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TECHNOLOGY-DRIVEN IMPROVEMENTS IN DAIRY CALF AND HEIFER MANAGEMENT: PERFORMANCE AND ECONOMIC IMPACTS

Luís Henrique Rodrigues Silva
Magister Scientiae

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LUÍS HENRIQUE RODRIGUES SILVA

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Dissertation submitted to the Animal Science Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Magister Scientiae*.

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Co-advisers: Alex Lopes da Silva
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To my parents,
I dedicate.

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ABSTRACT

SILVA, Luís Henrique Rodrigues, M.Sc., Universidade Federal de Viçosa, August, 2024. **TECHNOLOGY-DRIVEN IMPROVEMENTS IN DAIRY CALF AND HEIFER MANAGEMENT: PERFORMANCE AND ECONOMIC IMPACTS**. Adviser: Polyana Pizzi Rotta. Co-advisers: Alex Lopes da Silva and Marcos Inacio Marcondes.

This study aimed to investigate how productive tiers on dairy farms impact the rearing and production costs of dairy calves and heifers in Brazil and estimate the payback timeline in average number of lactations. Data were gathered from 311 dairy farms in Minas Gerais, classified into three milk productive tiers based on average milk production: low (LOW) at 12.00 L/cow/d (7.36 -14.50 L/cow/d), intermediate (INT) at 18.00 L/cow/d (14.60 – 22.50 L/cow/d), and high (UPP) at 26.70 L/cow/d (22.60 – 32.00 L/cow/d). Statistical analyses were conducted using the GLIMMIX procedure in SAS Studio®, considering P-values < 0.05 as statistically significant and values between 0.05 and 0.10 as indicative of trends. The study found the Holstein breed was prevalent in UPP systems, while a Holstein × Gyr crossbreed animals were more prevalent in the LOW and INT tiers farms. The LOW and INT farms, characterized by more extensive rearing practices, had lower total milk outputs, larger grazing areas, and less intensified facilities. These conditions resulted in inferior performance metrics such as lower average daily gain (LOW: 0.41 ± 0.01 kg/d; INT: 0.51 ± 0.01 kg/d; UPP: 0.60 ± 0.01 kg/d) and delayed age at first calving (LOW: 35.6 ± 0.50 months; 29.9 ± 0.35 months; UPP: 26.0 ± 0.50 months). Consequently, the cost of raising a heifer from birth to first calving was highest in LOW farms at approximately US$ 2,006.4 ± 62.52, compared to US$ 1,821.4 ± 44.35 in INT and US$ 1,884.6 ± 62.52 in UPP. Feeding, labor, and machinery costs were the primary expenses, accounting for over 83, 85 and 83% of total costs across for LOW, INT e UPP respectively. The payback time based on expected production for a heifer need to remain in the herd was 3.98, 2.64 and 1.64 lactations for the LOW, INT and UPP tiers. This analysis underscores the significant influence of a farm's milk productive tiers on both performance and economic outcomes in dairy calf and heifer rearing. Farms with lower milk productive tiers incurred higher costs due to less efficient animal performance. The findings highlight the critical role of targeted investments to enhance efficiency and in dairy operations.

Keywords: dairy farms; economic efficiency; farm management; calf;

heifer

RESUMO

SILVA, Luís Henrique Rodrigues, M.Sc., Universidade Federal de Viçosa, agosto de 2024. **MELHORIAS BASEADAS NA TECNOLOGIA NO MANEJO DE BEZERRAS E NOVILHAS LEITEIRAS: DESEMPENHO E IMPACTOS ECONÔMICOS**. Orientadora: Polyana Pizzi Rotta. Coorientadores: Alex Lopes da Silva e Marcos Inacio Marcondes.

Este estudo teve como objetivo investigar como os diferentes níveis produtivos em fazendas leiteiras impactam os custos de criação e produção de bezerras e novilhas leiteiras no Brasil e estimar o prazo de retorno em média de lactações. Os dados foram coletados de 311 fazendas leiteiras em Minas Gerais, classificadas em três níveis produtivos com base na produção média de leite: baixo (LOW) com 12,0 L/vaca/dia (7,36 – 14,50 L/vaca/dia), intermediário (INT) com 18,0 L/vaca/dia (14,60 – 22,50 L/vaca/dia) e alto (UPP) com 26,70 L/vaca/dia (22,60 – 32,00 L/vaca/dia). As análises estatísticas foram realizadas utilizando o procedimento GLIMMIX no SAS Studio®, considerando valores de $P < 0,05$ como estatisticamente significativos e valores entre 0,05 e 0,10 como indicativos de tendências. O estudo encontrou uma prevalência da raça Holandesa em sistemas UPP, enquanto animais mestiços Holandês × Gir foram mais prevalentes em fazendas dos níveis LOW e INT. As fazendas LOW e INT, caracterizadas por práticas de criação mais extensivas, apresentaram menores produções totais de leite, maiores áreas de pastagem e instalações menos intensificadas. Essas condições resultaram em métricas de desempenho inferiores, como menor ganho médio diário (LOW: 0,41 ± 0,01 kg/dia; INT: 0,51 ± 0,01 kg/dia; UPP: 0,60 ± 0,01 kg/dia) e maior idade ao primeiro parto (LOW: 35,6 ± 0,50 meses; INT: 29,9 ± 0,35 meses; UPP: 26,0 ± 0,50 meses). Consequentemente, o custo para criar uma novilha do nascimento ao primeiro parto foi maior nas fazendas LOW, aproximadamente US$ 2.006,4 ± 62,52, comparado a US$ 1.821,4 ± 44,35 nas INT e US$ 1.884,6 ± 62,52 nas UPP. Alimentação, mão-de-obra e custos com maquinário foram as principais despesas, representando mais de 83, 85 e 83% dos custos totais para LOW, INT e UPP, respectivamente. O tempo de retorno com base na produção esperada para que uma novilha permaneça no rebanho foi de 3,98, 2,64 e 1,64 lactações para os níveis LOW, INT e UPP. Esta análise destaca a influência significativa dos níveis de produção leiteira da fazenda nos resultados de desempenho e econômicos na criação de bezerras e novilhas leiteiras. Fazendas com menores níveis produtivos apresentaram custos mais elevados devido ao desempenho animal menos eficiente. Os resultados destacam o papel crítico dos investimentos direcionados para aumentar a eficiência nas fazendas leiteiras.

Palavras-chave: fazendas leiteiras; eficiência econômica; gestão de fazenda; bezerro; novilha.

BIOGRAPHY

Luís Henrique Rodrigues Silva, son of Maria Aparecida Teixeira Rodrigues da Silva and Luiz Henrique Santos da Silva, was born in Guiricema, MG – Brazil, on September 11, 1994. Coming from a family of rural producers, he has always shown an interest in the rural environment from an early age.

He began his studies in Animal Science in 2012 and became an Animal Scientist in 2022 from the Universidade Federal de Viçosa.

In August 2022, at the same institution, he started his master's degree in animal science in the area of Ruminant Nutrition and Production with an emphasis on Dairy Cattle, advised by Dr. Polyana Pizzi Rotta. He submitted his dissertation to the committee on August 21, 2024.

SUMMARY

GENERAL INTRODUCTION

The rearing phases of dairy heifers are integral and indispensable parts of a milk production system. These heifers will be the future dams and replacements of the herd, and they represent a significant portion of a dairy farm's expenses, surpassed only by the feeding of lactating cows (Tozer and Heinrichs, 2001). The decisions made by farmers directly influence the performance (Machado et al., 2019), productive life, and production cost of a heifer at calving (Hutchison et al., 2017). Among the factors that most burden the production cost is: 1) the rearing system, encompassing the predominant breed (Santos and Lopes, 2014), feeding, labor, housing (Hawkins et al., 2020), and management practices; 2) average daily gain (ADG); and 3) age at first calving (AFC; Daniels, 2010; Turiello et al., 2020), which directly interfere with the animal's productive capacity.

The production system strongly influences the zootechnical performance and final cost spent on rearing. In more extensive systems, there is a lower financial investment (Hawkins et al., 2020); however, it is common for zootechnical indicators to be worse, such as ADG (Hadfield et al., 2021) and consequently AFC (Handcock et al., 2020). Therefore, despite a lower monetary expenditure, a higher AFC would result in a higher final cost due to increased non-productive days within the herd (Hutchison et al., 2017). Conversely, in intensive systems, there is a higher financial investment, particularly in facilities (Hawkins et al., 2020). However, this scenario provides greater welfare and performance to the animals due to better thermal and sanitary comfort, which will directly reflect in higher fertility (Negrón-Perez et al., 2019) and shorten the non-productive phase. In this type of system, the cost of facilities surpasses the cost of labor when compared to dry-lot and pasture systems, due to a higher financial investment that simultaneously optimizes labor.

The predominant breed of the herd has a direct relationship with zootechnical indicators and production cost at calving. Quirino et al. (2022) reported higher ADG for Holstein × Gyr heifers compared to Holstein heifers in the same rearing system under tropical grazing. Santos and Lopes (2014) found higher production costs for Holstein heifers compared to Holstein × Gyr heifers. However, the first group had a shorter AFC by 89 days. In this scenario, despite the higher cost, due to the lower age at first calving, Holstein heifers will contribute positively to the farm's cash flow earlier because they begin producing milk before Holstein × Gyr heifers.

Previous studies have demonstrated that a reduction of age at puberty, and consequently the reduction of AFC is largely associated with an increase in ADG (Davis Rincker et al., 2011; Akins, 2016). The onset of puberty is obviously a prerequisite for successful conception and has consistently been shown to be more influenced by body weight than by age (Handcock et al., 2020). Hayes et al. (2019) evaluated the days needed between onset of puberty to the first conception according to different ADG (0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 kg/day). On average, 104, 87, 73, 61, 51, and 43 days were required for the respective ADG cited.

Zanton and Heinrichs (2005) recommended an average daily gain (ADG) of 0.8 kg for prepubertal Holstein heifers, with an acceptable range from 0.7 to 0.9 kg/day. However, excessively high ADG can lead to the accumulation of adipose rather than parenchymal tissue in the mammary gland, potentially compromising future milk production (Weller et al., 2016; Albino et al., 2017). Conversely, heifers with low ADG, ranging between 0.40 and 0.56 kg/day, may experience delayed puberty (Davis Rincker et al., 2011) and subsequently later calving (Raeth-Knight et al., 2009). Therefore, managing ADG to prevent improper mammary tissue development while minimizing the age at puberty can effectively reduce the AFC, benefiting both the health of the animal and the profitability of the dairy operation.

Tozer and Heinrichs (2001) documented an 18% reduction in rearing costs when the AFC was decreased from 25 to 21 months. However, a study by Turiello et al. (2020) noted a decrease in milk production of 1.7 kg per animal per day for heifers with an AFC of less than 23 months, compared to those calving at 24 months. Conversely, for heifers with an AFC exceeding 24 months, Turiello et al. (2020) observed an incremental increase in milk production: 0.6 kg per animal per day for an AFC of 27 months, 1.1 kg for 31 months, and 1.8 kg for 35 months, all compared to an AFC of 24 months.

At the conclusion of the first lactation, heifers with an AFC of 23, 27, 31, and 35 months experienced incrementally longer periods of open days—14.0, 6.5, 19.2, and 20.2 days more, respectively, compared to those with an AFC of 24 months (Turiello et al., 2020). Similar results were also described by Ettema and Santos (2004), who found the shortest open period in cows calving for the first time at 23–25 months of age. This delay resulted in a negative economic impact quantified as losses of $25.71, $104.73, $150.58, and $235.52, respectively, for each group (Turiello et al., 2020). These findings highlight the complex balance between reducing rearing costs through earlier calving and the potential long-term effects on milk production and economic outcomes.

Most studies that report lower milk production with reduced AFC attribute this to the ongoing growth needs of the animal, which require energy to be diverted from milk production to bodily development (Krpálková et al., 2014). The NASEM (2021) estimates that for each kg less body weight at the time of calving, there is a corresponding decrease of 10 kg in milk production during the first lactation. Conversely, an AFC exceeding 24 months is linked with diminished economic returns due to heightened rearing expenses, despite the potential for increased revenue from higher milk production (Turiello et al., 2020). This underscores the need for a balanced approach to managing AFC, optimizing both the physical development of heifers and the economic sustainability of dairy operations.

The AFC serves as a critical indicator from both zootechnical and economic perspectives. Calving heifers at younger ages effectively shortens the interval between generations, thereby enhancing the potential for accelerated genetic improvement within the herd (Lin et al., 1986; Hoffman et al., 1996). Furthermore, reducing AFC minimizes non-productive days within the herd (Boulton et al., 2017), which positively impacts the farm's cash flow by allowing animals to enter production sooner. This approach not only streamlines herd management but also maximizes profitability by reducing overhead costs associated with maintaining non-lactating animals.

Given the economic scenario, more important than the final cost of raising a heifer to calving is understanding the time required for these heifers to pay for themselves. The lowest cost is not always associated with maximized milk production or economic return. Therefore, a good parameter for observation would be to compare the number of lactations required for the farm to begin recovering the total value invested from birth to calving. According to Boulton et al. (2017), the studied herds required an average of 1.5 lactations to cover their production costs when heifers. In 23.6% of the farms, the cost of raising a heifer was covered by the end of the first lactation, increasing to 91.1% by the end of the second lactation (Boulton et al., 2017). Several factors are associated with this number, such as the net margin of the activity, milk price, average herd milk production, mortality, among others.

In this sense, an important tool to assist decision-making on dairy farms is the creation of benchmarks and the measurement of production costs of dairy calves and heifers. However, it is rare for farms to have accurate financial control over the production cost of these categories due to the particularities of dairy farming that make the calculation difficult, such as several interconnected sectors within the activity and different times of capital input and output (Mohd Nor et al., 2015).

Therefore, the primary aim of this study was to conduct a comparative analysis of different milk production systems, evaluate the impact of varying milk productive tiers on the rearing, performance, and production costs of dairy calves and heifers, as well as the number of lactations required to cover their costs within the production system. This analysis will help in understanding how milk productive advancements and management practices influence economic outcomes and productivity in dairy farming.

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CHAPTER I

Chapter formatted according to the scientific journal: Journal of Dairy Science.

Interpretative summary: **A comparative analysis of milk production systems: I. Milk production tiers and their impact on dairy calf and heifer rearing in Brazil**. By Silva et al. The present study aims to evaluate the impact of production tiers on dairy farms in the rearing strategies of calves and heifers in Brazil. Dairy farms were classified into three milk production tiers based on average milk production: 12.0, 18.0, and 26.7 kg/d for low, intermediate, and high production tiers, respectively. Low-tier farms employ systems, and management strategies of an extensive nature, whereas high-tier farms operate under more intensive conditions, leading to better performance in calf and heifer rearing, such as higher average daily gain and lower age at first calving.

Running Head: Dairy calves and heifers' production in Brazil

A comparative analysis of milk production systems: I. Milk production tiers and their impact on dairy calf and heifer rearing in Brazil

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ABSTRACT

This study aimed to describe and characterize the milk production systems for dairy calves and heifers based on the farm milk production tiers. We used 311 dairy farms located in the state of Minas Gerais, Brazil. Minas Gerais state is the largest milk producer in Brazil and is often considered representative of the average trends in Brazilian milk production. The data collected were provided by the GRUPO EDUCAMPO LEITE - SEBRAE-MG and contained complete information for the period from january to december 2021. The dairy farms were segregated into three milk production tiers according to average milk production: low production tiers (LOW) 12.00 L/cow/d (7.36 - 14.50 L/cow/d); intermediate (INT) 18.00 L/cow/d (14.60 – 22.50 L/cow/d), and high production tiers (UPP) 26.70 L/cow/d (22.60 – 32.00 L/cow/d). The predominant breed used in UPP systems was Holstein, while Holstein × Gyr was predominant in LOW and INT. Additionally, LOW and INT exhibited more extensive rearing characteristics for calves and heifers, such as lower total milk production despite having larger available areas, predominant use of pastures, and less elaborate facilities for cows, calves, and heifers. They also demonstrated greater use of natural mating with bulls and less artificial insemination, resulting in poorer performance, including lower ADG (LOW: 0.41 ± 0.01 kg/d; INT: 0.51 ± 0.01 kg/d; UPP: 0.60 ± 0.01 kg/d). and higher age at first calving (LOW: 35.6 ± 0.50 months; 29.9 ± 0.35 months; UPP: 26.0 ± 0.50 months), compared to UPP. Thus, the efficiency in rearing dairy calves and heifers is linked to the milk production profile adopted by dairy farms, given that the higher the tier of productivity, the better the performance these animals.

Key words: Brazilian dairy industry, calf, dairy farms, heifer rearing

INTRODUCTION

Milk production systems are undergoing a continual process of intensification to enhance zootechnical indicators and ensure the responsible use of environmental resources (Berton et al., 2023). An analysis of Brazil's agricultural censuses from 2006 to 2017 reveals significant shifts within the dairy sector. There was a 13% decline in the number of milk-producing establishments, from 1,350,809 to 1,176,295. Additionally, the population of milking cows decreased by 9.5%, from 12,710,701 to 11,506,788. In contrast, total milk output, encompassing raw, processed, and derivative products, had a substantial increase of 46.6%, rising from 20.6 billion to 30.2 billion liters (IBGE, 2006; 2017).

