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Economic and Environmental Gains from the Use of Yeast By-Products in the Feeding of Dairy Cows

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Abstract:

The increasing demand for sustainable livestock production has intensified the search for nutritional strategies to improve animal performance while reducing environmental impacts. Among these strategies, yeast by-products have gained attention due to their potential to enhance feed efficiency, animal productivity, and environmental sustainability. Therefore, this study aimed to evaluate the economic feasibility and environmental benefits of using yeast by-products in dairy cow diets. Economic feasibility was assessed over a 10-year project lifespan using NPV, IRR, MIRR, PI, B/C ratio, discounted payback period, sensitivity analysis, and Monte Carlo simulation. Environmental performance was evaluated through enteric methane (CH_4) emissions and their conversion to CO_2e. The project was economically feasible, with positive financial indicators (NPV = US$97,154.11; IRR = 12.39%; MIRR = 8.91%; PI = 1.45; B/C = 1.28) and a discounted payback period of 7.5 years. Economic viability remained robust under sensitivity and Monte Carlo analyses. Yeast supplementation reduced CH_4 emissions by up to 8.02 kg per cow per year (224.6 kg CO_2e) and decreased emissions per kilogram of energy-corrected milk. These findings indicate that yeast by-products are an economically attractive and environmentally sustainable option for dairy production systems. These findings indicate that yeast supplementation represents a viable strategy for dairy farms, simultaneously enhancing productive efficiency, generating economic returns, and contributing to greenhouse gas mitigation. Consequently, the adoption of yeast by-products may support the transition toward more sustainable and environmentally responsible dairy production systems.

Keywords:

1. Introduction

Liquid yeast residue is characterized as an effluent containing both viable and non-viable cells of *Saccharomyces cerevisiae*, as well as intracellular fractions (cytosol), originating from the fermentation of wort during ethanol production (Vukušić et al., 2019). Its generation is estimated at approximately 40 kg per ton of processed sugarcane (Mashoko et al., 2010; Ferreira et al., 2019). This residue is characterized by a high concentration of microbial biomass, with approximately 10 billion inactive cells per gram, and is also rich in nutrients, presenting a dry matter content of around 7% and crude protein levels ranging from 30 to 41% (Verdier-Metz et al., 2023).

Due to these characteristics, liquid yeast residue has a high pollution potential, significantly contributing to the organic load of industrial effluents when not properly treated or utilized (Sundaramahalingam et al., 2023). Furthermore, the accumulation, storage, and disposal of yeast biomass in ethanol plants may pose additional

environmental and operational risks, particularly under extreme conditions such as fires, due to its high organic load and the potential generation of combustible gases during decomposition.

In Brazil, milk production is predominantly carried out by small- and medium-scale producers, typically characterized by low-input production systems, limited access to resources, and greater sensitivity to fluctuations in production costs (Bach et al., 2023). In such systems, feed represents the largest component of operational costs, often exceeding 50% of total production expenses. Among the ingredients used in diet formulation, soybean meals stand out as the primary protein source for dairy cows; however, as a globally traded commodity, their price is subject to fluctuations that can directly affect farm profitability (Fonseca et al., 2016). In this context, the search for alternative feed ingredients, including agro-industrial by-products with adequate nutritional value, has been considered a promising strategy to reduce feeding costs and enhance the economic sustainability of dairy farms.

Within this framework, the use of yeast derived from the fermentation process emerges as a potential strategy to simultaneously address two challenges: the generation of a high-pollution industrial residue and the elevated cost of conventional protein sources in ruminant diets. The inclusion of yeast residue in dairy cow diets may partially replace traditional protein ingredients while promoting positive effects on nutrient digestibility, ruminal pH stability, fermentation patterns, dry matter intake, and productive performance during lactation (Lees et al., 2021; Verdier-Metz et al., 2023; Humer et al., 2023). In a synthesis of multiple studies, Robinson and Erasmus (2009) reported that yeast supplementation was associated with an average increase of approximately 0.9 kg of milk per cow per day. Similarly, Zaworski et al. (2014) and Dias et al. (2018) observed increases of 3.3 and 5.2 kg of milk per day in transition and mid-lactation cows, respectively, when fed yeast culture-based products. Additionally, Olagaray et al. (2019) reported an increase of 0.13 kg/day in milk fat yield with the administration of 19 g/day of yeast culture during the peripartum period.

