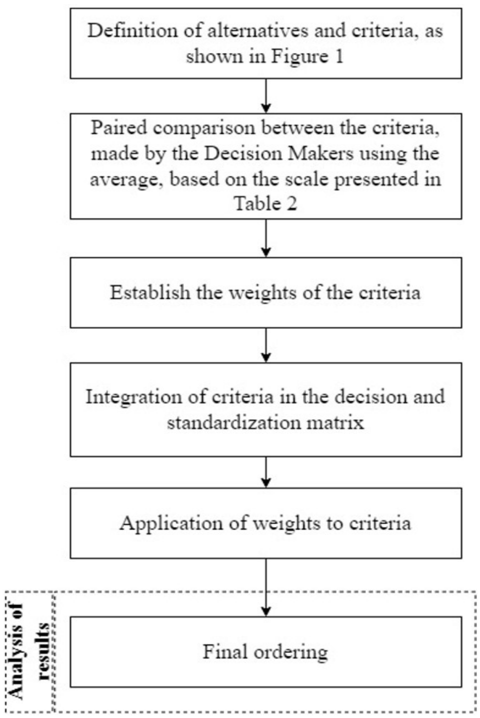

Figure 1 - Methodology design.
Source: Prepared by the authors (2023).

AHP is a compensatory and hierarchical method, indicated for solving problems with a reasonable number of alternatives and criteria, considering the opinion of decision-makers with peer comparisons (Santos et al., 2021). The weights will be calculated according to the AHP methodology, which according to Saaty (2008) and Bruno et al. (2012) is articulated in the following phases:

Phase 1 – Structuring the problem in a hierarchy: The hierarchies distribute the objective in the elements that are being compared, assigning characteristics to determine which influences or is most influenced among the variables.
Phase 2 – Comparison between elements. Measure the importance of the characteristics for the overall objective. The analysis takes place by comparing how important one of the two elements is to the problem. Table 2 demonstrates the Fundamental scale for weight definition.

Table 2 - Fundamental scale for weight definition

II*	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	One activity is strongly favored over another, its dominance demonstrated in practice
9	Extremely important	Evidence favoring one activity over another is of the highest possible order of assertion.

*Numerical scale. Source: Adapted from Saaty (2008).

Phase 3 – With the data obtained through the comparative judgment, the calculation of the weight priorities of each hierarchy element is performed and normalized using Equation 1:

$$\sum_{i=1}^{n} w_i = 1 \quad (1)$$

The normalization of the comparison matrix, can be done using different methods. To obtain the priority vector w, the additive normalization method was used, the elements of each matrix column are divided by the sum of the same column, then the average of the line elements is performed, according to Equation 2:

$$a_{ij}' = a_{ij} \sum i = 1 n a_{ij}, i, j = 1, 2, \ldots, n$$
$$w_i = (1/n) \sum j = 1 n a_{ij}', i = 1, 2, \ldots, n \quad (2)$$

In this step, the consistency analysis proposed by Saaty (2008) is carried out, allowing the assessment of consistency in assigning the scale values described in Table 2. The consistency of the judgment matrix is measured by the Consistency Index (CI), according to Equation 3:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

Knowing that n is the number of factors analysed and λmax is the highest eigenvalue of the judgment matrix, that is obtained by the sum of the products between each element of the weight vector and the sum of the columns of the comparison matrix evaluated pair-by-pair.

The CI value is compared with the index developed by Saaty (2008), called the Random Consistency Index (RI), which varies according to the number of factor analyses, as shown in Table 3.

Table 3 - Random index for different array sizes

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58	1.59

Source: Prepared by the authors (2023).

The RI represents the average consistency index derived from a randomly generated reciprocal matrix. The consistency ratio (CR) of a pairwise comparison, proposed by Saaty (2008), is the ratio of its consistency index (CI) and the corresponding random index (RI), according to Equation 4:

$$CR = \frac{CI}{RI} \tag{4}$$

If the CR ≤ 0.1 (10%) the inconsistency is acceptable. Otherwise, the criteria judgments should be reassessed. For consistent results, the consistency ratio value should not exceed 5% for a 3 x 3 matrix, 9% for a 4 x 4 matrix and 10% for larger matrices (Saaty, 2008).

Calculation of the global score and determination of the decision matrix d the weight values determined and sorted, the decision matrix is generated.