Genetics, nutrition, health, and management are the foundational pillars of efficient dairy production (Bach et al., 2020). Feed efficiency, a critical trait in dairy herds, is highly prized not only for its direct correlation to favorable economic returns but also for facilitating more sustainable land and resource utilization (Bach et al., 2020). A high number of calves and heifers within a herd often suggests a suboptimal age at first calving (**AFC**), which may correlate with increased mortality or culling rates among cows (Mohd Nor et al., 2015), as well as elevated maintenance costs (Overton and Dhuyvetter, 2020).

Few, if any, studies have directly aimed to describe and compare the impact of the productive level of dairy farms on the rearing and development of dairy calves and heifers. Understanding this gap is of utmost importance for generating benchmarks that support decision-making on dairy farms. Given the increasing concern about environmental sustainability, production systems will need to become increasingly productive within ever-smaller areas. This highlights the need for more efficient animals, which includes improvements in the calf and heifer rearing phases.

The objective of this study was to describe and characterize the milk production systems for dairy calves and heifers in State of Minas Gerais - Brazil. We hypothesized that farms with more advanced milk productive tiers would demonstrate more intensive rearing and management practices. Such enhancements are expected to be reflected in improved zootechnical indicators throughout the developmental phases of calves and heifers.

MATERIAL AND METHODS

Data and milk productive tiers

This study analyzed 311 dairy farms located throughout the state of Minas Gerais, Brazil. Notably, Minas Gerais is an important region for dairy production in Brazil, contributing approximately 27% to the country's total milk output (IBGE, 2022). This state is also emblematic of Brazil in terms of its economic, social, and political dimensions, making it an ideal representation for studying national trends in dairy farming.

These farms were part of the EDUCAMPO – LEITE group, a program supported by the Brazilian Micro and Small Business Support Service (SEBRAE-MG). Data were extracted from a comprehensive database provided by SEBRAE-MG, which underwent a thorough consistency check before analysis. The selected farms represented 126 different municipalities across Minas Gerais (Figure 1).

The data used in this study are retrospective, collected from 349 farms participating in the SEBRAE/EDUCAMPO – MILK project. All farms included in this study received technical and managerial assistance through the project for a period ranging from 1 to 15 years. During this time, all relevant technical and managerial information was recorded monthly in a dedicated dairy farm management system, forming the database used in this analysis.

The criteria for farm inclusion in the study were as follows: (1) farms must have been assisted by the EDUCAMPO – MILK project for at least one year, specifically during the period from January 1, 2021, to December 31, 2021; and (2) farms must have consistent data, covering at least 80% of the variables addressed in this study. Thus, 311 dairy farms remained in the study.

A comprehensive questionnaire was designed to gather detailed information on the distribution and characteristics of milk production systems across 311 dairy farms. This instrument captured data on various dimensions, including the predominant breed in the herd, primary facilities, and the management practices related to nutrition, health, and reproduction. Additionally, it sought details on key zootechnical indicators. Each farm's data were meticulously compiled to ensure an accurate representation of their operational specifics during this period.

For analytical comparison, the 311 farms were categorized into three distinct milk productive tiers based on daily milk production per cow: low (**LOW**), intermediate (**INT**), and upper (**UPP**). Classification was conducted using a percentile approach. The LOW group consisted of farms falling within the bottom 25% of the production scale (n = 78), with milk outputs ranging from 7.36 to 14.50 L/cow/d and an average of 12.0 L/cow/d. The INT group encompassed farms between the 25th and 75th percentiles (n = 155), featuring a range from 14.60 to 22.50 L/cow/d and an average of 18.0 L/cow/d. Conversely, the UPP group included the top 25% (n = 78), with milk production ranging from 22.60 to 32.00 L/cow/d and an average of 26.7 L/cow/d. This segmentation approach was specifically chosen to accentuate the pronounced variations in technology adoption and productivity across the spectrum of dairy farms as suggested by Zuliani et al. (2018).

Since all the farms participating in this study receive technical and managerial assistance through EDUCAMPO - LEITE, the information is naturally included in a database extracted from the software used by the group for financial and zootechnical management. Thus, the data were previously entered monthly by each consultant during their assistance visits to the farms. As this study utilized an existing database, submission and approval by an ethics committee were not required, as the data used were already present in the database.

Production Systems

To characterize the production systems, information was evaluated regarding: 1) predominant breed; 2) facilities and housing for cows, calves, and heifers; 3) number of live-born calves; 4) average number of lactating cows; 5) average daily milk production; 6) farm size; and 7) milk production per worker per day.

Breeds were divided into 1) Holstein; 2) Holstein × Gyr; 3) Jersey; 4) Holstein × Jersey; 5) Brown Swiss; 6) Holstein × Guzera; and 7) Gyr. However, due to negligible or low response rates, the breeds Jersey, Brown Swiss, Holstein × Guzerá, and Gyr were collectively classified under the category "other breeds."

The predominant facilities and management systems for cows evaluated were 1) free stall; 2) compost bedded pack barn; 3) pasture; 4) free stall cross ventilation; 5) CBP cross ventilation (forced ventilation barns); and 6) dry lot. Regarding lactating cow facilities, no responses were obtained for CBP cross ventilation and free stall cross ventilation.

The facilities and management systems for calves were divided into 1) tropical housing system (an enclosed environment where the calf is sheltered from rain and sun, with the presence of forage for resting areas); 2) pen on the floor (comprising concrete-floored pens with sides closed with wire mesh or masonry and with a roof); 3) tropical string (calves are tied with ropes connected to a steel cable allowing some mobility); 4) indoor suspended cage (suspended cage systems housed within masonry buildings).

The heifer management systems or facilities were divided into 1) CBP; 2) free stall; 3) extensive paddock; 4) intensive paddock; and 5) dry lot. Additionally, the use of the mentioned systems was divided into two rearing phases: 1) from weaning to heifer pregnancy; and 2) from pregnancy to calving. However, the free stall system was not mentioned at any tier for rearing systems.

Regarding reproduction, the predominant type of reproductive biotechnology adopted on the farm was characterized as one of the following: (1) bull; (2) bull and AI; (3) AI with sexed semen; (4) AI with conventional semen; (5) IVF/ET. The use of beef bull semen/breeding was also evaluated. Beef semen/breeding was considered when specialized beef production breeds were used. In addition, the average conception rate of each herd was also evaluated.

Calf and Heifer Management Practices

Regarding the care and management practices for calf rearing, we assessed whether there was night supervision of the maternity pen, with a positive response recorded if the farm assigned an employee to this function between 1800 and 0600 h. In terms of colostrum administration, we evaluated the type of colostrum provided, distinguishing among 1) fresh; 2) thawed; 3) colostrum replacer; or 4) enriched colostrum, defined as the addition of powdered colostrum to cow colostrum to improve the brix percentage, in cases where its quality is below 25%. Additionally, we assessed whether farms measured the Brix degree of colostrum and the timing after birth when colostrum was administered. The options for thawed, colostrum replacer, and enriched colostrum were consolidated into "other types" for analysis.

The provision of transition milk was evaluated based on the number of days it was offered and whether the practice of providing transition milk was adopted on the farm. Thus, in addition to evaluating whether the farm provides transition milk or not, the days of provision presented later represent an average only for those farms that do provide it. Calf feeding protocols were analyzed and included: 1) fixed volume; 2) step-down; or 3) step-up/step-down methods. Additionally, feeding methods such as 1) bucket feeding with or without a nipple; 2) bottle feeding; 3) automatic milk feeder; and 4) suckling from the dam were assessed. The type of milk provided—1) non-saleable milk (milk with antibiotic residues, primarily, or any other medications that require a withdrawal period); 2) saleable milk; or 3) milk replacer was also examined. Furthermore, the average daily milk volume provided and the total milk volume until weaning were evaluated.

The duration of milk feeding for calves was calculated based on the period from the first day of life to the last day of milk intake. The days of concentrate consumption were assessed from the first to the last day of concentrate provision during the rearing phase. Weaning BW was measured using either tape or scale, though the specific method used on each farm was not differentiated.

For male calves born on the dairy farm, their destinations were evaluated with several options: 1) donation within the first week of life; 2) retention on the farm for rearing until fattening; 3) sale after weaning; or 4) other (sold within the first week, reared for breeding purposes, sold before weaning, or donated after the first week). For male calves retained on the farm, it was also assessed whether they were reared under the same systems and management practices as female calves.

The rearing days (the interval from weaning to calving), total feed intake during this phase, and ADG were evaluated in relation to the average rearing period. Regarding feed management, the main forages utilized for heifers during winter and summer were assessed, with options including: 1) corn silage; 2) pasture; 3) chopped elephant grass (ensiled or fresh); 4) chopped sugarcane (ensiled or fresh); or 5) other forages. Additionally, the source of the concentrate used was evaluated, with options being: 1) formulated on the farm; or 2) commercial concentrate.

Statistical Analyses

Some variables exhibited low response and were grouped into an "others" category to facilitate statistical analysis. The criterion for this grouping was number of responses fewer than three across all milk productive tiers for multiple-choice variables. Variables with no responses at any milk productive tier were excluded from the analysis.

For continuous variables, an ANOVA was conducted using the GLIMMIX procedure in SAS (SAS Studio® 2024), with milk productive tiers (LOW, INT, and UPP) tested under a normal distribution of residuals. When necessary, the PDIFF option was included in the LSMEANS command to enable multiple comparisons of means. Differences were considered significant at a P value < 0.05 and trends were noted when $0.05 < P < 0.10$.

Binary variables were analyzed through logistic regression using the GLIMMIX procedure of SAS (SAS Studio® 2024), according to milk productive tiers s (LOW, INT, UPP), utilizing a binary distribution and the logit link. These variables were further analyzed to determine the odds ratio (OR) for an event or situation occurring among the contrasted milk productive tiers. For all analyses, differences were declared significant when the P value was < 0.05 and trends were identified when $0.05 < P < 0.10$.

Table 2 presents the descriptive statistics of the discrete variables for reference purposes. The PROC UNIVARIATE procedure of SAS (SAS Studio® 2024) was used to obtain the descriptive statistics data. The data presentation did not enter any statistical analysis but served as supplementary material to enhance understanding of the OR for the respective variables.

RESULTS

Characterization of Dairy Farms

The average milk production per cow/d were 12.00, 18.00, and 27.00 L for LOW, INT, and UPP respectively and was the criterion for dividing the technological levels ($P < 0.01$; Table 1). Additionally, the number of calves and the average number of lactating cows were higher ($P < 0.01$) for UPP compared to INT and LOW (Table 1). The total milk production of the farm, as well as the efficiency indicator of liters of milk per worker per day was higher ($P < 0.01$) for UPP, followed by INT and LOW (Table 1). Conversely, dairy farms classified as LOW - tier tended ($P = 0.06$) to have a larger area dedicated to dairy activity compared to those classified as UPP - tier, with an average of 45% more area. The time of involvement in dairy farming did not show differences ($P = 0.19$) among the three milk productive groups (Table 1). The average herd conception rate was lower ($P = 0.01$) for LOW but did not differ between INT and UPP (Table 1).

Regarding the predominant breed of the herd, INT and UPP had lower OR ($P < 0.01$) of having Holstein × Gyr as the predominant breed compared to LOW (Figure 2). The

Holstein breed was more commonly used in UPP and INT (Figure 2). Specifically, UPP had an odds ratio of 5.09 and 4.67 times higher for using Holstein (P < 0.01) and a 95% and 75% lower odds ratio (P < 0.01) for raising Holstein × Gir, compared to LOW and INT respectively, indicating a clear predominance of Holstein breed animals in UPP dairy farms.

The UPP tier had 83% lower OR ($P < 0.01$) of using beef bull semen in the herd compared to LOW, and 77% lower OR ($P < 0.01$) compared to INT (Figure 3). Furthermore, UPP farms showed 98% lower OR ($P < 0.01$) of using bull mating as the main reproductive biotechnology relative to LOW, and a 90% lower OR ($P = 0.03$) compared to INT. Conversely, UPP farms exhibit significantly higher OR of using AI with sexed female semen, being 12.5 times more likely compared to LOW ($P < 0.01$) and 4.06 times more likely than INT ($P < 0.01$).

The CBP was the most utilized facility by UPP dairy farms ($P < 0.01$), with a trend toward free stall use ($P = 0.10$) compared to INT. Conversely, UPP had a 73 ($P = 0.01$) and 65% ($P = 0.04$) lower OR of having other systems predominantly for lactation cows compared to INT and LOW, respectively (Figure 4). Additionally, UPP presented 93 ($P < 0.01$) and 97% ($P < 0.01$) lower OR for utilizing grazing systems for lactation cows compared to INT and LOW, respectively (Figure 4). This data indicates that pasture-based systems are predominant in LOW compared to INT ($P = 0.02$) and UPP. In contrast, dry lot systems were predominantly used by INT, while CBP and free stall systems were preferred by UPP (Figure 4).

Calf Rearing Practices

The most utilized maternity type in UPP was the CBP (Figure 5), with 14.2 times higher OR compared to INT ($P < 0.01$). There was no response for this system within the LOW group. For INT and LOW, the most adopted system was pasture-based maternity (Figure 5), with UPP having 85 ($P < 0.01$) and 86% ($P < 0.01$) lower OR compared to LOW and INT, respectively for this maternity type. The LOW farms did not engage in nighttime maternity checks (Figure 5). In contrast, UPP farms have 20.1 times higher OR ($P < 0.01$) compared to INT to support maternity nighttime (Figure 5).

The UPP and INT farms had higher ($P < 0.01$) OR compared to LOW farms for adopting colostrum storage. A trend ($P = 0.05$) was observed when contrasting INT and LOW for the presence of a colostrum storage, while an OR of 16.5 ($P < 0.01$) was found between UPP and LOW (Figure 6). Additionally, when UPP was contrasted with INT, an OR of 6.64 ($P < 0.01$) was found in favor of UPP (Figure 6). The practice of measuring the Brix degree of colostrum was higher for UPP farms, with OR of 16.5 ($P < 0.01$) and 6.64 ($P < 0.01$) compared to LOW and INT, respectively (Figure 6).

After birth, the shortest time to colostrum feeding (Table 3) occurred in UPP and LOW ($P < 0.01$), being an average of 2.7 h. Fresh colostrum was the predominant choice in LOW ($P = 0.01$) and INT ($P < 0.01$) compared to UPP. The UPP farms showed higher ($P < 0.01$) OR for providing colostrum replacer and other types of colostrum compared to the other systems evaluated in this study (Figure 6).

The UPP and INT farms had 2.35 ($P = 0.05$) and 2.09 ($P = 0.04$) times higher OR of providing transition milk to calves (Figure 7a) compared to LOW. Among the dairy farms that provide it, no statistical difference ($P = 0.19$) was observed for the number of days of transition milk provided (Table 3). The UPP and INT farms had 75 and 82% lower OR of providing saleable milk compared to LOW ($P < 0.01$), making non-saleable milk the predominant type, with OR of 3.61 ($P < 0.01$), and 2.23 ($P = 0.02$), respectively (Figure

7a). The UPP farms also had 5.59 times higher OR of using milk replacer in calf diets compared to LOW (*P* = 0.03), but no difference (*P* = 0.22) was observed when contrasted with INT.

The bucket with a nipple was the most used milk delivery method by UPP farms (Figure 7b), with 4.31 and 2.49 times higher OR compared to LOW and INT, respectively (*P* < 0.01). A trend toward lower use of bottles (Figure 7b) was observed by UPP dairy farms when contrasted with LOW (*P* = 0.06) and INT (*P* = 0.08). The LOW farms have higher OR of using suckling calf (Figure 7b) compared to INT (*P* < 0.01).

The average daily volume of milk provided differed among the milk productive tier (*P* < 0.01), being higher for UPP (5.3 L/d), followed by INT (4.8 L/d), and LOW (4.3 L/d; Table 3). Conversely, the days in the weaning period were longer (*P* < 0.01) for LOW but did not differ between INT and UPP (Table 3).

The UPP farms showed a greater predisposition to not retain male calves in the farm. The INT and UPP had 4.17 (*P* = 0.01) and 10.9 (*P* < 0.01) times higher OR, respectively, of donating male calves within the first week of life compared to LOW (Figure 8). Conversely, INT and UPP had 49 (*P* = 0.03) and 86% (*P* < 0.01) lower OR, respectively, of retaining these animals for fattening on the farm compared to LOW (Figure 8). It was also noted that, among male calves that remained on the farm, only LOW farms rear them similarly to females (facilities, weaning protocol, etc.), as INT and UPP had 58% lower OR (*P* = 0.01) for such management practices, respectively (Figure 8). Indoor suspended cage was the most used housing system for calves in the UPP group (*P* = 0.02). Additionally, INT showed an OR of 1.87 times (*P* = 0.03) for using the tropical system compared to LOW (Figure 9).