Beyond productive responses, yeast supplementation has also been associated with the mitigation of enteric methane emissions, either through the reduction of methanogenic microorganisms or by increasing the population of lactate-utilizing and acetogenic bacteria that compete with methanogenic archaea for hydrogen in the rumen environment (Bayat et al., 2015). However, although these mechanisms are well described, in vivo evidence remains limited, particularly regarding the use of liquid yeast

residue, as opposed to dried yeast and its derivatives, which have been extensively studied. Furthermore, information on the economic impacts of adopting this by-product in small-scale dairy production systems remains scarce.

Therefore, this study aims to evaluate the economic feasibility of establishing a small-scale dairy farm from year zero, incorporating liquid yeast residue supplementation into the cost and revenue structure of the production system. The objective is to provide support for decision-making by dairy producers regarding whether the adoption of this technology can ensure adequate return on investment over time, considering not only productive responses but also potential environmental benefits, particularly those related to the mitigation of impacts associated with industrial waste management and enteric methane emissions.

2. Materials and Methods

2.1. Experimental Description

The procedures for the use and management of animals in this study were approved by the Research Ethics Committee of the Federal University of Grande Dourados under protocol number 05/2022. The experiment was conducted at the dairy cattle farm "Nossa Senhora Abadia," located in the municipality of Douradina, Mato Grosso do Sul, Brazil (22°14′ S latitude, 54°49′ W longitude, and 450 m altitude), from May to August 2022.

The experiment was conducted on a dairy cattle farm, "Nossa Senhora Abadia," located in the municipality of Douradina, Mato Grosso do Sul, Brazil (22°14′ S, 54°49′ W; 450 m altitude), from May to August 2022.

The farm comprises a total area of 60 hectares and is dedicated to integrated milk and grain production, a system commonly observed in family-based farms in the region. The agricultural area is primarily used for the cultivation of corn for silage and grain, as well as soybeans, mainly for animal feeding.

The production system consisted of approximately 30 lactating cows. The animals were housed in conventional compost barn facilities, characterized by collective pens with a composted bedding system, compacted soil flooring covered with organic material, and periodic bedding turning to promote thermal comfort, animal welfare, and environmental hygiene. The space allowance was approximately 15 m^2 per cow, in accordance with technical recommendations for compost barn systems.

169 The experiment was conducted using two simultaneous 4 × 4 Latin squares. Each
170 Latin square consisted of four animals, four treatments, and four experimental periods.
171 Treatments were assigned to ensure that each animal received all treatments across the
172 experimental periods, thereby minimizing individual and temporal variation.

173 Treatments were arranged in a 2 × 2 factorial design, consisting of two dietary
174 crude protein levels (13% and 16%) and the inclusion or absence of liquid yeast residue,
175 totaling four treatments. Diets were formulated to meet the nutritional requirements of a
176 550-kg dairy cow producing an average of 20 kg of milk per day, according to NASEM
177 (2021). The experimental diets contained different crude protein levels (16.71%, 13.35%,
178 13.33%, and 16.77% on an as-fed basis) and were defined as follows: high true protein
179 without liquid yeast residue; low true protein with liquid yeast residue; low true protein
180 without liquid yeast residue; and high true protein with liquid yeast residue.

181 The experiment lasted 80 days, divided into four 20-day periods, with 14 days
182 (days 1–14) allocated for adaptation and 6 days (days 15–20) for data collection
183 (Machado et al., 2016). Diets were offered twice daily at 06:00 and 14:00 h,
184 corresponding to 60% and 40% of total dry matter (DM) supply, respectively. Feed was
185 provided to allow for approximately 10% refusals, ensuring ad libitum intake.

186 Feeding was carried out using linear collective feed bunks located at the front of
187 the barn, allowing simultaneous access by all animals. Water was supplied through
188 collective drinkers with continuous availability, ensuring unrestricted ad libitum access
189 throughout the experimental period.

190 Diets were formulated with a forage-to-concentrate ratio of 73:27 to meet the
191 nutritional requirements of a 550-kg dairy cow producing 20 kg of milk per day,
192 according to NASEM (2021). The diets consisted of corn silage, oat hay, and a cereal-
193 based concentrate, with the inclusion of different proportions of liquid yeast residue
194 (Table 1). The chemical composition of the feed ingredients used in diet formulation is
195 presented in Table 2.