Phase 4 – listing of potential suppliers as alternatives, with a comparison of alternatives based on an approach considering the preferences of decision-makers using the multicriteria approach. In the end, the results found are compared, in order to lead to more assertive decisions for the buyer.

4 Results and discussion

Three robotic milking systems were analyzed for acquisition and implementation: Lely, Delaval, and Ordemilk. The AHP method was used for multiple decision-making criteria, to aid the decision-making in choosing the most suited system to the reality of rural producers.

From the visit and interview carried out with the managers of the rural properties, Table 3 shows the results of applying the AHP method for defining the weights of the criteria, with the three criteria of prior choice of the qualification of the suppliers pointed out by the rural owners. They are crossed through interviews with managers, where values ranging from 1 to 9 are defined for the criteria: Technical, Financial and Decision-making (Almeida et al., 2022). Table 4 presents AHP evaluation matrix for criteria weights.

Table 4 - AHP evaluation matrix for criteria weights

	Technician	Financial	Decisive	EigenVector	Weights %
Technician	1.00	0.33	7.00	1.326	29.0%
Financial	3.00	1.00	9.00	3.000	65.5%
Decisive	0.14	0.11	1.00	0.251	5.5%
∑	**4.14**	**1.44**	**1.00**	**4.578**	**100.0%**
	λmax			**3.080**	
				0.040	
	CI =			**0.069**	Ideal ≤ 0.52

Source: Prepared by the authors (2023).

Performing the sums of each criteria and normalizing, we will have the priorities and results. Based on Table 4, the technical criteria represents 29.00%% in the priority of choosing the milking systems, followed by the financial criteria with 65.55%, representing the highest weight among the criteria. The decision criteria represented 5.5% of priority, being the lowest index. The calculation of the consistency index demonstrated that the application is fully consistent, for the 3x3 matrix, with a result of 0.069, well below the maximum limit of 0.52, for this matrix format.

Next, the application of AHP for the three alternative robotic systems (Lely, Delaval and Ordemilk) is demonstrated. The applications are demonstrated in three different tables, considering the three criteria (Technical, Financial and Decision-making), for the alternative systems. Table 5 shows the evaluation of the Technical criteria.

Table 5 - Technical criteria evaluation matrix

	Lely	Delaval	Ordemilk	EigenVector	Weights %
Lely	1.00	7.00	7.00	3.659	75.3%
Delaval	0.14	1.00	0.20	0.306	6.3%
Ordemilk	0.14	5.00	1.00	0.894	18.4%
∑	**1.29**	**13.00**	**8.20**	**4.859**	**100.0%**
	Λmax			**3.295**	
				0.147	
	CI =			**0.254**	Ideal ≤ 0.52

Source: Prepared by the authors (2023).

Based on Table 5, evaluating the Technical criteria, the Lely system represents 75.3%% in the priority of choice of milking systems, followed by the Delaval system, with 6.3% in the priority of milking systems and finally, the Ordemilk system represented 18.4% of priority. The calculation of the consistency index demonstrated that the application is consistent, for the 3x3 matrix, with a result of 0.254, below the maximum limit of 0.52, for this matrix format. Table 6 shows the evaluation of the financial criteria.

Table 6 - Financial criteria evaluation matrix

	Lely	Delaval	Ordemilk	EigenVector	Weights %
Lely	1.00	3.00	5.00	2.466	65.9%
Delaval	0.33	1.00	1.00	0.693	18.5%
Ordemilk	0.20	1.00	1.00	0.585	15.6%
∑	**1.53**	**5.00**	**7.00**	**3.744**	**100.0%**
	λmax			**3.029**	
				0.015	
	CI =			**0.025**	Ideal ≤ 0.52

Source: Prepared by the authors (2023).

Based on Table 6, evaluating the Financial criteria, the Lely system represents 65.9% in the priority of choice of milking systems, followed by the Delaval system, with 18.5% in the priority of milking systems and finally, the Ordemilk system represented 15.6% of priority. The calculation of the consistency index demonstrated that the application is consistent, for the 3x3 matrix, with a result of 0.025, well below the maximum limit of 0.52, for this matrix format. Table 7 shows the evaluation of the Decisive criteria.