Regarding solid diet, the type of forage offered to calves (Figure 10) tended to differ only when INT and LOW were contrasted (*P* = 0.05), with INT having 1.98 times higher

OR of offering corn silage compared to LOW dairy farms. For concentrate provision, INT and UPP have 50 (P = 0.07) and 71% (P < 0.01) lower OR of using commercial concentrate formulations for calves. Concentrate provision for calves tended to be later in LOW (P = 0.05), where animals had their first access to concentrate after the fifth day of life, while in INT and UPP it was on average after the first day (Table 3). The average daily concentrate intake also followed this pattern, being lower (P < 0.01) for LOW (0.8 kg/d) compared to INT (0.9 kg/d) and UPP (0.9 kg/d).

Heifer Rearing Practices

The INT and UPP farms present 53 (P = 0.02) and 75% (P <0.01) lower OR compared to LOW for the use of commercial concentrates in growing phase, respectively (Figure 10), with UPP having a reduced OR of 46% for this characteristic compared to INT (P = 0.03). The average daily and total concentrate intake (kg/d) were respectively lower (P < 0.01) in LOW, followed by INT and UPP (Table 4).

For heifer growing phase, the intensive grazing system was the most utilized between the periods from weaning to pregnancy, and from pregnancy to calving in UPP group farms. These farms had 11.2 (P < 0.01) and 2.01 (P = 0.03) times higher OR compared to LOW and INT, respectively (Figure 11a), for the period from weaning to pregnancy, and 14.2 (P < 0.01) and 3.86 (P < 0.01) higher OR for the rearing period from pregnancy to calving (Figure 11b). Conversely, extensive grazing was the most utilized system by LOW farms, with INT and UPP being 86 (P < 0.01) and 92% (P < 0.01) lower, respectively, compared to LOW for the period from weaning to pregnancy (Figure 11a).

Grass was the primary forage used by the LOW milk productive tier. During the winter period (Figure 12a), UPP did not utilize pasture, while INT had an 82% lower OR of utilizing pasture compared to LOW (*P* < 0.01). In the summer period (Figure 12b), both INT and UPP exhibited significantly lower OR — 84 and 99%, respectively— compared to LOW for utilizing pasture (*P* < 0.01). Conversely, corn silage was the most frequently used forage by both INT and UPP compared to LOW, during both the winter and summer periods.

The BW at first service did not show any significant differences among the groups (*P* = 0.74; Table 4). However, the age at first service was significantly lower for UPP, followed by INT, and was highest for LOW (*P* < 0.01; Table 4). The observed ADG was higher for UPP, followed by INT and LOW (*P* < 0.01). Age at first calving was significantly higher in lower milk productive tiers, with LOW averaging 35.6, INT 29.9, and UPP 26.0 mo (Table 4). Birth BW was lower in LOW (*P* < 0.01) and showed no significant differences between INT and UPP. Finally, days in rearing were longest for LOW, followed by INT, and shortest for UPP (*P* < 0.01; Table 4).

DISCUSSION

A significant finding was the higher land use efficiency in UPP dairy farms, where fewer resources are used to achieve greater productivity. This efficiency is increasingly important as environmental concerns grow, prompting the industry to reduce its carbon footprint while enhancing productivity (Crosson et al., 2011).

The study also highlighted a predominance of Holstein × Gyr animals in LOW and INT groups, with Silva et al. (2015) noting that this breed accounts for 80% of Brazil's milk production. In contrast, UPP farms primarily use pure Holstein breeds, which are more productive in intensive systems (Bargo et al., 2002; Black et al., 2013).

Maximizing the proportion of lactating cows is crucial for dairy farms, as milk sales are their main revenue source. Many farms have adopted sexed semen technology to increase female births and decrease male calves, which are less valuable (Haskell, 2020). The UPP farms have shifted from natural mating to AI, using sexed semen intensively.

As dairy farms increasingly seek to boost the number of female births, the concerns regarding the fate of male calves also intensify. Apart from a select few kept for breeding, Holstein purebred males typically hold low market value, making it financially impractical to maintain them within the productive system. Consequently, dairy farms are compelled to consider various outcomes for these male calves, which may include on-farm slaughter, rearing for a few weeks before being sold for slaughter, or selling them for veal production shortly after birth (Haskell, 2020). Additionally, the care provided to male calves often suffers, with common issues including delayed colostrum feeding and the provision of lower quality colostrum (Shivley et al., 2019), further compounding their challenging start in life.

In Canada, while some dairy producers report sacrificing male calves shortly after birth, most rear them for veal production (Renaud et al., 2017). In contrast, Brazilian practices vary, with significant numbers reporting calf sacrifice due to lack of pasture (Hötzel et al., 2014). The UPP farms typically donate male-born calves early, while LOW and INT farms are more likely to rear them similarly to females.

Given the increasing concern among professionals and consumers about animal welfare and the fate of male calves on dairy farms, it is imperative to explore alternatives that are aligned with these concerns (Hendricks et al., 2022). One such alternative is the use of semen or mating with bulls from specialized beef breeds. This approach not only helps to reduce the birth of male dairy calves but can also address the issue of surplus females on dairy farms facing herd growth constraints. By breeding some of the genetically inferior animals with beef bulls, the resulting crossbred calves typically have a higher market value than those from specialized dairy breeds. Additionally, this strategy aids in the genetic improvement of the herd, as it prevents genetically inferior animals from perpetuating their lineage within the herd (Ettema et al., 2017).

In this study, the use of mating or AI with beef semen was more prevalent in LOW and INT groups, which may explain why these farms are more likely to retain male calves. This practice is often associated with larger land perimeters available on these farms, supporting the findings by Hötzel et al. (2014) that larger farm sizes can influence decisions regarding male calf disposal. This trend underscores the need for integrated approaches that consider both economic viability and ethical practices in dairy farming.

During transition periods, more specifically during the pre-partum period, UPP farms prefer free bed systems like Compost Bedded Pack barn in the maternity, which are favored for their sanitary benefits and animal comfort (Black et al., 2013; Fávero et al., 2015, Leso et al., 2020). Conversely, LOW and INT farms often use less intensive systems such as pastures for example, considering that they require lower financial investment compared to the adoption of Compost Bedded Pack Barn systems.

Regarding colostrum management practices, there was a notable adherence to the use of colostrum banks and the measurement of colostrum Brix degrees exclusively among UPP dairy farms. These finding points to a concerning lack of adoption of these practices among most dairy farms in the database (LOW and INT). Effective colostrum management is critical as it significantly enhances the health and welfare of calves, contributing to reduced mortality rates and lower incidences of diseases, particularly diarrhea and respiratory diseases (Mellor and Stafford, 2004). The absence of such practices in most farms highlights a significant area for improvement that could have substantial benefits for calf health and overall farm productivity.

Fresh colostrum was the predominant choice among dairy farms, aligning with findings from Azevedo et al. (2023), which reported that 44% of farms primarily utilize it. Despite this general trend, UPP farms notably also exhibit greater adherence to practices such as the use of colostrum replacer and enriched colostrum compared to INT and LOW. These alternatives are particularly beneficial in scenarios where natural colostrum production is inadequate in quantity or quality, as noted by Tomaluski et al. (2022).

The overall adoption of these tools in Brazil remains low, primarily due to the high costs associated with commercial colostrum replacers. This economic factor largely restricts their use to higher milk productive tier dairy farms, where the financial capacity to invest in such practices is greater. This underscores a disparity in farm management practices influenced by economic constraints, highlighting a gap in the accessibility of advanced colostrum management tools across different milk productive tiers of dairy farms.

The time elapsed between birth and the first colostrum feeding was longer than recommended across all evaluated systems. According to Godden et al. (2019), this crucial first feeding should occur within a maximum of 2 h post-birth to optimize the absorption of immunoglobulins in the calf's intestine, as efficiency declines over time (Fischer et al., 2018). In this study, the observed times for LOW, INT, and UPP were 2.7, 3.2, and 2.7 h respectively, exceeding the recommended threshold. Although it was not directly measured in this study, these delays suggest that all milk productive tiers might be at risk of inadequate passive immunity transfer to calves, potentially leaving them more vulnerable to early-life health issues. This points to a need for improved management practices to ensure timely colostrum feeding post-birth.

The provision of transition milk was least adhered to by farms at the LOW milk productive tier. Transition milk is crucial for intestinal health and development in calves due to its rich content of bioactive substances (Fischer et al., 2018). Among the farms that did adopt this practice, the duration of provision was consistent, ranging between 2 and 3 days. While the specific reasons for the lower adoption rate of transition milk provision by LOW dairy farms were not investigated in this study, a plausible explanation is the smaller scale of these operations. Producers at this tier might prefer to sell the milk sooner to maximize daily milk deliveries and, consequently, revenue from milk sales, rather than using it for calf feeding. This decision reflects the economic pressures and resource allocation priorities that can influence management practices on smaller-scale farms.

The primary calf housing systems in INT and UPP dairy farms were tropical string barns, while LOW utilized various other housing types. The tropical string system has gained popularity in Brazil, as noted by Azevedo et al. (2023), due to its low construction costs and its ability to promote good sanitary conditions for the animals. Moreover, it provides greater comfort and welfare compared to indoor suspended cages, offering calves more space to move and lie down on less abrasive flooring (Sinnott et al., 2022).

Despite these advantages, the tropical string system faces challenges during the rainy seasons in Brazil. Problems arise particularly when the shelter is only shaded by synthetic mesh rather than more protective tiles, or if there is an absence of a concrete flooring area. In such conditions, excess mud can accumulate, potentially compromising the health and welfare of the calves. This issue underscores the need for careful consideration of geographical and climatic factors when choosing and designing calf housing systems.

Calf housing systems in our study showed significant differences compared to those reported by Hötzel et al. (2014), where individual pens were the most common type of calf housing in southern Brazil, specifically in the state of Santa Catarina, accounting for 56% of cases while the tropical string system was only 9%. This variation is typical in a country like Brazil, where there are significant temperature differences between regions such as Minas Gerais and Santa Catarina. These climatic variations often necessitate different housing characteristics to ensure appropriate thermal comfort for the calves.

Additionally, it's important to note that our study was conducted 10 yr after Hötzel et al. (2014), and changes in preferred housing systems over time are expected. These temporal shifts can reflect evolving management practices, economic considerations, or adaptations to new research findings on animal welfare and productivity.

The study revealed that UPP dairy farmers primarily use non-saleable milk for calf feeding, whereas LOW farms often provide saleable milk. This difference could be influenced by the feeding methods. LOW farms typically allow calves to suckle directly on the cows, potentially reducing the detection and treatment of mastitis, thereby decreasing the incidence of non-saleable milk. Additionally, there is a genetic correlation, even if moderate, between milk production and clinical mastitis (Chegini et al., 2018), which could further impact the availability of non-saleable milk. Consequently, LOW farms are more likely to use saleable milk for calf feeding due to lower production of non-saleable milk.

The volume of milk provided to calves varied with the milk productive tier of the dairy farms; higher tiers offered more milk. However, the quantities provided, especially in LOW and INT farms, were approximately half of the ad libitum milk consumption observed in dairy calves (Appleby et al., 2001), potentially indicating a state of hunger (Vieira et al., 2008) and leading to suboptimal performance, which could affect productivity in their first lactation (Soberon et al., 2012). Contrary to expectations, lower milk consumption did not result in higher concentrate intake, which contradicts findings from Welk et al. (2023) where higher milk provision typically resulted in lower concentrate consumption. This discrepancy could be inferred to the quality or acceptability/palatability of the concentrates used (Ghaffari and Kertz, 2021), although we did not adopt direct measures to evaluate differences in the quality and acceptability/palatability of the concentrates used.

Furthermore, the lower volume of liquid diet provided, coupled with lower concentrate consumption and delayed introduction of solid diet in LOW farms, extended the suckling period required to achieve comparable weaning weights, indicating inefficiencies in calf rearing. The predominant use of buckets with nipples for liquid diets in higher milk productive tier farms, as seen in the Alta CRIA program (Azevedo et al., 2023), enhances performance by promoting better health and reducing cross-suckling issues, as it facilitates the proper routing of milk in the gastrointestinal tract by stimulating the esophageal groove (Sjaastad et al., 2010), and promote a sucking behavior closer to the natural.

Regarding feeding protocols, no significant differences in milk supply systems were observed in this study, unlike the Alta CRIA program (Azevedo et al., 2023), where the step-down protocol was predominantly used. While some studies suggest that step-up/step-down systems may enhance performance (Omidi-Mirzaei et al., 2015), other factors such as final milk consumption and concentrate intake might be more influential (Valehi et al., 2022).

Corn silage is widely used for cattle in Brazil (Bernardes and do Rêgo, 2014) and worldwide (Ferraretto et al., 2018) due to its ease of use and good nutritional value, and was the most utilized forage for dairy calves as reported by Hötzel et al. (2014) and the

Alta CRIA program (Azevedo et al., 2023). The choice of calf and heifer concentrates is influenced by the milk productive tier; higher tiers are less likely to use commercial formulations. This discrepancy is more pronounced in heifer concentrate formulation, where the scale of production plays a significant role; smaller farms like those at the LOW tier may not find the high initial investment in equipment and facilities justifiable due to lower volume needs.

The heifer rearing systems primarily consisted of pastures, with intensive pasture paddock being the most common method regardless of milk productive tier. However, UPP farms supplemented pasture with corn silage during winter and summer to meet nutritional requirements (Machado et al., 2019), resulting in better performance outcomes.

In summary, ADG and AFC are closely linked. Higher ADG typically results in lower AFC (Krpálková et al., 2014). Extreme ADG values, either too low or too high, can negatively affect mammary development and future milk production (Daniels 2010; Albino et al., 2017). The optimal age at first calving is around 24 mo (NASEM 2021), with deviations from this norm potentially affecting productivity. Although this study's ADG and AFC values were lower than recommended, especially for LOW, it is unclear whether these will impact future productivity. Recommendations for optimal BW at key developmental stages should be adjusted based on mature BW, which varies with breed and genetic background. This approach ensures more precise management and better long-term productivity outcomes.

CONCLUSION

Dairy farms with higher milk productive tiers exhibit greater efficiency in raising calves and heifers. These farms demonstrate decreased age at first calving, improved average daily gain, enhanced reproductive efficiency, and increased total milk production. Notably, these outcomes are achieved even on comparatively smaller land areas, indicating more efficient utilization of both land and labor resources. Key factors contributing to this superior efficiency include the predominant Holstein breed of the herd, advanced reproductive biotechnologies, intensified nutritional strategies, and substantial investments in facilities and rearing systems. These elements together suggest an ongoing trend of family succession within the dairy industry, potentially fostering continued innovation and sustainability.

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TABLES

Table 1. Characterization of the dairy farms in LOW, INT, and UPP milk productive tiers.

Items	LOW[1] (n = 78)			INT[2] (n = 155)			UPP[3] (n = 78)			*P* value
	Mean ± SE	Min	Max	Mean ± SE	Min	Max	Mean ± SE	Min	Max	
Calves number	$42.6^{b} \pm 6.23$	4.0	238.0	$56.2^{b} \pm 4.42$	8.0	350.0	$88.7^{a} \pm 6.23$	14.0	400.0	<0.01
Lactating cows number	$56.7^{b} \pm 7.78$	8.0	242.0	$73.4^{b} \pm 5.52$	14.0	334.0	$138.2^{a} \pm 7.78$	27.0	500.0	<0.01
Total farm milk production (L/d)	$806^{c} \pm 197.62$	100	8,489	$1{,}309^{b} \pm 140.19$	2,167	4,900	$3{,}752^{a} \pm 197.62$	625	13,344	<0.01
Milk/worker/d (L)	$235^{c} \pm 13.4$	200	400	$327^{b} \pm 9.5$	200	700	$492^{a} \pm 13.4$	200	1,000	<0.01
Time in dairy farming (yr)	$18.6^{a} \pm 0.85$	1.0	25.0	$18.3^{a} \pm 0.60$	2.0	25.0	$20.2^{a} \pm 0.85$	2.00	25.0	0.19
Farm size (ha)[4]	$133^{A} \pm 12.28$	6.0	500	$107^{AB} \pm 8.72$	7.0	752	$99^{B} \pm 12.28$	12.0	501	0.06
Herd conception rate (%)	$38.6^{b} \pm 0.01$	25.0	70.0	$43.9^{a} \pm 0.01$	20.0	75.0	$43.9^{a} \pm 0.01$	20.0	75.0	0.01
Milk price (US$)	$0.50^{AB} \pm 0.001$	0.39	0.68	$0.50^{B} \pm 0.001$	0.31	0.73	$0.51^{A} \pm 0.001$	0.44	0.61	0.05

[1]Low milk productive tier.
[2]Intermediate milk productive tiers.
[3]Upper milk productive tiers.
[4]10,000 m^2.
Different lowercase superscript letters indicate statistical significance.
Different uppercase superscript letters indicate a statistical trend.

Table 2. Descriptive statistics for the discrete variables analyzed.