196 **Table 1.** Proximate and nutritional composition of the experimental diets on a dry matter
197 (DM) basis.

Ingredients	**Experimental diets (% DM)**			
	Low protein		High protein	
	Without	With	Without	With
Oat hay	6.8	6.1	6.4	5.3
Liquid yeast	0	20	0	24.4
Corn silage	60.1	50	59	50.5

Corn grain	21.4	16	10	14.3
Soybean grain	10.2	2	22.5	5
Mineral-vitamin premix[1]	1	1	1.1	0.7
Urea	0.5	0	1	0.3
Nutritional composition (g/kg DM)				
Dry matter	543.4	546.1	515.5	380
Organic matter	920.6	897.9	913.5	903.3
Crude protein	133.3	133.5	167.1	167.7
Neutral detergent fiber	384.1	338	385.4	320.6
Non-fiber carbohydrates	388.4	409.2	342.9	401.9
Total digestible nutrients	561.8	626.4	554.8	637.4

Guaranteed levels (kg/product): Calcium 190 g/kg, Phosphorus 60 g/kg, Sulfur 20 g/kg, Magnesium 20 g/kg, Potassium 35 g/kg, Sodium 70 g/kg, Cobalt 15 mg/kg, Copper 700 mg/kg, Chromium 10 mg/kg, Iron 700 mg/kg, Iodine 40 mg/kg, Manganese 1,600 mg/kg, Selenium 19 mg/kg, Zinc 2,500 mg/kg, Vitamin A 400,000 IU/kg, Vitamin D_3 100,000 IU/kg, Vitamin E 2,400 IU/kg, Fluoride 600 mg/kg.
Source: Research data (2025).

Table 2. Proximate and nutritional composition of the experimental diets

Ingredients	**Nutritional composition (g/kg DM)**				
	DM	OM	Ash	CP	NDF
Oat hay	852.8	920.1	92.1	86.7	658.4
Liquid yeast	69.4	915.0	85.0	301.2	50.2
Corn silage	312.0	920.3	79.7	102.7	486.0
Corn meal	842.7	973.1	29.0	109.8	128.2
Soybean grain	874.9	956.3	43.7	302.8	194.5

Source: Research data (2025).

2.1.1. Milk Production and Composition

From days 15 to 20 of each experimental period, milk samples were collected from both daily milkings and pooled to obtain a composite sample for fat analysis. Milk fat content was determined by infrared spectrometry using a LACTOSCAN® analyzer. Milk yield was corrected to 3.5% fat using the following equation: fat-corrected milk (FCM) = [(0.432 + 0.1625 × milk fat %) × milk yield] (Sklan et al., 1992). Based on dry matter intake (DMI) and milk yield data, feed efficiency (FE) of the cows was calculated according to Nasrollahi et al. (2017):

2.2. Economic Evaluation of the Project

2.2.1. Description of Project Cash Flow Formation

Cash flow was estimated on an annual basis, expressed in constant 2025 US dollars, considering a 10-year time horizon (T = 10), with the total investment fully disbursed in

year 0 and a dairy farm producing milk with 30 animals. Project revenues were estimated based on: (i) milk sales, (ii) sale of culled cows, and (iii) sale of male calves.

Milk revenue was determined from the annual milk production (175,000 liters) and the price per liter (US$0.56), based on the average price practiced in Brazil over the last 12 months (June 2024 to June 2025), according to data from the Center for Advanced Studies in Applied Economics (Cepea, 2025). Revenue from the sale of culled cows and male calves was based on regional market prices. For the former, the sale of four animals per year was considered at an average price of US$955.19 per head. For the latter, the sale of 17 animals was estimated at an average price of US$416.42 per head.

Costs and expenses included expenditures on fuel, yeast acquisition, concentration, insemination, silage and hay, veterinary medicines, outsourced services, taxes (Funrural), electricity, and permanent labor with payroll charges of 45.59% (Conab, 2020), applied to the monthly minimum wage of US$269.18 or BRL 1,518.00 (the national minimum wage in force for 2025).