Table 7 - Decision Criteria Evaluation Matrix

	Lely	Delaval	Ordemilk	EigenVector	Weights %
Lely	1.00	3.00	3.00	2.080	58.4%
Delaval	0.33	1.00	0.33	0.481	13.5%
Ordemilk	0.33	3.00	1.00	1.000	28.1%
∑	**1.67**	**7.00**	**4.33**	**3.561**	**100.0%**
	λmax			**3.136**	
				0.068	
	CI =			**0.117**	Ideal ≤ 0.52

Source: Prepared by the authors (2023).

Based on Table 7, evaluating the Decisive criteria, the Lely system represents 58.4% in the priority of choice of milking systems, followed by the Delaval system, with 13.5% in the priority of milking systems and finally, the Ordemilk system represented 28.1% of priority. The calculation of the consistency index demonstrated that the application is consistent, for the 3x3 matrix, with a result of 0.117, well below the maximum limit of 0.52, for this matrix format.

After having the priorities of the selection criteria (Technical, Financial and Decision-making), this prioritization is used to choose the best alternative among the three robotic systems previously analyzed. In this next step, the final choice is made of which alternative is the most appropriate among the three systems, with the respective criteria and their weights, as shown in Table 8.

Table 8 - Criteria priority matrix

	Technician	Financial	Decisive
Lely	75.31%	65.86%	58.42%
Delaval	6.29%	18.52%	13.50%
Ordemilk	18.40%	15.62%	28.08%
Weight	**28.97%**	**65.54%**	**5.49%**

Source: Prepared by the authors (2023).

Table 8 shows the priority of each criteria compared to the analysed alternatives, in addition to the respective criteria weights, according to the decision-makers. Additionally, Table 9 presents the final decision matrix, which considers the results from calculating the criteria for the alternatives in relation to their respective weights.

Table 9 - Final decision matrix

	Technician	Financial	Decisive	Final priority	Ordination
Lely	21.82%	43.16%	3.21%	**68.19%**	**1th**
Delaval	1.82%	12.14%	0.74%	**14.70%**	**3th**
Ordemilk	5.33%	10.24%	1.54%	**17.11%**	**2th**

Source: Prepared by the authors (2023).

The results of the presented approaches are compared, through the decision index, as shown in Table 9. This result is the benchmark to help the farmer's decision, providing greater assertiveness in choosing the milking robot system. Given the weight of each acquisition criteria, the Lely system is preferred as an overall priority of 68.19%, followed by the Ordemilk system with a priority of 17.11% and lastly the Delaval system with a priority of 14.7%.

In this phase, the ordering hierarchy of the milking robot systems was created, with a better decision rate. The formation of the index demonstrates which is the preferable system for implantation, creating a priority order, according to the opinion of the decision maker. From the implementation of the Lely milking robot system, we sought to identify the respective benefits within the concept of Agribusiness 4.0.

From the visit and interview carried out with the manager of the rural property, it was identified that the Lely robotic milking system was implemented in December 2022, when there were around 70 lactating cows. Currently (July/2023), the herd in lactation is 107 cows. The two robots have the capacity to milk between 120 and 140 cows/day. In this way, there was a need to purchase heifers so that they would soon reach the installed capacity of the robots. Figure 2 shows the image of the Robot and a matrix in the milking process.

Figure 2 - Milking process in the Robot.
Source: Rural property images (2022).

From the implantation of the robotic system, the dairy cows are identified with a collar on the neck which contains a chip that records each milking individually. Currently, due to idleness in the process, there is no limitation on the number of daily milkings, but the system can be adjusted to a time of 6 hours, for example.

Among the advantages of robotization is the control of milk by matrix. The system has a device that separates the discarded milk when a dairy mother is medicated, into a sewer container, avoiding the loss of all production. The period which respects the grace period that can be one day or up to 3 days.

With the robotic system it's possible to measure the quality of the milk (fat, protein). In the case of somatic cells, it performs the individual control by matrix. It controls the number of visits by each cow to the milking robots, providing information on the last 24 hours and the last 7 days, allowing the producer to monitor productivity and identify problems. The herd's average production is 30.5 liters of cow's milk/day. The number of milkings for each cow is not uniform, with an average of 3.2 milkings/day.

The robot performs individual control of each cow, including lactation time. For example: a cow that has just calved (for approximately 60 days) is challenged to produce more through a larger amount of feed. In this case, each die is fed according to the production cycle. It is also controlled in the system when the cow is inseminated and at the end of the lactation period, the robot reduces the amount of feed and informs when to stop milking, as it must be prepared for the new lactation cycle (approximately 60 days, so receives less feed). These activities guarantee control for the producer, but also favor the care of the matrices, guaranteeing better conditions of animal welfare, which can favor their productivity in the medium term.