Item	LOW[1]		INT[2]		UPP[3]	
	Yes(n)/(%)	n	Yes(n)/(%)	n	Yes(n)/(%)	n
Breed						
Holstein × Gyr	68(87,2)	78	93(60,0)	155	21(26,9)	78
Holstein	8(10,3)	78	57(36,8)	155	57(73,01)	78
Others	2(2,6)	78	5(3,2)	155	0(0,0)	78
Use semen of beef bulls	31(3,8)	78	51(32,9)	155	8(10,3)	78
Predominant reproductive biotechnology						
Bull mating	31(3,8)	78	18(11,6)	155	1(1,3)	78
Bull mating and artificial insemination	23(29,5)	78	53(34,2)	155	29(37,2)	78
Artificial insemination with sexed semen	3(3,8)	78	17(11,0)	155	26(33,3)	78
Artificial insemination with conventional semen	20(25,6)	78	62(40,0)	155	19(24,4)	78
in vitro fertilization or embryo transfer	1(1,3)	78	5(3,2)	155	3(3,8)	78
Cow house system						
Pasture	63(80,8)	78	102(65,8)	155	9(11,5)	78
Compost bedded pack barn	0(0,0)	78	13(8,4)	155	58(74,4)	78
Free stall	0(0,0)	78	3(1,9)	155	5(6,4)	78
Others	15(19,2)	78	37(23,9)	155	6(7,7)	78
Type of maternity						
Compost bedded pack barn	0(0,0)	78	8(5,2)	155	34(43,6)	78
Pasture	62(79,5)	78	125(80,6)	155	29(37,2)	78
None	15(19,2)	78	18(11,6)	155	12(15,4)	8
Others	1(1,3)	78	4(2,6)	155	3(3,8)	78
Night time maternity support	0(0,0)	78	1(0,6)	55	9(11,5)	78
Colostrum storage	3(3,8)	78	19(12,3)	155	31(39,7)	78
Measures colostrum brix	3(3,8)	78	14(9,0)	155	31(39,7)	78
Colostrum supplied						
Fresh colostrum	78(100,0)	78	152(98,1)	155	65(83,3)	78
Pasteurized colostrum	0(0,0)	78	1(0,6)	155	1(1,3)	78
Colostrum replacer	1(1,3)	78	1(0,6)	155	7(9,0)	78
Others	0(0,0)	78	3(1,9)	155	13(16,7)	78
Milk supply						
Bucket without nipple	27(34,6)	78	70(45,2)	155	31(39,7)	78

Bucket with nipple	18(23,1)	78	53(34,2)	155	44(56,4)	78
Bottle	7(9,0)	18	12(7,7)	155	1(1,3)	78
Automatic milk feeder	3(3,8)	78	12(7,7)	155	2(2,6)	78
Suckling calf	23(29,5)	78	8(5,2)	155	0(0,0)	78
Transition milk	58(74,4)	78	133(85,8)	155	68(87,2)	78
Liquid diet						
Non-saleable milk	38(48,7)	78	120(77,4)	155	53(67,9)	78
Saleable milk	38(48,7)	78	23(14,8)	155	15(19,2)	78
Milk replacer	2(2,6)	78	12(7,7)	155	10(12,8)	78
Milk supply system						
Fixed volume	26(33,3)	78	56(36,1)	155	30(38,5)	78
Step-down	51(65,4)	78	96(61,9)	155	47(60,3)	78
Step-up/step-down	1(1,3)	78	1(0,6)	155	0(0,0)	78
Male calves destination						
Donates in the first week	11(14,1)	78	63(40,6)	155	50(64,1)	78
Keep in the farm	29(37,2)	78	36(23,2)	155	6(7,7)	78
Sells after weaning	25(32,1)	78	43(27,7)	155	15(19,2)	78
Others	13(16,7)	78	13(8,4)	155	7(9,0)	78
Calf housing						
Tropical housing system	5(6,4)	78	13(8,4)	155	3(3,8)	78
Pen on the floor	5(6,4)	78	14(9,0)	155	10(12,8)	78
Tropical (string)	27(34,6)	78	77(49,7)	155	41(52,6)	78
Indoor suspended cage	0(0,0)	78	1(0,6)	155	6(7,7)	78
Others	41(52,6)	78	48(31,0)	155	18(23,1)	78
Forage to calves						
Hay	4(5,1)	78	13(8,4)	155	3(3,8)	78
Corn silage	58(74,4)	78	132(85,2)	155	66(84,6)	78
Commercial concentrate						
Calves	67(85,9)	78	117(75,5)	155	50(64,1)	78
Heifers	61(78,2)	78	97(62,6)	155	37(47,4)	78
System from weaning to pregnancy						
Extensive pasture	49(62,8)	78	29(18,7)	155	3(3,8)	78
Intensive pasture	20(25,6)	78	102(65,8)	155	62(79,5)	78
Compost barn	0(0,0)	8	0(0,0)	155	3(3,8)	78
Others	9(11,5)	78	24(15,5)	155	10(12,8)	78

System from pregnancy to calving						
Extensive pasture	49(62,8)	78	49(31,6)	155	3(3,8)	78
Intensive pasture	19(24,4)	78	84(54,2)	155	64(82,1)	78
Compost bedded pack barn	0(0,0)	78	0(0,0)	155	0(0,0)	78
Others	10(12,8)	78	22(14,2)	155	10(12,8)	78
Forage used during winter for heifers						
Corn silage	24(30,8)	78	87(56,1)	155	67(85,9)	78
Pasture	18(23,1)	78	8(5,2)	155	0(0,0)	78
Elephant grass chopped	4(5,1)	78	6(3,9)	155	1(1,3)	78
Sugar cane chopped	5(6,4)	78	5(3,2)	155	0(0,0)	78
Others	27(34,6)	78	49(31,6)	155	10(12,8)	78
Forage used during summer for heifers						
Corn silage	5(6,4)	78	61(39,4)	155	60(76,9)	78
Pasture	59(75,6)	78	51(32,9)	155	2(2,6)	78
Elephant grass chopped	5(6,4)	78	10(6,5)	155	0(0,0)	78
Sugar cane chopped	0(0,0)	78	1(0,6)	155	0(0,0)	78
Others	9(11,5)	78	32(20,6)	155	16(20,5)	78

[1]Low milk productive tiers.
[2]Intermediate milk productive tiers.
[3]Upper milk productive tiers.

Table 3. Characterization of management practices and indicators during the calf phase.

Items	LOW[1] (n = 78)			INT[2] (n = 155)			UPP[3] (n = 78)			*P*-value
	Mean ± SE	Min	Max	Mean ± SE	Min	Max	Mean ± SE	Min	Max	
Time to colostrum feeding (h)	$2.7^{b} \pm 0.16$	0.5	5.0	$3.2^{a} \pm 0.11$	1.0	5.0	$2.7^{b} \pm 0.16$	0.5	5.0	<0.01
Transition milk feeding (d)	$2.4^{a} \pm 0.17$	1.0	5.0	$2.6^{a} \pm 0.12$	1.0	5.0	$2.2^{a} \pm 0.17$	1.0	5.0	0.19
Milk volume offered (L/d)	$4.3^{c} \pm 0.11$	2.1	7.1	$4.8^{b} \pm 0.08$	2.0	6.5	$5.3^{a} \pm 0.11$	2.7	9.0	<0.01
Days in milk feeding (d)	$106^{a} \pm 2.4$	90	240	$92^{b} \pm 1.7$	70.0	190	$89^{b} \pm 2.4$	60	150	<0.01
Start of feed supply (d of life)	$5.8^{A} \pm 1.53$	1	181	$1.6^{B} \pm 1.04$	1	91	$1.4^{B} \pm 1.53$	1	31	0.05
Concentrate intake (kg/d)	$0.8^{b} \pm 0.03$	0.1	1.5	$0.9^{a} \pm 0.02$	0.3	2.1	$0.9^{a} \pm 0.03$	0.4	1.6	<0.01
Body weight at weaning (kg)	$103^{a} \pm 1.6$	75	145	$100^{a} \pm 1.2$	75	145	$103^{a} \pm 1.6$	85	125	0.19

[1]Low milk productive tiers.
[2]Intermediate milk productive tiers.
[3]Upper milk productive tiers.
Different lowercase superscript letters indicate statistical significance.
Different uppercase superscript letters indicate a statistical trend.

Table 4. Characterization of management practices and zootechnical indicators during the growing phase.

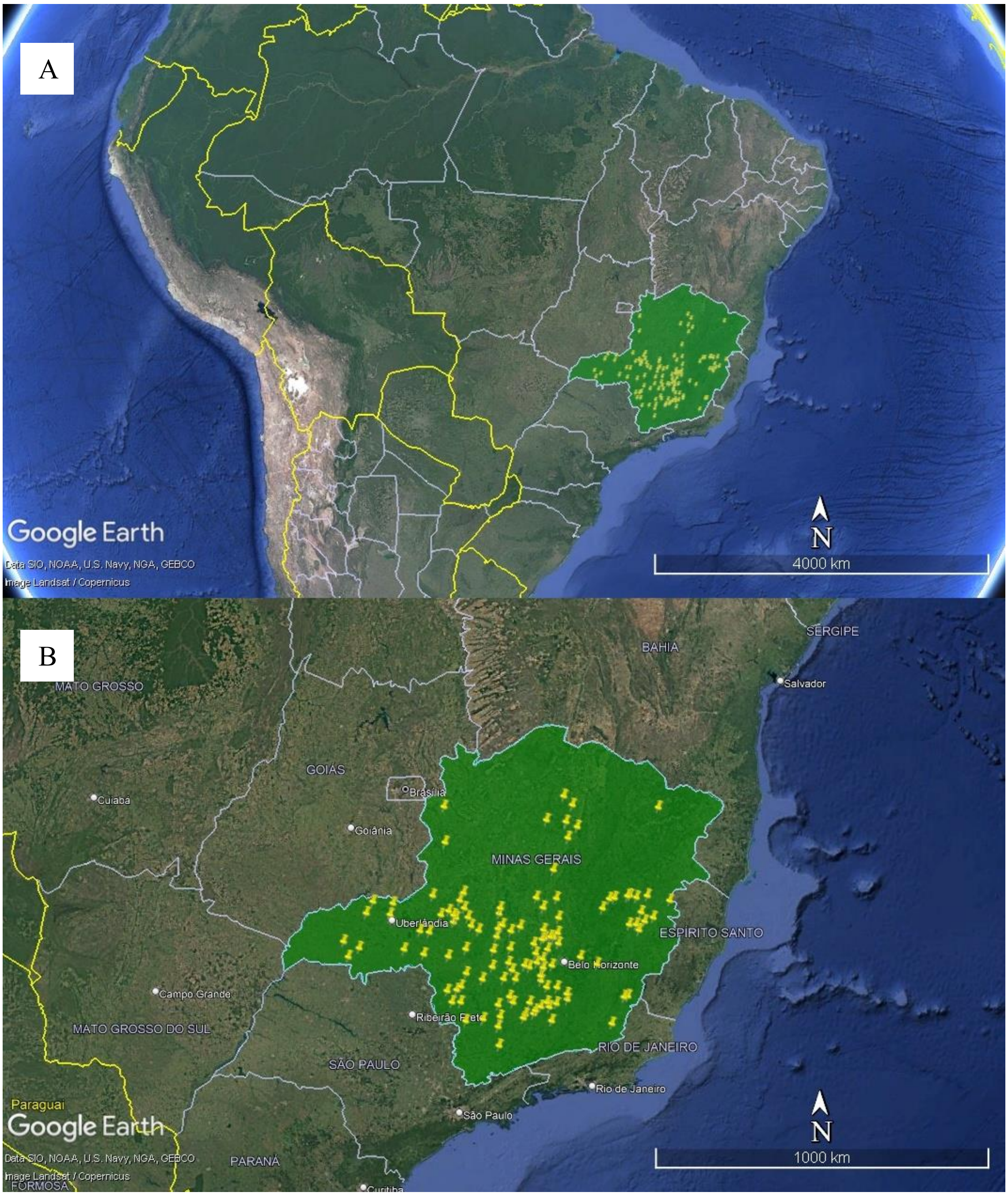
Items	LOW[1] (n = 78)			INT[2] (n = 155)			UPP[3] (n = 78)			*P*-value
	Mean ± SE	Min	Max	Mean ± SE	Min	Max	Mean ± SE	Min	Max	
BW[4] at first service (kg)	343.2^{a} ± 3.25	262.0	419.0	340.2^{a} ± 2.31	280.0	475.0	340.5^{a} ± 3.25	289.0	435.0	0.74
ADG[5] (kg/d)	0.41^{c} ± 0.01	0.26	0.62	0.51^{b} ± 0.01	0.30	0.73	0.60^{a} ± 0.01	0.47	0.76	<0.01
AFS[6] (mo)	18.6^{a} ± 0.23	13.0	20.0	16.4^{b} ± 0.16	12.0	20.0	13.9^{c} ± 0.23	11.0	18.0	<0.01
AFC[7] (mo)	35.6^{a} ± 0.50	25.0	60.0	29.9^{b} ± 0.35	23.0	46.0	26.0^{c} ± 0.50	23.0	32.0	<0.01
CBW[8] (kg)	492^{b} ± 4.38	415	568	508^{a} ± 3.11	402	632	517^{a} ± 4.38	405	588	<0.01
TCI[9] (kg)	813^{c} ± 46.08	11	2,141	1,030^{b} ± 32.69	18.0	223	1,168^{a} ± 46.08	98.0	2,013	<0.01
CID[10] (kg/d)	0.9^{c} ± 0.05	0.1	2.0	1.3^{b} ± 0.04	0.2	2.7	1.7^{a} ± 0.05	0.5	3.0	<0.01
Days in growing phase (d)	977^{a} ± 14.79	670	1,644	816^{b} ± 10.49	609	1,293	701^{c} ± 14.79	609	883	<0.01

[1]Low milk productive tiers.
[2]Intermediate milk productive tiers.
[3]Upper milk productive tiers.
[4]Body weight.
[5]Average day gain.
[6]Age at first service.
[7]Age first calving.
[8]Calving body weight.
[9]Total concentrate intake.
[10]Concentrate intake per day.
Different lowercase superscript letters indicate statistical significance.

FIGURES

Figure 11. Odds ratio for heifer rearing system from weaning to pregnancy (A) and from pregnancy to calving (B) in lower, intermediate, and upper milk production systems in Brazil.

Figure 12. Forages used to feed heifers during the winter (A) and summer (B) periods in lower, intermediate, and upper milk production systems in Brazil.



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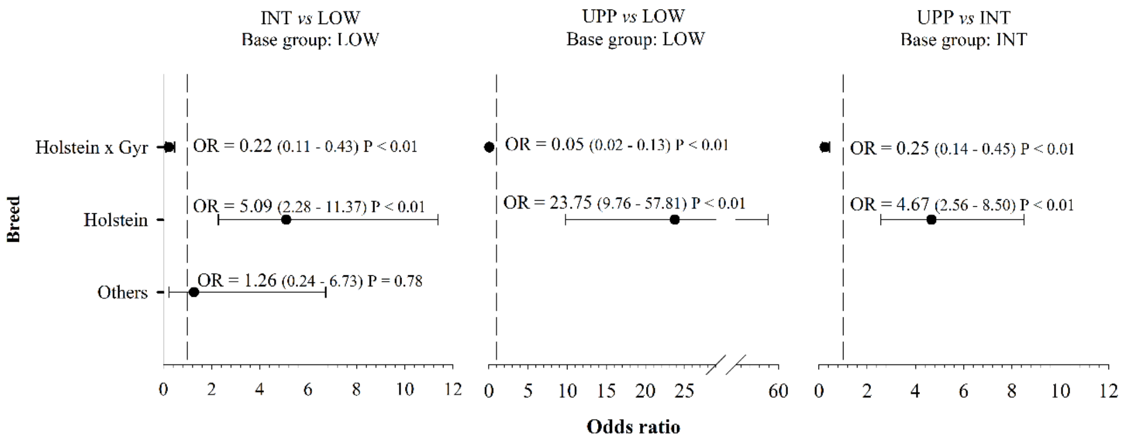

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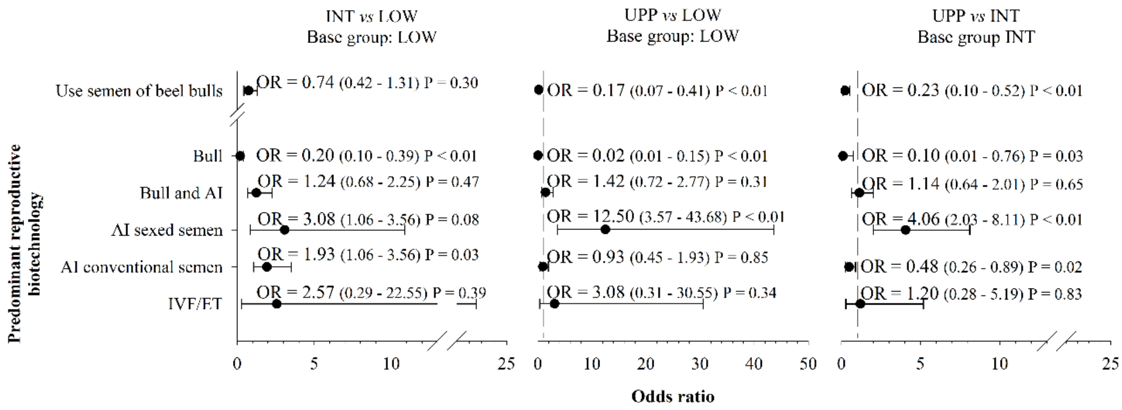