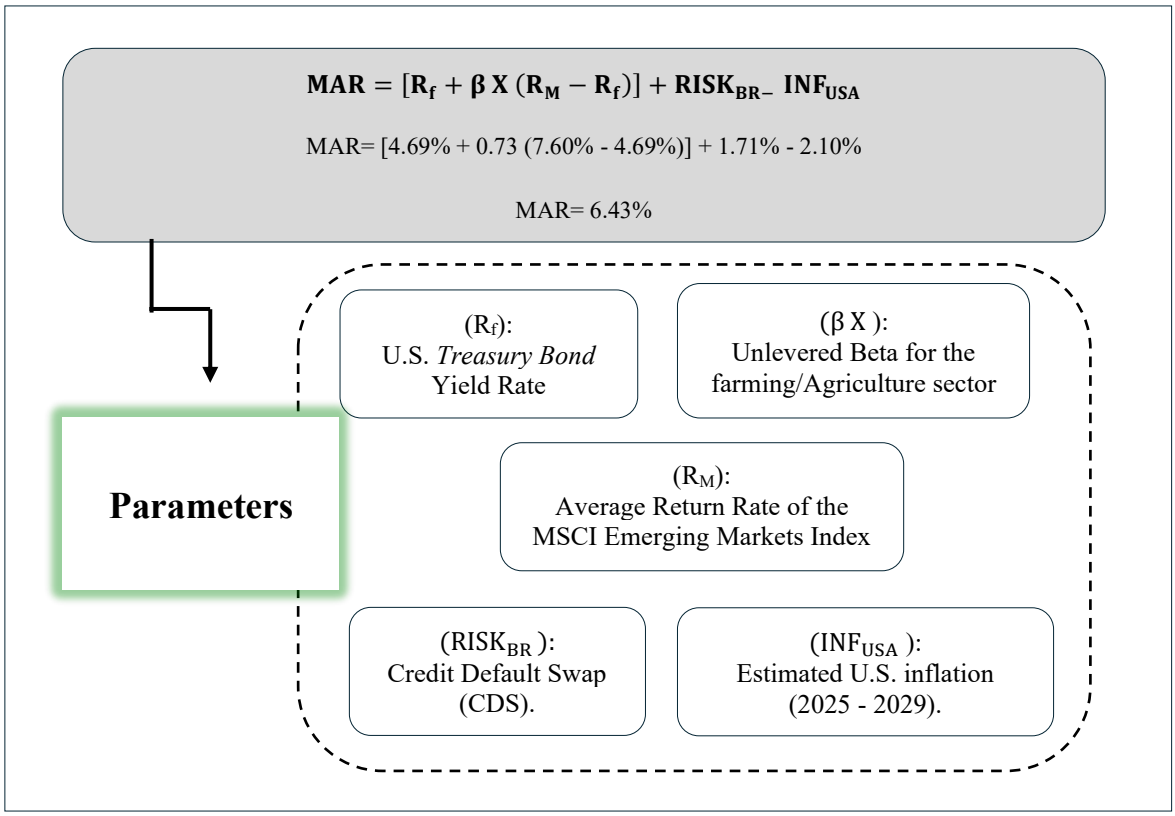
In addition, expenses related to maintenance and repairs (assumed at a 1% rate), insurance on fixed capital (assumed at a 0.75% rate), and depreciation were estimated. Depreciation was calculated using the straight-line method, according to parameters established by Conab (2020).

To finalize the cash flow more realistically, working capital requirements were also calculated to ensure sufficient resources to maintain the daily operations of the dairy production system and to enable the enterprise to withstand periods of price volatility and production seasonality. This practice is recommended both in the dairy cost literature (Embrapa, 2003) and by corporate finance researchers (Assaf Neto, 2020; Ross et al., 2019).

2.2.2. Economic Indicators for the Evaluation of Economic Feasibility

Project feasibility was assessed following four sequential steps: (1) definition of the Minimum Acceptable Rate of Return (MAR); (2) estimation of feasibility indicators; (3) sensitivity analysis; and (4) Monte Carlo simulation. The first step (definition of the project MAR) was conducted using the Capital Asset Pricing Model (CAPM), constructed based on the assumptions described in Figure 1, as referenced in the study by Souza et al. (2025). The resulting real MAR was 6.43% per year.

Figure 1. Estimation of the project's Minimum Acceptable Rate of Return (MAR).