Another important piece of information is to identify which cows were in heat in the last 24 hours. In this case, the robot indicates the most appropriate time to carry out the insemination, reducing the number of dairy cows that do not become pregnant. At this stage, the producer also indicates the advantage of acquiring sexed semen, although it has a higher cost, it has a 90% probability of being born female), because in milk production, it is important to form new matrices to replace the herd.

The robot even helps decide when to discard the matrices, by passing on production information, that is, having individualized information on each animal, decisions can be made when the dairy matrix has low productivity. The information that the robot informs the rural manager daily is shown below in Table 10:

Table 10 - Robotic system information

Milking	Udder control	Calendar	Food
Daily production	Conductivity	playback status	total/remainder yesterday
Deviation in daily production	With	Date of last insemination	Rumination (minutes)
Expected milk production	Milking dead time (to)	number of inseminations	
Milking (average)	milking time	date of delivery	
today's flaws		Expected drying	
today's refusals			
Interval			
Last milking temperature			
Separates contaminated milk			

Source: Survey data.

It appears that the information controlled by the robot allows for identifying milking data, production control by ceilings, production calendar by matrix and daily feeding. It is observed in Table 10 that the manager can identify the total destination of the milk suitable for consumption, vaccinated dairy mothers and colostrum milk (dairy mothers who have just given birth). The robot separates the colostrum milk, which goes through a channel to another container where it is collected and used to feed calves, as well as separating it in cases of cows that are medicated.

The manager indicated that of the 107 dairy cows milked by the robots, he did not have to discard any, all of them adapted to the system. He even reports that "there were 2 cows that kicked during mechanized milking, and it was necessary to tie the leg to wash the teats for milking. In the robots, they were a little annoying for 2 days, but now they are very calm. In general, the matrices are like the robots". However discards may occur due to having a dairy matrix with non-standard udders, that is, with udders below 30 cm, as the robot cannot place its arm under the dairy matrix.

As for the feeding of the cows, they receive concentrate (feed), every 17.5 Kg they produce 100 liters of milk. In addition to the food provided during milking, the dairy cows receive a meal of hay, corn silage and 5 kg of feed, regardless of production. The producer can monitor the consumption per head, as well as the cow with the highest daily production (for example, on this day of the interview there was a cow with a production of 59 litters, although she had already produced 70 litters/day). Furthermore, it is possible to detail information on the number of days in lactation and days pregnant, as well as see the projection of lactation production and the levels of fat and lactation historically, on each. "Another report is about the health of each cow, for example, the dairy cows 70, has the conductivity information on the front left ceiling, for now it appears only as an observation, because it has an index of 89, from 85 it is considered mastitis, and the milk from this teat will be discarded". According to the manager, this is another advantage of the robot, as it discards only milk from this ceiling, and does not affect the storage of the entire production, which possibly occurs in a property that does not have robotization. In these situations, the robot washes the cooler and the equipment/pipes, as well as uses another parallel container (with a capacity of 300 litters), i.e., if a dairy mother comes into the milking process and needs to dispose of the milk, the robot does the cleaning before starting a new milking. There is also a specific cooler for the robot because when the milkman is collecting the milk, the robot continues milking, working 24 hours a day.

The productivity of the rural property also improved after the investiment. Previously mechanized milking was carried out twice a day, with an average of 28 to 31 liters per day per dairy cow. Currently, with the new system, the average is 32 to 35 liters/day/cow. However, there was a 50% increase in the herd of dairy cows. Proportionally, the system allowed to increase production with a reduction in feed consumption. Previously, the production was 2.5 liters of milk per Kg of feed consumed. Currently the production is 3.2 liters of milk per kg of feed.

Water and electricity increased proportionally, by around 40%. As for cleaning materials (detergents or chemicals), it did not change, compared to the costs of mechanized milking. In the context of labor, the manager indicates one of the main advantages of the robotization process, because even with the increase in the dairy herd, it is possible to maintain the execution of activities only with family labor (3 family members). According to the manager, considering its structure: "With robots, if a person dedicates himself only to this activity, it would be possible to maintain production: treating, cleaning, medicating, insemination, etc. With that number of dairy cows in the mechanized milking system, 4 to 5 people would be needed working, considering the 3 milkings as the robot performs, there would be a demand for at least 5 people".