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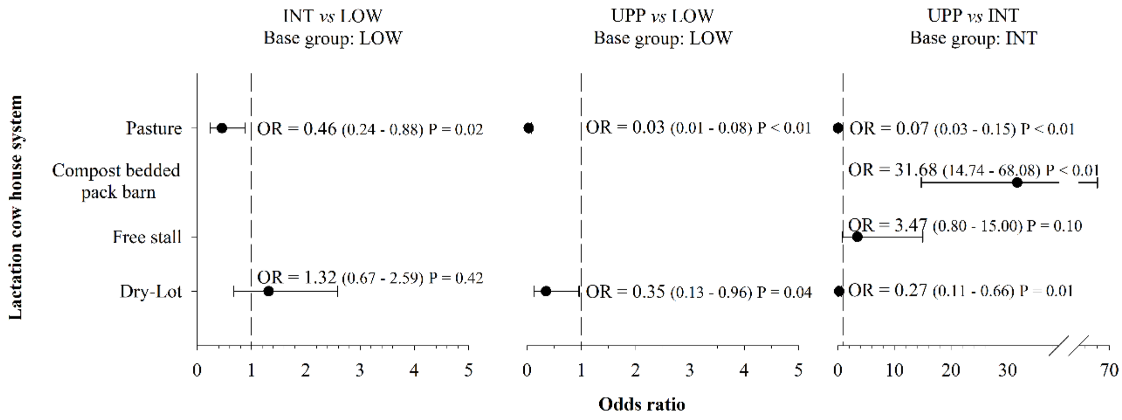

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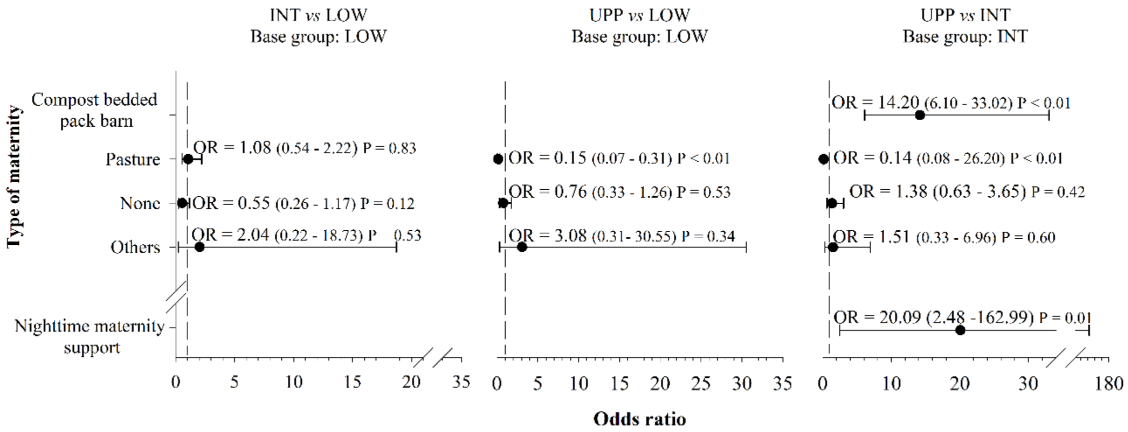

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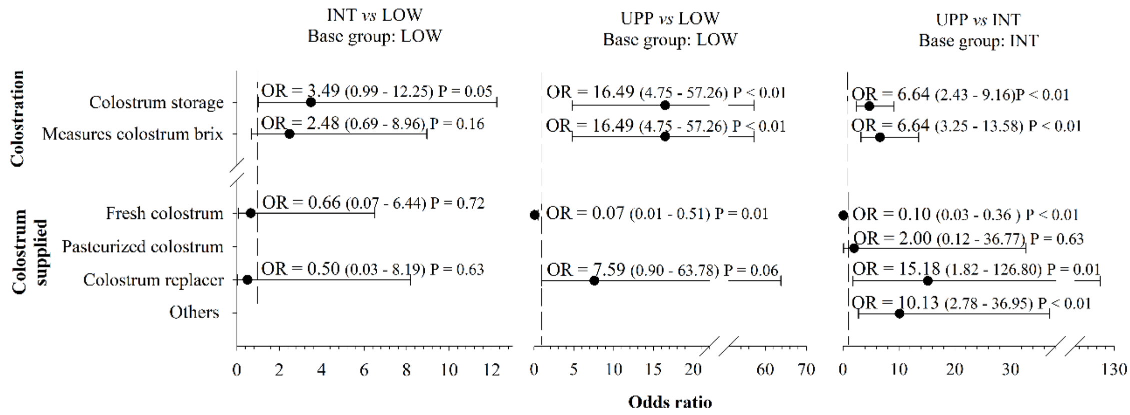

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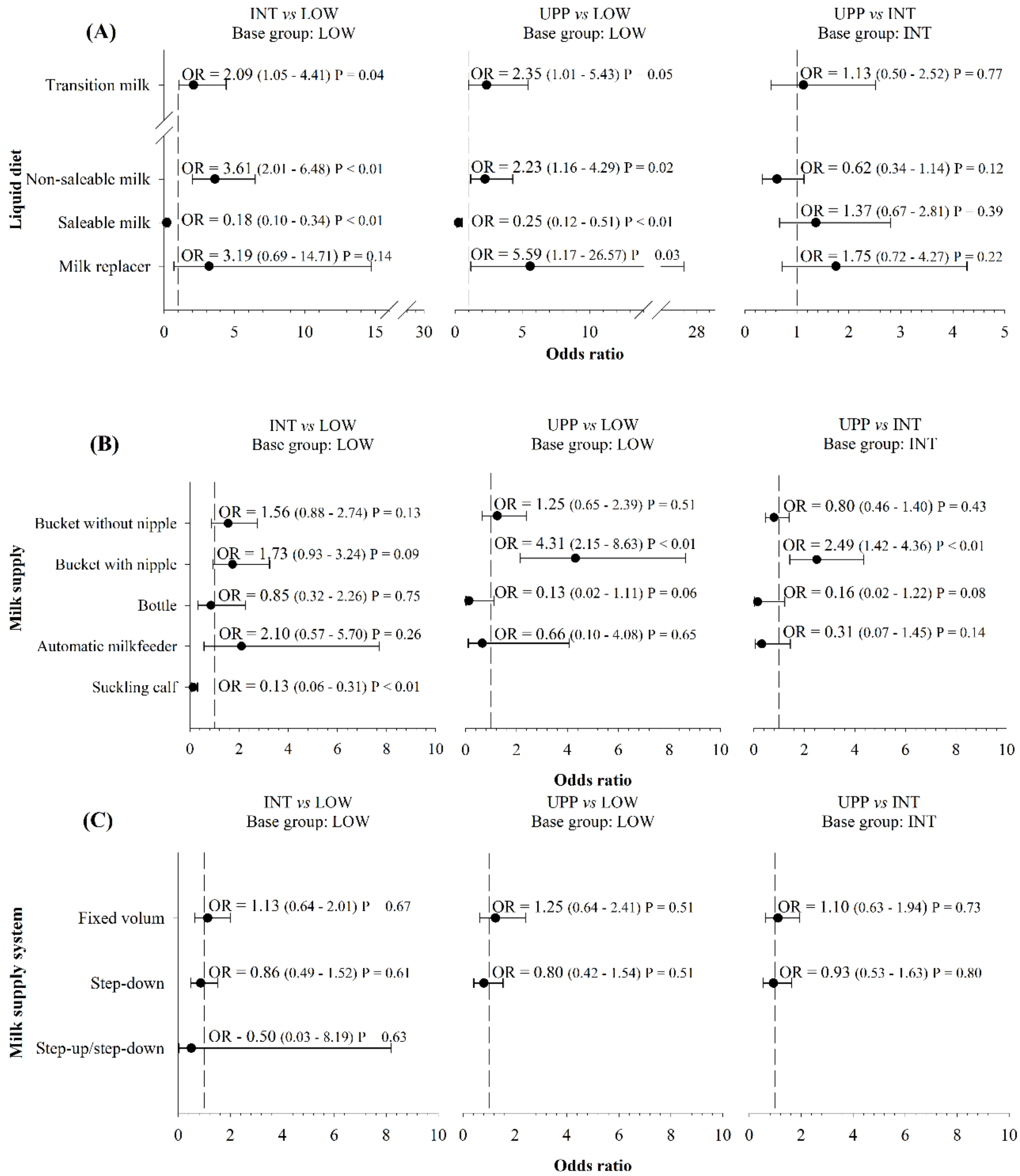

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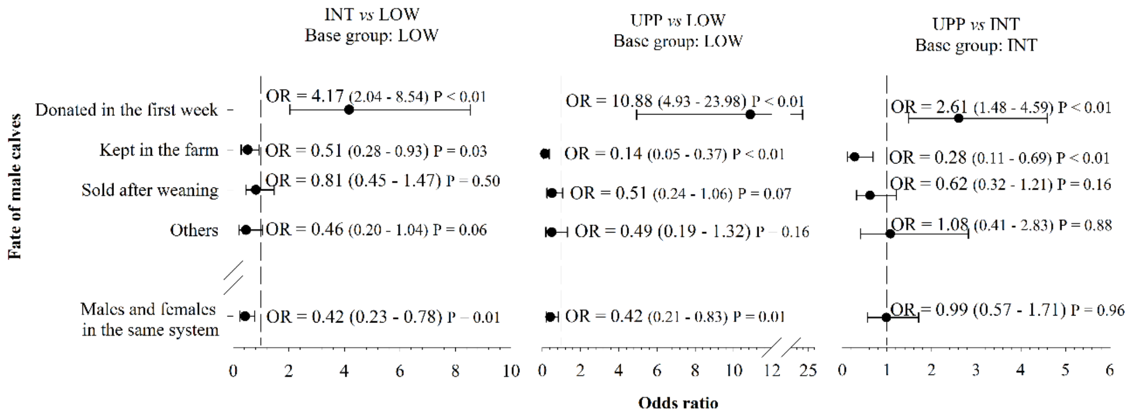

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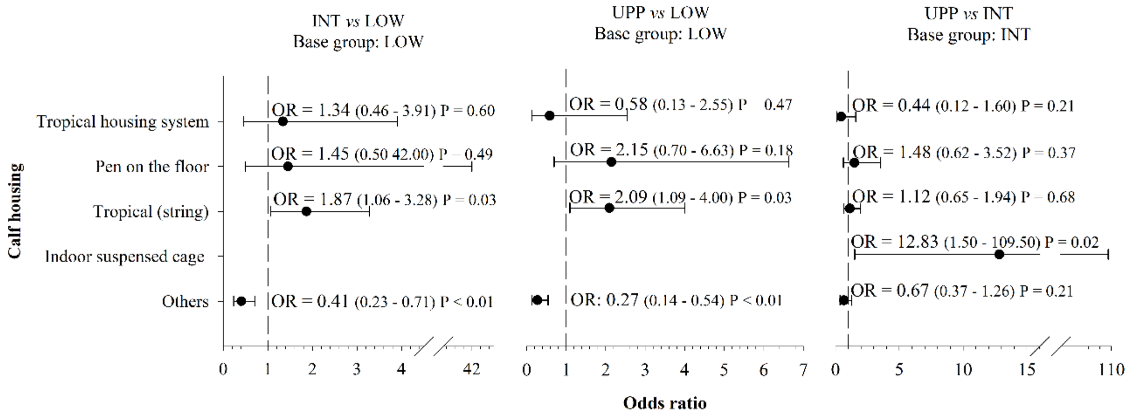

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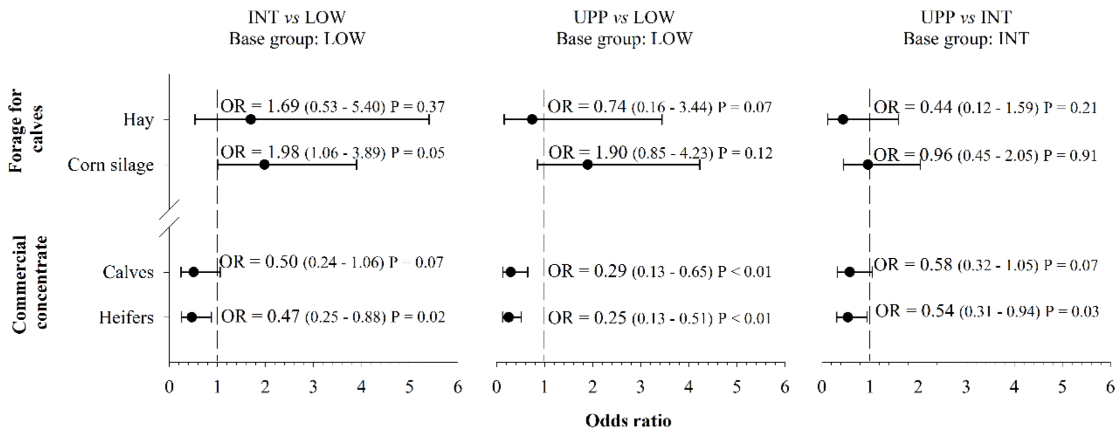

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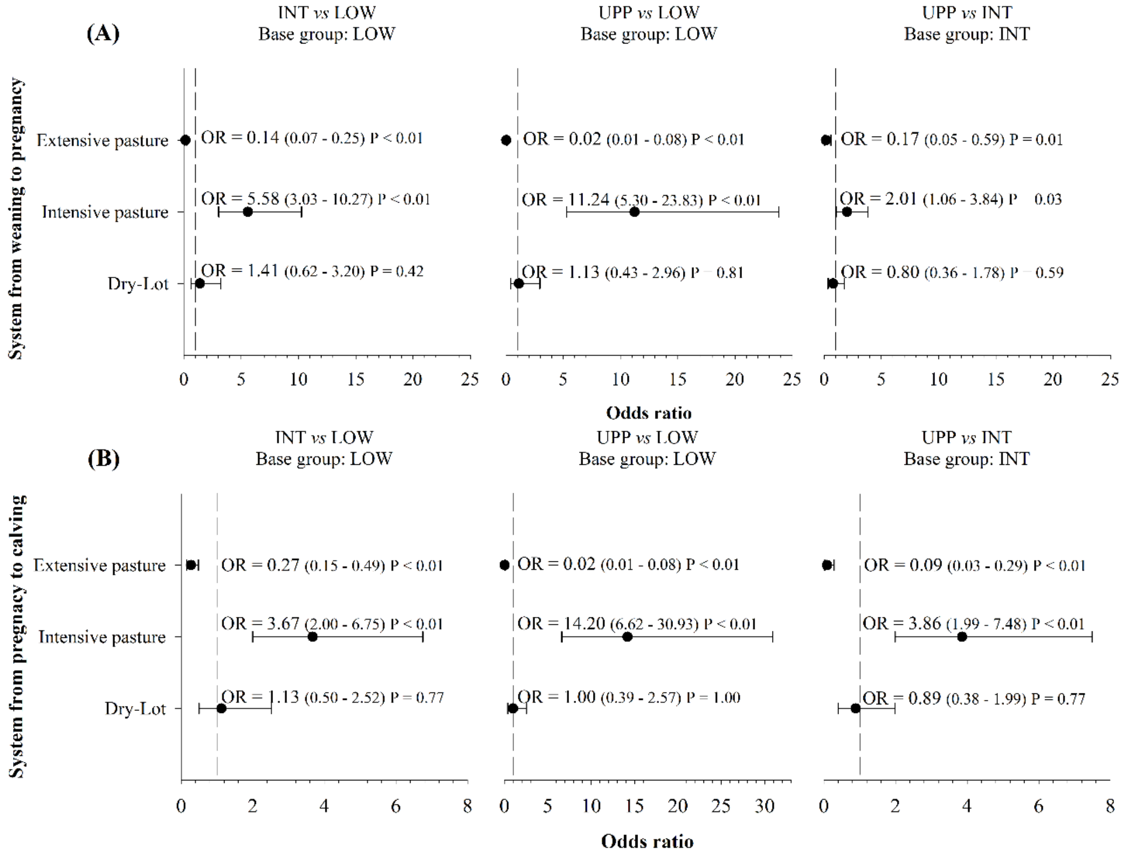