Note: MAR: Minimum Attractive Rate (Global CAPM / Benchmarking – real rate). Source: prepared by the authors based on information extracted from the U.S. Department of the Treasury (2025), Damodaran (2025), MSCI (2025), ICE Data Indices, LLC (2025), and the Congressional Budget Office (2025).

The second stage (calculation of feasibility indicators) was conducted using multiple tools to mitigate the risks, assumptions, and uncertainties inherent to the project, following Siziba and Hall (2021), who state that no single technique is sufficient to address the complexity and uncertainty of projects.

The net present value (NPV) technique was estimated to verify whether future cash flows, discounted to present value using the discount rate, would be sufficient to cover the initial investment and generate real profit for the investor (Ross et al., 2019). Its calculation was based on Equation 1, adopting the criterion that only projects with a positive NPV should be accepted, whereas those with a negative NPV should be rejected (Assaf Neto, 2020).

(1)

$$\text{NPV} = -I_0 - \sum_{t=1}^{n} \frac{I_t}{(1+\text{MAR})^t} + \sum_{t=1}^{n} \frac{FC_t}{(1+\text{MAR})^t}$$

Where: Io = Initial Investment (Year 0); It = Additional Capital Outlays at Year t; FCt = Free Cash Flow at Year t; MAR = Minimum Attractive Rate; n = Project Lifetime (years).

The internal rate of return (IRR) was estimated to compare the results with market rates, thereby assessing the feasibility of investing in the project under analysis (Assaf Neto, 2019). For its calculation, Equation 2 was used, adopting as an acceptance criterion IRR values greater than the MAR estimated for the project, considering that an IRR lower than the MAR indicates that the project will not generate sufficient return to compensate for the risk and the cost of capital invested by the dairy producer (Ross et al., 2020; Assaf Neto, 2019).

$$0 = -I_0 - \sum_{t=1}^{n} \frac{I_t}{(1+r^*)^t} + \sum_{t=1}^{n} \frac{FC_t}{(1+r^*)^t} \Rightarrow \text{IRR} = r^* \quad (2)$$

Where: Io = Initial Investment (Year 0); It = Additional Capital Outlays at Year t; FCt = Free Cash Flow at Year t; r∗ = Discount Rate that sets NPV to zero (the IRR); n = Project Lifetime (years).

To overcome the limitations of the traditional IRR, which does not explicitly account for the reinvestment rate of intermediate cash flows, the Modified Internal Rate of Return (MIRR) was determined (Sun, 2020) using Equation 3, adopting as the acceptance criterion a MIRR greater than the MAR (Oliveira et al., 2020).

$$\text{MIRR} = \left(\frac{\sum_{t=0}^{n} \text{Y}_t (1 + \text{r}_{reinv})^{n-t}}{\left| \sum_{t=0}^{n} \frac{C_t}{(1 + r_{fin})^t} \right|} \right)^{1/n} - 1 \quad (3)$$

Where: Yt = Positive Cash Flow in Year t (compounded at the reinvestment rate, rreinv); Ct = Negative Cash Flow in Year t (discounted at the finance rate, rfin); rreinv = Reinvestment Rate; rfin = Finance Rate; n = Project Lifetime (years).

The Profitability Index (PI) was calculated to assess investment efficiency, i.e., to determine the present net profit generated per dollar invested (Rong, 2023). Accordingly, Equation 4 was used, with the following acceptance criterion: PI > 1 (Oliveira et al., 2020).

$$\text{PI} = \frac{\text{NPV} + I_0}{I_0} = \frac{\sum_{t=1}^{n} \frac{FC_t}{(1 + MAR)^t}}{I_0} \quad (4)$$

Where: Io = Initial Investment; FCt = Free Cash Flow in Year t; MAR = Minimum Attractive Rate; NPV = Net Present Value (Equation (1)); n = Project Lifetime (years).

The Benefit–Cost ratio (B/C) was defined to identify the return obtained per unit of invested capital (Souza & Clemente, 2012). The B/C ratio was calculated using Equation 5, adopting as the acceptance criterion only projects with a B/C inde (5) er than 1 (Oliveira et al., 2020).

$$B/C = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+MAR)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+MAR)^t}}$$

Where: Bt = Benefits (Revenues) in Year t; Ct = Costs in Year t; MAR = Minimum Attractive Rate; n = Project Lifetime (years).