In addition to the demand for milking the dairy herd, there is concern with the production of inputs for food, as it uses 25 hectares of its own and has 25 leased. For the next harvest, it will need to have 60 hectares to feed the entire herd, considering the increase in animals. The manager also indicates that he only has outsourced workers to help with the hay harvest and to make the silage.

In this sense, the workforce is one of the main concerns in the development of the activity, especially since the activity requires full dedication. According to the manager to produce milk "there are no holidays and/or weekends, so it is difficult to hire labor for the activity, especially due to the need for daily hours of work". Consequently, this cost of labor can also be another difficulty in making it possible to hire third parties.

The results indicate the importance of using multi-criteria methods to contribute to the decision-making process in rural farming, following discussions and the context of the advantages of using technologies to support the milk production process. The insertion of technologies and data analysis can contribute to reducing costs and increasing productivity (Fernandes et al., 2021; Bassotto et al., 2023).

Table 11 presents a summary of the main perceptions of the advantages identified in the implementation of robotization in dairy activity.

It is observed in Table 11 a summary of the main advantages pointed out by the manager, regarding the implementation of robotic milking in the rural property. In the economic context, the previous production, which was 60 to 70 thousand liters/month, increased to 90 to 100 thousand liters/month. Also, the robotic system allows controlling the daily production by dairy matrix, on the computer, the record of each milking, and the production of the dairy matrix, including each teat. Such controls guarantee the analysis of productivity and health of the matrices, avoiding waste.

Table 11 - Main advantages identified from the implementation of robotization

Characteristics	Mechanized milking	Robotization
Feeding the animals	Diet based on hay, silage, hay and feed, distributed in the shed.	Control of feed per animal, according to its productivity and production phase. Control of milk quality and production by teats.
Animal health and welfare	Periodic control with the help of a veterinarian and spreadsheets.	Control by matrix, with daily measurement of temperature and quality of milk. Identification of the appropriate period for insemination. Milk quality control allows milk to be discarded by teats, avoiding waste and losses with disposal.
Herd productivity	Average of 60 to 70 thousand liters/ month, with 28 to 31 liters per day per dairy cow.	Average of 90 to 100 thousand liters/ month, the average is 32 to 35 liters/ day/dairy matrix.
Labor	Demand of 4 to 5 people to supply the process of milking, feeding and care for the herd. In addition to the demand in the planting and harvesting process.	Demand of 1 to 2 people to supply the process of milking, feeding and care for the herd, even with the increase in the number of animals. People's demand remains in the process of planting and harvesting.

Source: Elaborated by the authors based on the research.

The rural producer indicates that one of the problems initially faced with the change to the robotic system was to increase the number of dairy matrices to optimize the installed capacity of the robots, as they had to acquire animals from other producers. From now on, they intend to reach the maximum number of matrices for the robot's milking capacity, with heifers raised on the property.

As for the prospects for maintenance, the manager indicates that "if the robot breaks down, there will be higher expenses, because specialized labor is more expensive, as you need to call a specialized technician, and pay for travel and working hours". Considering reports from other managers, he points out that "properties that have already implemented robots, found maintenance differences of 30 to 40% more with robots". The investment made by the producer totaled around BRL 2,300,000.00, of which around BRL 1,890,000.00 for the robots, BRL 190,000.00 for the cooler and generator, in addition to the construction of the structure for the robots BRL 220,000.00 and expansion of animal confinement. The period contracted to repay the financing was 10 years. "Considering the increase in the price of milk and that it is possible to reach the projected capacity of 4 thousand liters per day in the first year of the robotic system, we will not have difficulties in paying the investment. The contract provides for the payment of interest only in the first 3 years (every 6 months), with time to complete the installed capacity".

As for the control information on income and expenses for the month, the producer indicates that he has accounting records and monitors the results, the gross margin is around 50%. In this sense, the manager indicates that he is fully satisfied with the implementation of robotization in the rural property, not only for the financial advantages but for the improvement in the quality of activities, especially for reducing manual work and avoiding hiring third-party labor. The manager has a son who works in the activity, with an interest in continuing the business and ensuring the process of family succession in the future.

Considering the manager's satisfaction with the results of the activity, he also commented that "the dairy activity stands out compared to other investments in rural areas, because it has a monthly cash inflow, contributing to the family income and the livelihood of the family in rural areas", as well as he considers that the return on investment is viable and satisfactory.