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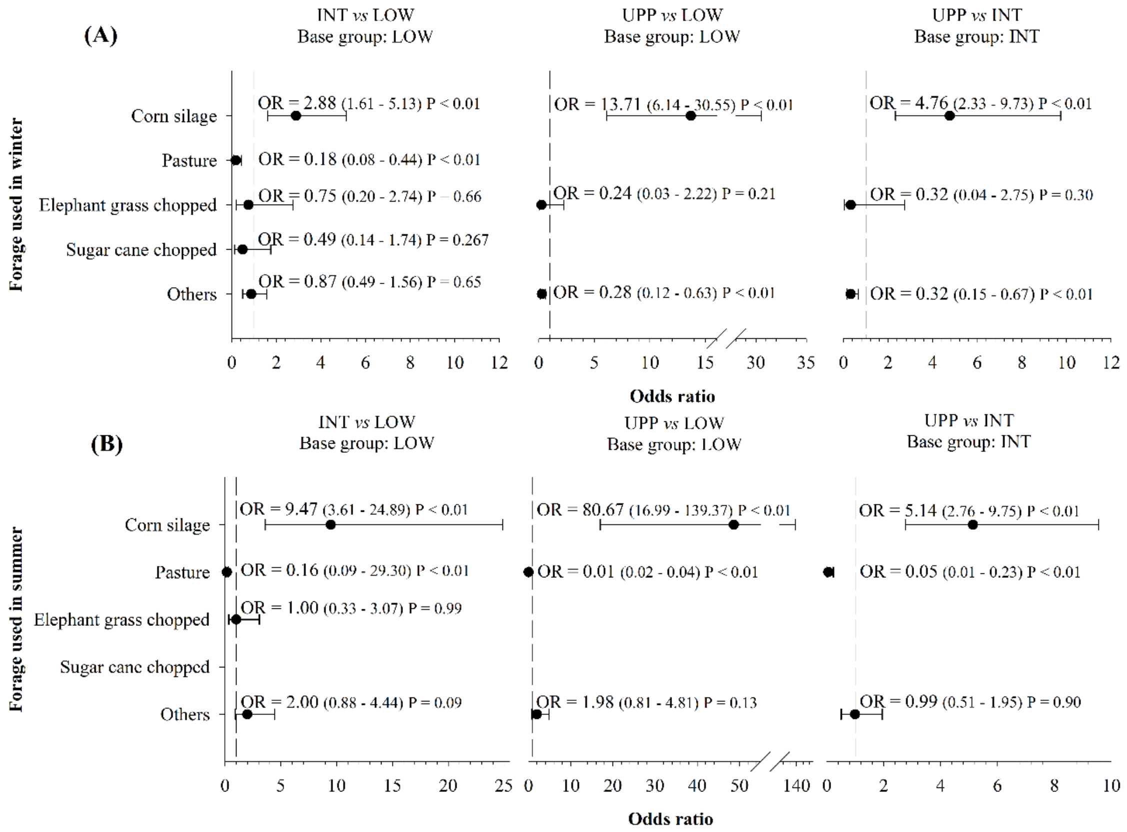

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CHAPTER II

Chapter formatted according to the scientific journal: Journal of Dairy Science

Interpretative Summary: **A comparative analysis of milk production systems: II. Milk productive tiers and their impact on dairy calf and heifer cost of production in Brazil**. By Silva et al. This study assessed how milk productive tiers impact the production costs of dairy calves and heifers in Brazil. Dairy farms were categorized into low, intermediate, and high milk productive tiers with average milk outputs of 12.0, 18.0, and 26.7 kg/cow/d, respectively. Results indicate that farms with lower milk productive tiers incurred higher production costs despite poorer zootechnical performance, additionally, they require a higher number of lactations to break even. The primary cost drivers were feed, labor, and machinery. Consequently, the milk productive tier of a farm is directly correlated with the production costs associated with raising dairy calves and heifers.

Running Head: Cost of production of dairy calf and heifer

A comparative analysis of milk production systems: II. Milk productive tiers and their impact on dairy calf and heifer cost of production in Brazil

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ABSTRACT

This study aimed to estimate the costs associated with raising dairy calves and heifers in Brazil during 2021, and the average number of lactations that heifers should remain in the herd to cover their production costs, analyzing data from 311 dairy farms in Minas Gerais. These farms were categorized into three milk productive tiers based on daily milk production per cow low production tiers (LOW) 12.00 L/cow/d (7.36 - 14.50 L/cow/d); intermediate (INT) 18.00 L/cow/d (14.60 – 22.50 L/cow/d), and high production tiers (UPP) 26.70 L/cow/d (22.60 – 32.00 L/cow/d). Using the GLIMMIX procedure in SAS Studio®, we identified statistically significant differences ($P < 0.05$) and noted trends ($0.05 \leq P < 0.10$). The main cost factors were feed, labor, and machinery, which together accounted for 83%, 85%, and 83% of the total costs for LOW, INT, and UPP, respectively. The cost of raising a heifer from birth to calving tended to be lower for INT farms (US$ 1,821.4 ± 44.35) and higher for LOW-tier farms (US$ 2,006.4 ± 62.52), while UPP farms had a cost of US$ 1,884.6 ± 62.52, which was statistically similar to both LOW and INT. To cover their production costs, the average number of lactations that heifers should remain in the herd was 3.98 lactations for the LOW tier, 2.64 lactations for the INT tier, and 1.64 lactations for the UPP tier. This study underscores that the milk productive tier significantly impacts the economic outcomes of raising dairy calves and heifers, with lower milk productive farms incurring higher costs despite less intensive rearing systems and lower productive potential. These findings highlight the critical role of milk productive investment in enhancing the efficiency and profitability of dairy operations.

Key words: dairy heifer costs, economic efficiency, farm management, milk productive tiers

INTRODUCTION

Dairy young animals are pivotal for the sustainability and progression of milk production systems, representing the future productivity and genetic advancement of the herd. The rearing and development phases from birth to calving are crucial, accounting for approximately 20 to 30% of a farm's operational expenditures (Tozer and Heinrichs, 2001; Karszes et al., 2008). Despite their critical role, these stages are frequently perceived as mere costs rather than strategic investments, often overshadowed by the immediate economic returns from lactating cows.

Neglecting essential management practices for calves and heifers can lead to suboptimal nutrition, underperformance, and increased mortality rates. These deficiencies often prolong the age at first calving (**AFC**), escalating costs due to extended non-productive periods (Le Cozler et al., 2008; Hutchison et al., 2017). Additionally, the type of production system markedly influences these costs. More extensive systems, characterized by lower financial investments, typically result in poorer performance and reproductive outcomes, such as reduced ADG and delayed AFC (Pirlo et al., 2000; Tozer and Heinrichs, 2001; Hadfield et al., 2021). In contrast, intensive systems, which require substantial capital for improvements and facilities, generally improve animal welfare and performance through enhanced environmental and sanitary conditions, potentially shortening the rearing phase and reducing associated costs (Negrón-Perez et al., 2019; Hawkins et al., 2020).

Accurate financial tracking and control of costs are rarely implemented on farms, largely due to the complex nature of accounting in dairy operations. This complexity arises from the interconnection of various sectors and the fluctuating timing of capital flows (Mohd Nor et al., 2012; Mohd Nor et al., 2015). Consequently, it is crucial to develop and implement production and management strategies that improve the cost-effectiveness of dairy heifer rearing, to subsequently benchmark each business and support future decision-making regarding the management of heifers on dairy farms.

This study aimed to estimate the costs associated with raising dairy calves and heifers in Brazil throughout 2021 and estimate the number of lactations necessary for such heifers to remain in the herd until they cover their production costs. We hypothesize that farms with lower milk productive tiers will demonstrate poorer performance and reproductive indicators, such as decreased ADG and increased AFC, which in turn, lead to higher overall production costs.

MATERIAL E METHODS

Study Population

This study analyzed data from 311 dairy farms participating in the EDUCAMPO LEITE program, managed by SEBRAE-MG, a program supported by the Brazilian Micro and Small Business Support Service (SEBRAE-MG). Data were extracted from a comprehensive database provided by SEBRAE-MG, which underwent a thorough consistency check before analysis. The selected farms represented 126 different municipalities across Minas Gerais (Figure 1).

The data used in this study are retrospective, collected from 349 farms participating in the SEBRAE/EDUCAMPO – MILK project. All farms included in this study received technical and managerial assistance through the project for a period ranging from 1 to 15 years. During this time, all relevant technical and managerial information was recorded monthly in a dedicated dairy farm management system, forming the database used in this analysis.

The criteria for farm selection and inclusion were the same as those used by Silva et al. (2025). However, instead of the Google Forms questionnaire previously used, an Excel spreadsheet containing economic and zootechnical information was utilized for this database.

For analytical comparison, the 311 farms were categorized into three distinct milk productive tiers based on daily milk production per cow: low (**LOW**), intermediate (**INT**), and upper (**UPP**). Classification was conducted using a percentile approach. The LOW group consisted of farms falling within the bottom 25% of the production scale (n = 78), with milk outputs ranging from 7.36 to 14.50 L/cow/d and an average of 12.0 L/cow/d. The INT group encompassed farms between the 25th and 75th percentiles (n = 155), featuring a range from 14.60 to 22.50 L/cow/d and an average of 18.0 L/cow/d. Conversely, the UPP group included the top 25% (n = 78), with milk production ranging from 22.60 to 32.00 L/cow/d and an average of 26.7 L/cow/d. This segmentation approach was specifically chosen to accentuate the pronounced variations in technology adoption and productivity across the spectrum of dairy farms as realized by Zuliani et al. (2018). For further details on performance, reproductive and economic indicators and the characterization of production systems, see Silva et al. (2025).

To estimate production costs, a custom spreadsheet was developed in Microsoft Excel. Data for each farm were extracted from the EDUCAMPO LEITE system and input into individual spreadsheets, facilitating detailed cost analysis. Since all the farms participating in this study receive technical and managerial assistance through EDUCAMPO - LEITE, the information is naturally included in a database extracted from the software used by the group for financial and zootechnical management. Thus, the data were previously entered monthly by each consultant during their assistance visits to the farms. As this study utilized an existing database, submission and approval by an ethics committee were not required, as the data used were already present in the database.

The data collected for this study encompassed a comprehensive set of cost-related variables during the rearing and development phases of dairy calves and heifers, specifically: (1) feeding; (2) machinery costs; (3) labor; (4) reproduction; (5) disease treatments; (6) vaccinations and preventatives; (7) mortality rates; (8) depreciation; (9) opportunity costs; and (10) other costs. All financial values were initially recorded in Brazilian Real (R$). To account for economic fluctuations, these values were adjusted for inflation based on the General Price Index - Internal Availability as provided by the Central Bank of Brazil on January 29th, 2024. For equivalence, as of the conversion date on January 29th, 2024, R$1.03 was required to match R$1.00 in 2021. Subsequently, the adjusted values were converted to US dollars on the same date, with an exchange rate of R$ 4.92 to US$ 1.00 on the conversion date. By anchoring the economic data to the US dollar, the study aims to mitigate the impact of local inflation, enhancing the international relevance and comparability of the findings.

Finally, the final cost presented in this study was adjusted according to Equation 1:

$$Present\ final\ cost\ (US\$) = R\$(2021) * \frac{currency\ adjustment\ (R\$)}{Exchange} Rate(US\$)$$

Equation 1

Where:

- Present final cost (US$): Final cost at the transformation date
- R$ (2021): Cost obtained from the database extracted in 2021

- Currency adjustment (R$): Value in Brazilian reais needed to account for inflation between 2021 and January 2024. Value reported by the Central Bank of Brazil on that date (R$1.03)
- Exchange rate (US$): Dollar value based on the Brazilian real to US dollar exchange rate. Value reported by the Central Bank of Brazil on that date (US$ 4.92).

Feeding Cost Analysis

Feeding costs were differentiated between calves and heifers, encompassing various dietary components. For calves, feeding costs included, liquid diet (milk or milk replacer), concentrate, and forage. In contrast, heifer costs comprised forage, concentrate, and minerals.

Colostrum costs were calculated based on the average expense incurred by each farm, using either pure powdered colostrum or enriched colostrum. Due to the minimal use of powdered colostrum, these costs were ultimately categorized under 'other costs'.

The cost of the liquid diet for calves was determined by the average daily volume of milk offered, multiplied by the number of days until weaning and the market price per liter received by each farm. This cost was standardized across all farms based on the market price of saleable milk, regardless of whether the milk was saleable or not. This approach was adopted to standardize the results.

For both calves and heifers, the costs of concentrate and forage were calculated by multiplying the number of feeding days by the average daily consumption and the price per unit of each feed type. For farms producing their own forage, such as silage, pasture, or hay, the cost was based on the production cost incurred on the farm. Conversely, for farms purchasing forage, costs were derived from regional market prices. This methodology ensures that the calculated forage costs accurately reflect the effective operational costs, encompassing all direct expenses associated with forage production on the farm.

Machinery Cost Analysis

Machinery costs were primarily assessed during the rearing phase of heifers, as machinery use in the calf phase is uncommon or manual within Brazilian contexts. These costs encompassed the expenses for machine hours required for various activities, including feeding the animals, transporting them from the calf barn to the post-weaning area, and managing general facility operations such as bedding replacement, aeration, and pasture management.

To calculate final machinery costs, the average cost per machine hour documented on each farm was multiplied by the average number of hours per day allocated to these activities and by the total number of days in the rearing phase. This approach provides a thorough assessment of the machinery-related expenditures essential for maintaining the infrastructure and operations critical to optimal heifer development.

Exclusively, the depreciation cost of machinery was embedded in the machine hour rate to improve the accuracy of the final value and simplify calculations. Consequently, the machinery-related costs might be slightly overestimated. However, we ensured that the final cost of the heifer at calving was not affected by this standardization. This is because the labor cost was deducted from the depreciation cost, which will be discussed later.

Labor Cost Analysis

Labor costs were calculated by evaluating the average expenditures for each employee directly engaged in managing calves and heifers, including all associated labor charges. The average hourly cost for each worker was determined by dividing their total salary, inclusive all labor-related charges, by the total number of hours dedicated monthly to calf and heifer management activities.

To compute the total labor cost, the derived average hourly wage for each employee was multiplied by the average daily hours spent on managing calves and heifers. This product was then multiplied by the total number of days in each developmental phase. This method provides a precise measure of the labor investment required for effective management across the various growth stages of calves and heifers.

Even on farms where family labor predominated, it was accounted for as hired labor. While family labor is typically considered an opportunity cost in cost methodologies, for greater accuracy and simplicity in calculations, we standardized the approach by treating family labor (in cases where it was predominant) as hired labor. As a result, labor costs might be slightly overestimated; however, this adjustment did not affect the final cost of the animal at each stage. This is because the labor cost was deducted from the opportunity cost, which will be discussed later.

Reproduction Cost Analysis

Reproduction costs were carefully assessed and categorized between the rearing and development phases of calves and heifers. At birth, reproduction costs were allocated equally, with 50% attributed to the calf, covering gestational investments, and the remaining 50% to the cow as it transitioned into lactation. Similarly, upon reaching reproductive maturity, half of the heifer's reproduction costs were ascribed to it, with the other half allocated in anticipation of its potential offspring.

To compute the final reproduction costs for each phase, we calculated the cost per pregnancy attempt, which varied depending on the reproductive biotechnologies utilized on each farm. These costs were then adjusted according to the herd's conception rate, to ensure that the financial estimates accurately reflect both the direct expenses associated with breeding attempts and the efficiency of the reproductive outcomes.

Diseases Treatments Cost Analysis

In this study, treatment costs were confined to the expenses incurred for medications necessary to treat the primary diseases affecting calves and heifers. These ailments include: (1) diarrhea, with or without fever; (2) bovine anaplasmosis and others tick-born diseases; (3) respiratory diseases; and (4) umbilical infections. Costs associated with these health issues were systematically evaluated for both the calf and heifer phases of development, ensuring a comprehensive assessment of healthcare expenditures throughout the growth stages of the animals.

Vaccination and Preventative Cost Analysis

Vaccination and preventive costs for both calves and heifers were thoroughly assessed in this study. The analysis incorporated the costs of vaccines administered pre-partum to cows, which confer immunological benefits to the calves in utero, enhancing their resilience and health outcomes early in life. Preventative measures included a comprehensive array of expenditures aimed at sustaining animal health, such as the control of endo and ectoparasites, administration of anthelmintics, and other health-preserving interventions.

Mortality Cost Analysis

The cost of mortality for both calves and heifers was systematically calculated by apportioning the average cost of each deceased animal across the surviving members of the herd. For heifers, this cost was determined by dividing the total expenditures incurred during the phase prior to death by two, ensuring that the financial impact of mortality was accurately distributed among the remaining animals. Since it was not possible to determine the exact timing of each death within the herd and thus calculate a proportional cost based on the time each deceased animal remained part of the herd, we opted to divide the final cost per deceased animal by two. This adjustment aimed to estimate the average cost of mortality, assuming that deaths could occur either at the beginning or the end of each phase. This method provides a precise reflection of mortality costs within the overall financial assessments of herd management.

Depreciation Cost Analysis

Depreciation costs for assets used in both the calf and heifer phases were calculated separately. This method involved assessing the current market value of improvements, facilities, and other assets essential for rearing calves and heifers at the time of data collection and accounting for their estimated useful life span. In line with EDUCAMPO’s methodology, the salvage value of these assets was assumed to be zero. Depreciation was thus determined by dividing the initial value of each asset by its useful life, providing a clear annual measure of the financial depletion of these assets over their operational period.

Opportunity Cost Analysis

Opportunity costs for both calves and heifers were separately calculated, excluding the value of land (farm). This analysis accounted for improvements, machinery, and the final cost associated with each heifer. A hypothetical nominal interest rate of 6% per year, as prescribed by EDUCAMPO's methodology, was applied. This rate was chosen to reflect the potential earnings that could have been realized if the invested capital had been allocated to an alternative financial instrument or investment yielding the same rate of return. We emphasize that all opportunity costs calculated in this study pertain to the capital required for the production of dairy calves and heifers, excluding the capital invested in land.

Other Costs Analysis

Expenditures not encompassed by the previously specified categories were classified as "other costs." This category included items essential for calf management and welfare, such as feeding containers, teats, ear tags, and thermal blankets. Notably, these costs were quantified exclusively during the calf phase of rearing, given that such expenditures become negligible or are absent during the growing phase of heifers.

Payback

A more meaningful analysis than simply evaluating the production cost of dairy calves and heifers is to estimate how long these animals must remain in production to cover the expenses incurred during the breeding and rearing phases. To determine this payback period, a Monte Carlo simulation was performed, taking into account: (1) the final cost of the heifer at calving; (2) the average price received per liter of milk; (3) the net milk margin, discounted by the expenses on heifers; (4) the average culling rate of the cow herd and its average market price; (5) the average productivity of the herd; (6) the proportion of male and female births in the herd; and (7) the opportunity cost of selling male and female calves shortly after birth.

The final cost of the heifer at calving and the value received per liter of milk were considered as the averages of each farm and their respective standard deviations of the mean, as well as the maximum and minimum values. In this study, we did not measure the net milk margin nor the culling rate of cows on each farm. Therefore, these values were pre-defined based on the expertise of the authors in a plausible manner according to each milk productive tier. Thus, net milk margin values of 25%, 30%, and 35% were considered for the LOW, INT, and UPP tiers respectively, with a standard deviation of 0.03 for both. The culling rate was 15% for LOW, 20% for INT, and 25% for UPP, and the average selling price was calculated as 75% of the average price of a finished cattle arroba in 2021, provided by CEPEA and adjusted to January 2024.

The average productivity of the herd was taken into account to estimate productivity per lactation in each scenario, and the values used were the same as those that weighted the farm divisions into their respective milk productive tiers, as presented previously by Silva et al. (2025). The proportion of male and female births in each milk productive tier was adopted based on the criteria of reproductive biotechnology used and described by Silva et al. (2025). Since UPP farms make greater use of AI with sexed female semen, the male/female birth ratio considered was 40/60, while for LOW and INT it was 50/50. Thus, the average selling prices considered for male and female calves were different according to the milk productive tiers, given that the genetic standard differs as presented by Silva et al. (2025).

Statistical Analysis

The data analysis related to the cost of production was conducted using the GLIMMIX procedure in SAS® software (SAS Studio), employing a Gaussian distribution model to explore potential fixed effects of the milk production tier on cost components. Adjusted treatment means were compared using the lsmeans statement with adjustments for multiple comparisons (pdiff), and significant differences were delineated using grouping lines. The COST factor was analyzed across milk production levels, and results were presented based on adjusted mean groupings generated by lines commands. Residuals were graphically assessed to evaluate model adequacy and error normality. Statistical significance was set at $P < 0.05$, with tendencies noted for P-values between 0.05 and 0.10.

Table 1 presents the descriptive variables, as well as the minimum, maximum and median values of the production cost item in the calves and heifers rearing phases. These values were obtained through the "PROC UNIVARIATE" procedure of the SAS® software (SAS Studio). The data presentation did not enter any statistical analysis but served as supplementary material to enhance understanding for the respective variables.

The Monte Carlo simulation was conducted using ModelRisk software (Vose Software). The final cost of the heifer at calving, the net milk margin, and the price received per liter of milk were considered as stochastic variables and were subjected to collinearity testing. Initially, the final cost of the heifer and the milk price were tested for normality using the Shapiro-Wilk test via R software (R Development Core Team, 2015). We used a lognormal distribution for the production costs of heifers with parameters mean = 2,006.4, 1,821.4, and US$ 1,884.6 with sd =875.3, 394,3 and US$ 363.2 for the LOW, INT, and UPP tiers, respectively. For the milk price and net milk margin, a normal distribution was applied. The means for milk price were 0.50, 0.50, and 0.51 with standard deviations of 0.06, 0.05, and 0.04 for LOW, INT, and UPP tiers, respectively. The mean used for the net milk margin was 0.25, 0.30, and 0.35 for the respective LOW, INT, and UPP tiers, with a standard deviation of 0.03 for all. We considered the correlation of variables being 0.1 for final cost *vs*. net milk margin, 0.3 for final cost *vs*. milk price, and 0.7 for net milk margin *vs*. milk price. The Monte Carlo simulation was configured to run 5000 iterations, using the Latin Hypercube Sampling.

RESULTS

Production Cost of Dairy Calves

The cost analysis across different levels of milk production on dairy farms revealed similar patterns in dairy calf rearing. Across all production levels, the liquid diet represented the highest cost (Table 2). However, UPP farms incurred the highest costs ($P < 0.01$) for the liquid diet (US$ 238.9 ± 3.46) compared to LOW (US$ 220.7 ± 3.46) and INT (US$ 214.3 ± 2.45) farms.

Conversely, labor costs were higher on LOW farms (US$ 57.1 ± 3.46, $P < 0.01$) and showed no significant differences when compared to INT (US$ 28.4 ± 2.45) and UPP (US$ 28.8 ± 3.46) farms (Table 2). Other costs were significantly higher ($P < 0.01$) for UPP farms (US$ 31.6) but did not differ between INT (US$ 10.7) and LOW (US$ 9.7) levels (Table 2). The remaining components of production costs showed no differences due to the milk production level of the farm ($P > 0.05$; Table 2).

Within milk productive tier, changes were observed in the contribution of each cost item to the final cost (Table 2). On LOW farms, the liquid diet accounted for the largest portion of the cost (55.3%), followed by labor (14.3%), concentrate (9.1%), and reproduction (5,7%). Smaller contributions to overall production costs included opportunity cost (3.8%), mortality (3.0%), vaccination and preventive care (2.6%), disease treatments (1.5%), depreciation (1.3%), forage (0.8%), and other costs (2.4%).

On INT-tiers farms (Table 2), the liquid diet remained the most burdensome cost item (59.2%), followed by concentrate (11.4%). Labor (7.8%) and reproduction (7.1%) ranked third, followed by opportunity cost (3.8%), mortality (2.8%), vaccination and preventive care (2.4%), disease treatments (1.2%), depreciation (0.8%), forage (0.4%), and other costs (3.0%).

For UPP farms (Table 2), the liquid diet also showed the greatest impact (56.8%), followed by concentrate (10.2%) and reproduction (7.5%). Labor (6.8%), opportunity cost of tied-up capital (3.4%), mortality (3.2%), vaccination and preventive care (2.0%), disease treatments (1.4%), depreciation (0.7%), forage (0.3%), and other costs (7.6%) followed.

Additionally, the final cost of a weaned calf was significantly lower for INT farms (US$ 361.7 ± 9.35, $P < 0.01$) compared to LOW and UPP farms, which had costs of US$ 399.7 ± 13.19 and US$ 420.4 ± 13.19, respectively (Table 2).

Production Cost of Dairy Heifers

The main differences in the final costs influenced by the milk production tier were associated with feed and machinery expenses. LOW farms showed higher expenditures on forage and lower spending on concentrate (P < 0.01), whereas UPP farms displayed the opposite trend (Table 3). The expenditure on concentrate was significantly higher (P < 0.01) for UPP farms, amounting to US$ 523.0 ± 14.25, followed by INT and LOW farms, which spent US$ 465.9 ± 10.11 and US$ 367.8 ± 14.25, respectively (Table 3). Conversely, forage costs were highest for LOW farms (US$ 562.8 ± 14.25) and progressively decreased for INT and UPP farms, which had the lowest (P < 0.01) expenditure (US$ 478.1 ± 10.11 and US$ 435.8 ± 14.25, respectively; Table 3). Machinery costs did not differ significantly between INT (US$ 239.8 ± 10.11) and UPP (US$ 240.8 ± 14.25) farms but were higher for LOW farms (US$ 321.0 ± 14.25; P < 0.01). Labor costs showed significant differences (P < 0.01) only between LOW and UPP farms, with LOW farms incurring higher costs (US$ 99.6 ± 14.25) compared to UPP farms (US$ 50.2 ± 14.25; Table 3).

Within the LOW tier (Table 3), forage represented the largest cost component (35.0%), followed by concentrate (22.9%), machinery (20.0%), opportunity cost of tied-up capital (8.7%), and labor (6.2%). Additional costs included depreciation (3.0%), mortality (.8%), reproduction (1.4%), vaccination and preventive care (0.7%), and disease treatment (0.3%).

In INT-tier farms (Table 3), the highest cost was for forage (32.7%), which did not differ statistically from concentrate costs (32.0%). This was followed by the opportunity cost of tied-up capital (7.9%), machinery costs (16.4%), and labor (4.8%). Other costs, without significant statistical differences, included depreciation (2.0%), reproduction (1.8%), mortality (1.6%), vaccination and preventive care (0.6%), and disease treatment (0.2%).

For UPP-tier farms (Table 3), concentrate costs were the highest (35.7%), followed by forage (29.8%), machinery (16.4%), opportunity cost of tied-up capital (7.8%), and labor (3.4%). Additional costs included reproduction (2.2%), mortality (1.8%), depreciation (1.8%), vaccination and preventive care (0.7%), and disease treatment (0.3%).

There was a noticeable trend (*P* = 0.09) towards lower production costs between the post-weaning and calving phases for INT farms, which exhibited the lowest costs (US$ 1,459.7 ± 40.85) compared to LOW and UPP farms (US$ 1,606.7 ± 57.59; US$ 1,464.1 ± 57.59, respectively) (Table 3). In the same way, the INT farms showed a trend (*P* = 0.06) towards the lowest production cost from birth to first calving (US$ 1,821.4 ± 44.35), contrasting with the highest costs recorded for LOW farms (US$ 2,006.4 ± 62.52). The UPP farm costs were similar to both other milk productive tiers (US$ 1,884.6 ± 62.52; Table 3).

Payback

The mean for the payback is shown by the reference lines (Figure 2). The average payback, for LOW the mean farms was approximately 3.98 lactations (minimum 1.33 and maximum 9.33), while for INT it was 2.64 lactations (minimum 1.33 and maximum 6.33), and for UPP it was 1.64 lactations (minimum 0.66 and maximum 3.66). However, only 60% of LOW farms were able to reach the breakeven point at the average payback, while the percentages for INT and UPP tiers were 68% and 70%, respectively (Figure 2).

DISCUSSION

Consistent with findings from Boulton et al. (2017), Erickson et al. (2020), and Hawkins et al. (2020), feed remains a significant contributor to the production costs of calves and heifers. Milk, which serves as the primary feed during the rearing phase (Godden et al., 2019), emerged as the most substantial cost across all milk productive tiers. Farms at the UPP milk productive tier incurred higher costs for liquid diets due to the greater volumes of milk provided (Silva et al., 2025). This finding exceeds the average costs reported by Akins et al. (2017), which were US$126.0 across various rearing systems including individual and automated feeders. In contrast, our study reported costs of US$ 220.7, US$ 214.3, and US$ 239.0 for LOW, INT, and UPP milk productive tiers, respectively. Forage contributes minimally during the initial rearing phase due to low intake, primarily serving as an adaptation tool for subsequent dietary transitions (Akins, 2016).

Labor costs emerged as the second-largest expense for farms with LOW milk productive tiers, underscoring the intensive manual labor required in more extensive farming operations. This observation is consistent with Hawkins et al. (2020), who noted that labor demands typically escalate in systems with lower milk productive sophistication. Interestingly, machinery costs were also significant higher for LOW farms, exacerbated by prolonged durations of AFC (Silva et al., 2025). This finding contrasts with reports by Karszes and Hill (2020), who noted higher labor than machinery costs, possibly reflecting variations in herd sizes and operational scales. Meanwhile, concentrate feeding—a critical factor for achieving high ADG was a major cost driver in INT and UPP milk productive tier farms, leading to improved animal performance and reduced non-productive periods, as reported by Turiello et al. (2020) and Masello et al. (2021).

Despite the employment of advanced reproductive biotechnologies, such as AI, reproduction costs were surprisingly lower than anticipated, particularly in farms with INT and UPP milk productive tiers (Silva et al., 2025). This indicates an efficient application of these technologies in reducing overall reproduction expenses. Moreover, the lack of significant variation in mortality and preventive costs across different milk productive tiers suggests that health conditions were uniformly managed throughout the study, reflecting consistent health management practices across all farms.

The analysis revealed no significant differences in opportunity costs across milk productive tiers, contrasting with findings by Hawkins et al. (2020), who reported higher costs associated with more extensive dairy farms. This discrepancy likely stems from our methodological approach, which excludes the value of land from the calculations of calf and heifer rearing costs. Instead, our focus was strictly on direct operational expenses, potentially accounting for the lack of observed variance in opportunity costs among the different tiers.

The economic efficiency of dairy farms demonstrated variability, with INT milk productive tier farms showing the lowest production costs from birth to calving. This finding contradicts the expectation that UPP farms would be more cost-effective due to their higher ADG and reduced AFC, as suggested by Daniels (2010) and Turiello et al. (2020). The observed cost-efficiency in INT farms may be attributed to breed differences and the tier of facility investment. Specifically, INT farms, which predominantly house mixed-breed cattle (Holstein × Gyr), benefit from less elaborate infrastructure requirements compared to the purebred Holstein herds typically found in UPP farms (Silva et al., 2025).

Significant inefficiencies have been noted in the rearing of calves and heifers on farms with LOW milk productive tiers, characterized by high production costs and diminished productive potential of these animals (Silva et al., 2025). In addition to the higher production cost at calving, LOW farms exhibited a large dispersion in the data regarding the lowest and highest values in the group (US$ 874.6 and US$ 6,048.6, respectively). This behavior suggests the presence of variables that are difficult to control, such as management practices and herd efficiency, as well as less standardization among the farms in this group. The fact that INT and UPP showed less variation between minimum and maximum values suggests greater stability, predictability, and control over the production cost of dairy calves and heifers**.**

Considering the retention time in the herd due to adopted mortality rates, in the LOW systems, 4% of the farms would never break even, while in the INT systems, this value was 3.5%. For the UPP milk productive tier, all farms would comfortably reach the breakeven point. Since we did not collect information on the calving interval of the herd, we assumed a hypothetical value of 12 months for both milk productive tiers. Therefore, this scenario might be even less favorable than described for LOW and INT farms, as the calving interval will likely follow more extensive management trends, which would consequently further reduce the number of lactations and total milk production until the end of life or culling (Pérez-Méndez et al., 2020; Adamie et al., 2023).

The average productivity of the herd associated with the production cost was determinant for a shorter payback period, given that the UPP milk productive tier was the closest to the data from the literature. Bach (2011) and Boulton et al. (2017) found that, for a heifer to pay for its costs and start being profitable for the farm, an average of 1.5 lactations is necessary. In other words, despite the lower production cost observed in INT, the best scenario for economic return was found for the UPP milk productive tier. This occurs because the higher average milk production on UPP farms offsets the investment in a shorter period, even though it is numerically higher than on INT farms.

To address these challenges and potentially elevate the milk productive prowess of their dairy operations, a strategic shift could be considered. Selling calves at birth and purchasing pregnant heifers from higher milk productive tier farms could serve as a viable alternative. This approach not only circumvents the initial rearing costs but also accelerates the integration of advanced genetics and enhanced productivity into the herd, thereby improving overall economic efficiency and productivity. The LOW farms may consider selling calves at birth and acquiring pregnant heifers from farms with higher genetic potential. This approach bypasses the expenses and complexities associated with young stock rearing and facilitates rapid genetic advancement. By purchasing heifers close to calving, farms can immediately benefit from superior genetics and potentially higher productivity, thus improving the economic efficiency and productivity of the dairy operation. This strategy provides LOW farms with opportunities to realign their operational focus towards more cost-effective and productive practices, potentially leading to enhanced profitability and sustainability within the competitive dairy industry.

CONCLUSION

Farms with low milk productive tier experience significant inefficiencies in the rearing of dairy calves and heifers, marked by elevated production costs and reduced animal productivity, which consequently requires a greater number of lactations to break even, delaying the economic return. Feed constitutes the primary expense, followed by labor and machinery costs. Critical factors influencing successful development include breed selection, age at first calving, and rearing systems. For low-tech farms aiming to enhance their operations by increasing milk production and genetic merit, a strategic shift towards purchasing genetically superior animals, rather than rearing calves and heifers, is advisable. This approach not only diminishes costs but also expedites genetic improvement, thereby boosting milk production and enhancing farm profitability. The integration of animals with high genetic potential can substantially improve herd performance and promote overall farm sustainability.