In this sense, the control information and analysis of the results of activities developed in rural areas are relevant for the evaluation of the performance of activities (Kruger et al., 2020), especially for the control and analysis of the results of the dairy activity (Kruger et al., 2019). The study corroborates the recommendations of Franco Neto & Lopes (2014), highlighting the characteristics of the robotic milking system and comparing economic results, demonstrating that the technology proposed by Agribusiness 4.0 can favor the production increased, control of milk quality, and the analysis of results.

There is also a reflection on the workforce in the field after the implementation of the concept of agriculture 4.0, mainly in the need for specialization to work with new technologies as indicated in the study by Fernandes et al. (2024) and Bassotto et al. (2022, 2023). The results also indicate that the reflection of using prioritization methods for decision-making can improve operating costs, making the activity more profitable, corroborating the results of Lizot et al. (2024).

The analysis allows us to observe that investments in technologies improve processes and contribute to improving quality, corroborating the indications by Vilela et al. (2017), as well as with the findings of Córdova et al. (2018), demonstrating the importance of robotization for monitoring the management of cows, animal welfare and dairy productivity, consequently favoring the evaluation and management of results.

5 Conclusions

The problem of selecting technological systems is very relevant for any company and requires the consideration of a large number of factors, some of which can be quantitative and qualitative. Several approaches have been suggested in the literature for solving the equipment selection problem. However, the results of this study indicate that the use of the AHP method creates a more robust application for decision makers to select and evaluate the available systems throughout the acquisition process, allowing them to make choices based on both qualitative and quantitative criteria.

The objective of the article was to select a robotic system for milking and identify its benefits within the concept of Agribusiness 4.0. The AHP method was used for the process of selecting the most appropriate system, considering three basic criteria, which proved to be consistent. The analysis comparatively considered the perceptions and information of the mechanized milking process, with the implantation of robotization in the studied rural property.

The results allow us to observe several benefits of robotization in milking:

(i) reduction in the demand for operational and manual activities, helping managers to reduce family and outsourced labor (labor reduction).

(ii) information management, making it possible to control daily production by dairy matrix, milk quality, consumption, temperature (in case of any illness), fertile period, etc. The robot controls productivity by matrix. This control prevents loss of production, especially when there is a need to discard some milking due to illness.

(iii) improvement in animal health and well-being, the robot controls the individual feeding of dairy cows, noting the need to increase inputs for cows that have had recent calves, those that are in the final stage of lactation or insemination, consequently, also occurs improvement in the productivity of the herd.

(iv) cost reduction, given that the robot controls consumption and productivity per dairy cow, this individual management per head generates cost savings.

(v) satisfaction of rural producers with the dairy activity, based on the relationship between investments made and the economic and financial return of the activity.

The implementation of robotization shows that the activities carried out by the robot guarantee control for the producer, favoring the care of the matrices, and guaranteeing better conditions of animal welfare. It also favors the reduction of the demand for labor, being one of the difficulties identified for the development of production, since there is a need for 24-hour care. Another perception identified with robotization is related to the management of information and costs since the system offers this control for the analysis and monitoring of the manager. In the evidenced context, the manager reports his satisfaction with the implementation of the robotic system, not only for the perceived financial advantages but for the reduction of the work demand.

In general, it can be noted that the results demonstrate the relevance of investments in technologies, in the context of Agribusiness 4.0, aiming to improve productivity, milk quality, management of cows and their well-being, contributing to the generation of information for control, planning and management of results.

The study contributes to discussions about the need for investments and financing, as well as public policies that can favor family farming and small rural producers, especially to enhance the permanence of young people in rural areas, as successors of existing enterprises. In this sense, the relevance of the role of accounting for the analysis of economic-financial results is highlighted, to relate economic performance with dairy productivity. To complement the present research and/or for the purposes of giving continuity to it and/or with a view to future research, approach from a methodological point of view a “comparative case study”, aiming to favor the decision-making process of those producers in the sector. Dairy has expectations of investing to implement robotization as an instance of innovation for the technological and productive transformation of their systems, within the framework of the Agribusiness 4.0 paradigm.

The study has its limitations because it is a specific case study and cannot generalize the results. For future research, multiple case studies evaluating the financial gains of dairy farms after the implementation of robotic milking are suggested.

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