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TABLES

Table 1. Descriptive statistics of dairy heifer and calf production costs in Brazil under different milk productive tier systems.

Cost (US$)	LOW[1] (n=78)					INT[2] (n=155)					UPP[3] (n=78)				
	Mean	SDM[4]	Min[5]	Max[6]	Med[7]	Mean	SDM[4]	Min[5]	Max[6]	Med[7]	Mean	SDM[4]	Min[5]	Max[6]	Med[7]
Calves															
Liquid diet	220.7	96.32	95.2	496.2	195.63	214.3	52.60	23.8	476.7	213.7	239.0	53.43	142.5	443.2	238.7
Concentrate feed	36.5	21.03	0.0	169.7	32.32	41.5	19.75	14.1	163.2	39.3	42.7	12.41	10.4	101.8	41.4
Labor	57.1	89.03	3.5	665.1	20.95	28.4	25.38	2.3	212.8	22.0	28.8	24.90	5.2	177.7	21.3
Reproduction	23.0	23.05	0.0	124.2	21.34	25.7	30.12	0.0	215.5	17.8	31.7	35.26	0.0	230.4	19.6
Oportunity	15.3	8.28	5.8	40.5	13.03	13.6	7.39	5.3	91.4	12.8	14.2	3.58	6.8	25.3	13.4
Mortality	11.9	11.25	0.0	47.7	8.40	10.0	6.96	0.0	40.6	8.5	13.3	10.58	0.0	53.9	9.8
Vacination and preventive care	10.6	10.15	0.0	39.52	7.6	8.6	7.81	0.0	43.6	5.9	9.4	8.86	0.0	34.3	6.5
Diseases treatment	6.1	4.27	0.1	16.61	5.7	4.3	3.57	0.3	24.3	3.3	5.7	4.83	0.0	33.1	4.9
Depreciation	5.3	6.05	0.0	31.71	3.2	3.0	1.89	0.2	10.0	2.7	2.9	1.79	0.0	8.0	2.5
Forage	3.5	5.86	0.0	30.15	0.6	1.6	3.10	0.0	24.5	0.4	1.4	2.30	0.0	12.3	0.5
Others	9.7	19.42	0.0	160.90	5.7	10.8	23.48	0.0	269.7	5.7	31.6	77.67	0.6	468.9	8.3
Heifers															
Forage	562.8	396.52	213.4	3423.9	479.9	478.1	172.24	148.8	1312.6	453.9	435.8	135.29	227.2	1288.5	429.3
Concentrate feed	367.8	224.96	0.0	948.2	333.7	465.9	171.65	93.6	965.4	448.2	523.0	126.54	0.0	781.4	536.8
Machinery	321.0	375.56	0.0	1665.9	174.6	239.8	192.20	0.0	919.5	195.5	240.8	1.35	0.0	822.9	216.4
Oportunity	139.1	64.62	63.5	399.3	123.4	115.5	29.40	56.4	233.2	112.0	114.0	24.52	72.9	187.2	111.8
Labor	99.6	98.69	7.7	550.7	73.5	70.5	54.90	0.0	298.0	58.3	50.2	41.88	5.4	267.7	39.5
Depreciation	49.6	40.91	6.7	191.4	35.3	29.7	17.90	3.2	86.1	26.3	26.3	15.36	0.0	75.3	22.5

Reproduction	23.0	23.06	0.0	124.2	21.3	25.7	30.11	0.0	215.5	17.8	31.6	35.26	0.0	230.4	19.6
Mortality	28.9	43.27	0.0	289.9	15.7	22.8	18.61	0.0	137.4	17.3	26.7	21.00	0.0	101.2	19.4
Vacination and preventive care	10.6	6.46	1.3	29.1	9.0	9.1	5.16	1.5	27.5	8.1	10.6	5.13	0.6	21.1	9.4
Diseases treatment	4.3	5.32	0.0	22.6	2.9	2.7	3.77	0.1	33.4	1.9	5.1	5.59	1.6	26.2	2.7

[1]Lower milk productive tier.
[2]Intermediate milk productive tier.
[3]Upper milk productive tier.
[4]Standard deviation of the mean.
[5]Minimum value.
[6]Maximum value.
[7] Median value.

Table 2: Cost of production of dairy calves in Brazil under different milk production tiers.

Cost (US$)	LOW[1] (n = 78)				INT[2] (n = 155)				UPP[3] (n = 78)				*P* value
	Mean	Min[4]	Max[5]	Med[6]	Mean	Min[4]	Max[5]	Med[6]	Mean	Min[4]	Max[5]	Med[6]	
Liquid diet	220.7^b ± 3.46	95.2	496.2	195.6	214.3^b ± 2.45	23.8	476.7	213.7	238.9^a ± 3.46	142.5	443.2	238.7	<0.01
Concentrate feed	36.5^a ± 3.46	0.0	169.7	32.3	41.5^a ± 2.45	14.1	163.2	39.3	42.7^a ± 3.46	10.4	101.8	41.4	0.39
Labor	57.1^a ± 3.46	3.5	665.1	21.0	28.4^b ± 2.45	2.3	212.8	22.1	28.7^b ± 3.46	5.2	177.7	21.3	<0.01
Reproduction	22.9^a ± 3.46	0.0	124.2	21.3	25.7^a ± 2.45	0.0	215.5	17.8	31.7^a ± 3.46	0.0	230.4	19.6	0.19
Oportunity	15.3^a ±3.46	5.8	40.5	13.0	13.6^a ± 2.45	5.3	91.4	12.8	14.2^a ± 3.46	6.9	25.3	13.4	0.93
Mortality	11.9^a ± 3.46	0.0	47.7	8.4	10.1^a ± 2.45	0.0	40.6	8.5	13.3^a ± 3.46	0.0	53.9	9.8	0.74
Vacination and preventive care	10.6^a ± 3.46	0.0	39.5	7.6	8.6^a ± 2.45	0.0	43.6	6.0	9.4^a ± 3.46	0.0	34.3	6.5	0.89
Treatment health	6.1^a ± 3.46	0.1	16.6	5.7	4.3^a ± 2.45	0.3	24.3	3.3	5.7^a ± 3.46	0.0	33.1	4.9	0.89
Depreciation	5.3^a ± 3.46	0.0	31.7	3.2	3.0^a ± 2.45	0.2	10.0	2.7	2.9^a ± 3.46	0.0	8.0	2.5	0.84
Forage	3.5^a ± 3.46	0.0	30.2	0.6	1.6^a ± 2.45	0.0	24.5	0.4	1.4^a ± 3.46	0.0	12.3	0.5	0.88
Others	9.7^b ± 3.46	0.0	160.9	5.7	10.7^b ± 2.45	0.0	269.7	5.7	31.6^a ± 3.46	0.6	468.9	8.3	<0.01
Final cost calf	399.7^a ± 13.19	217.8	860.6	358.9	361.7^b ± 9.35	129.5	667.8	351.9	420.4^a ± 13.19	252.6	944.3	393.3	<0.01

[1]Lower milk productive tiers.
[2]Intermediate milk productive tiers.
[3]Upper milk productive tiers.
[4]Minimum value.
[5]Maximum value.
[6]Median value.
Different lowercase superscript letters indicate statistical significance.
Different uppercase superscript letters indicate a statistical trend.

Table 3: Cost of production of dairy heifers in Brazil under different milk production tiers.

Cost (US$)	LOW[1] (n = 78)				INT[2] (n = 155)				UPP[3] (n = 78)				*P* value
	Mean	Min[4]	Max[5]	Med[6]	Mean	Min[4]	Max[5]	Med[6]	Mean	Min[4]	Max[5]	Med[6]	
Forage	$562.8^{a} \pm 14.25$	213.4	3423.9	479.9	$478.1^{b} \pm 10.11$	148.8	1312.6	453.9	$435.8^{c} \pm 14.25$	227.2	1288.5	429.3	<0.01
Concentrate feed	$367.8^{c} \pm 14.25$	0.0	948.2	333.7	$465.9^{b} \pm 10.11$	93.6	965.4	448.2	$522.9^{a} \pm 14.25$	0.0	781.4	536.8	<0.01
Machinery	$321.0^{a} \pm 14.25$	0.0	1666.0	174.6	$239.8^{b} \pm 10.11$	0.0	919.5	195.6	$240.8^{b} \pm 14.25$	0.0	822.9	216.4	<0.01
Oportunity	$139.1^{a} \pm 14.25$	63.5	399.3	123.4	$115.5^{a} \pm 10.11$	56.4	233.2	112.0	$113.9^{a} \pm 14.25$	72.9	187.2	111.8	0.34
Labor	$99.6^{A} \pm 14.25$	7.7	550.7	73.5	$70.5^{AB} \pm 10.11$	0.0	298.0	58.3	$50.2^{B} \pm 14.25$	5.4	267.7	39.5	0.05
Depreciation	$49.6^{a} \pm 14.25$	6.7	191.4	35.3	$29.7^{a} \pm 10.11$	3.2	86.1	26.3	$26.3^{a} \pm 14.25$	0.0	75.3	22.5	0.43
Reproduction	$22.9^{a} \pm 14.25$	0.0	124.2	21.3	$25.7^{a} \pm 10.11$	0.0	215.5	17.8	$31.6^{a} \pm 14.25$	0.0	230.4	19.6	0.91
Mortality	$28.9^{a} \pm 14.25$	0.0	289.9	15.7	$22.8^{a} \pm 10.11$	0.0	137.4	17.3	$26.7^{a} \pm 14.25$	0.0	101.2	19.4	0.94
Vacination and Preventive care	$10.6^{a} \pm 14.25$	1.3	29.1	9.0	$9.1^{a} \pm 10.11$	1.5	27.5	8.2	$10.6^{a} \pm 14.25$	0.6	21.1	9.4	0.99
Treatment health	$4.4^{a} \pm 14.25$	0.0	22.6	2.9	$2.7^{a} \pm 10.11$	0.1	33.4	1.9	$5.1^{a} \pm 14.25$	1.6	26.2	2.7	0.99
Final cost heifer	$1,606.7^{A} \pm 57.59$	596.9	5,630.7	1,387.4	$1,459.7^{B} \pm 40.85$	608.8	2,653.4	1,425.4	$1,464.1^{AB} \pm 57.59$	952.7	2,287.1	1,443.7	0.09
Final cost calf + heifer	$2,006.4^{A} \pm 62.52$	874.6	6,048.6	1,699.7	$1,821.4^{B} \pm 44.35$	962.9	3,163.7	1,782.3	$1,884.6^{AB} \pm 62.52$	1,205.4	2,872.9	1,839.7	0.06

[1]Lower milk productive tiers.
[2]Intermediate milk productive tiers.
[3]Upper milk productive tiers.
[4]Minimum value.
[5]Maximum value.
[6]Median value.
Different lowercase superscript letters indicate statistical significance.
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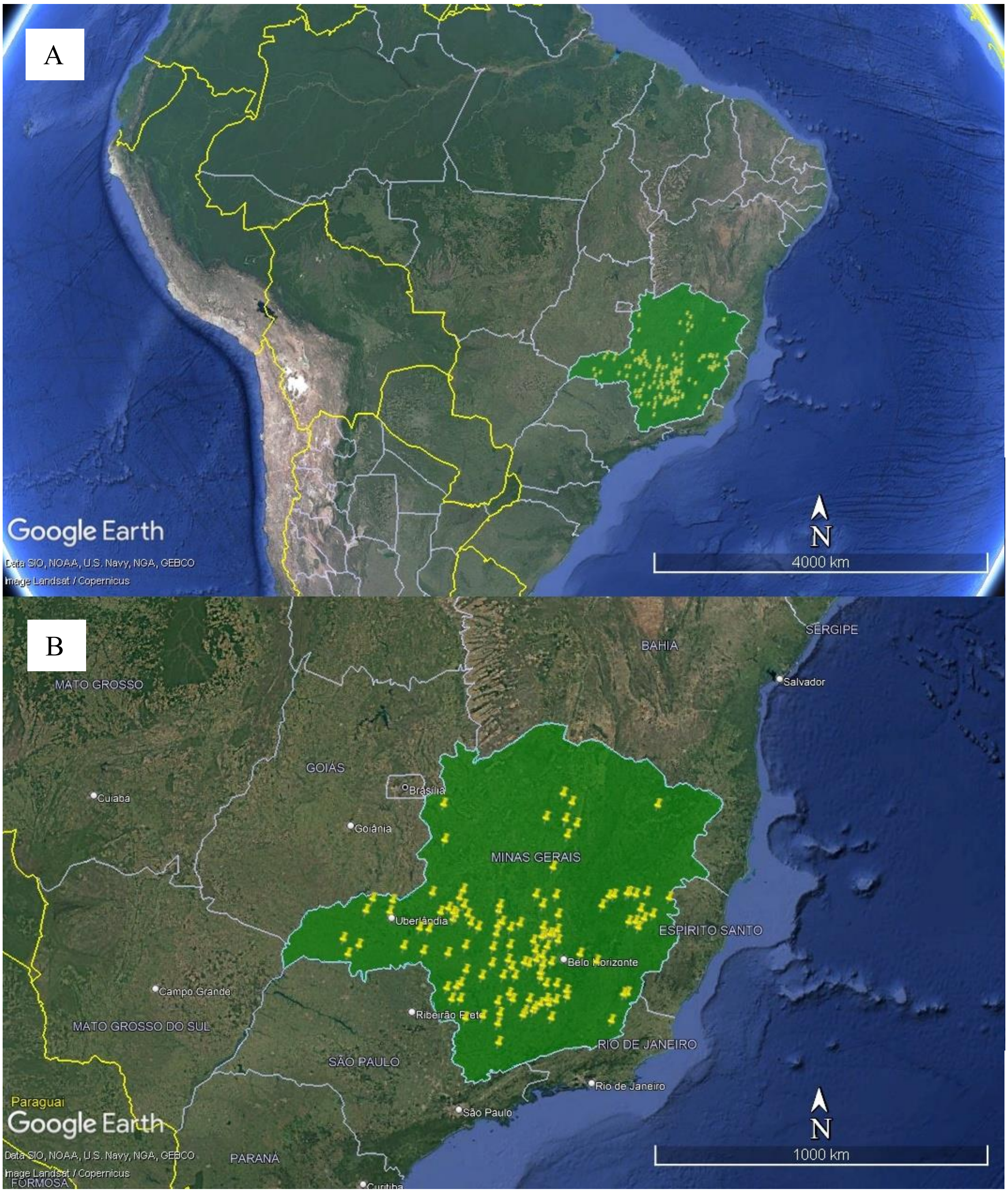
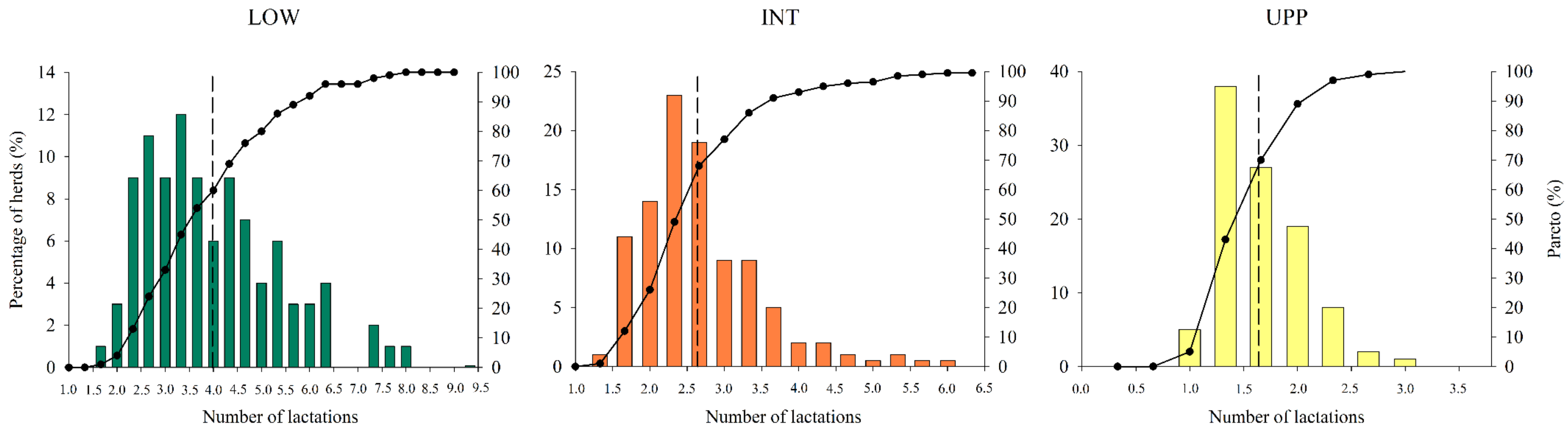
FIGURES

Figure 1. Geographic localization of State of Minas Gerais (A) and distribution dairy farms participating in the study in the state of Minas Gerais (B).

Figure 2: Payback related to the LOW, INT, and UPP milk productive tiers for the production cost of heifers at calving



Silva, Figure 1.



Silva, Figure 2.