To determine the time required for the recovery of the invested capital with greater accuracy, the discounted payback period (DPBP) was calculated using Equation 6. Based on the premise that project acceptance under this technique depends on a time horizon defined by the investor (Oliveira et al., 2020), the project evaluated in this study (use of yeast) was considered viable if the calculated DPBP was shorter than the project reference period, established at 10 years.

$$\text{DPBP} = min\left\{ J\epsilon\{1,\dots,n\} : \sum_{t=1}^{j} \frac{FC_t}{(1+MAR)^t} \geq I_0 \right\} \quad (6)$$

Where: FCt = Free Cash Flow in Year t; MAR = Minimum Attractive Rate; Io = Initial Investment; n = Project Lifetime (years); J = Payback Year.

The third stage (sensitivity analysis) was conducted to evaluate how changes in input variables could affect the evaluation criteria, thereby providing information on investment risk resulting from changes in the assumptions used in the analysis (Borgonovo & Peccati, 2004). The variables considered in this study were: milk price (US$/L), concentrates (US$/year), silage and hay (US$/year), yeast acquisition (US$/year), and investment (US$). The evaluation criterion adopted was the NPV.

Finally, in the fourth stage (Monte Carlo analysis), Monte Carlo simulation was performed to capture the risks and uncertainties inherent to project execution (Karanovic & Gjosevska, 2012), using the project NPV as the reference indicator. Ten thousand iterations were executed using triangular distributions for each input variable. The first and second stages were conducted using Microsoft Excel, while the third and fourth stages were performed using @RISK software (version 8.0), part of the DecisionTools Suite developed by Palisade Corporation.

2.3. Environmental Evaluation

The environmental evaluation was conducted based on data on enteric methane emissions from dairy cows. Enteric methane (CH_4) production was estimated using Tier 2 equations from the Intergovernmental Panel on Climate Change (IPCC, 2006), with results expressed as kg CH_4 per head per year, kg CH_4 per head per day, g CH_4 per head per day, and g CH_4 per kg of energy-corrected milk (ECM), considering 365 days.

The calculation of methane emission factors considered the following zootechnical and nutritional variables: animal category (lactating cows), body weight (kg), feeding system (confinement), and dietary digestible energy content (%), according to the methodology proposed by Berndt (2015).

The annual methane emission factor was calculated using the following equation:

$$EF_{CH_4} = \frac{GE \times Y_m \times 365}{55.65}$$

where:

- EF_{CH_4}= methane emission fator (Kg CH_4/head/year).
- GE= gross energy intake (MJ/head/day).
- Ym= methane conversion rate, expressed as the fraction of gross energy intake converted to methane.

55.65 = energy content of methane (MJ/kg CH_4).

Based on the annual emission factor, methane emissions were converted to other units through arithmetic conversions, allowing results to be expressed daily and per unit of energy-corrected milk production.

Based on the estimated emissions, the reduction in enteric methane emissions associated with yeast supplementation was evaluated by comparing scenarios with and without the inclusion of the additive in the diet, considering diets with high and low crude protein content. Methane emission reduction was quantified as the absolute difference between emissions estimated in the absence and presence of yeast, according to the following expressions:

High-protein diet:

$$\Delta CH_4^{HP} = CH_4^{HP\ \text{without}} - CH_4^{HP\ \text{with}}$$

Low-protein diet:

$$\Delta CH_4^{LP} = CH_4^{LP\ \text{without}} - CH_4^{LP\ \text{with}}$$

Additionally, the average reduction in methane emissions independent of protein level was estimated using the mean emissions across the two nutritional contexts to express the overall effect of yeast supplementation:

$$\Delta CH_4^{\text{mean}} = \frac{\left(CH_4^{HP\ \text{without}} + CH_4^{LP\ \text{without}}\right)}{2} - \frac{\left(CH_4^{HP\ \text{with}} + CH_4^{LP\ \text{with}}\right)}{2}$$

Positive values indicate a reduction in enteric methane emissions associated with the inclusion of yeast in the diet.

Methane emission reduction was also expressed relative to milk production, through the ratio between daily CH_4 reduction and daily energy-corrected milk yield, allowing the assessment of the environmental efficiency of the production system.

Finally, the estimated reductions in CH_4 were converted to carbon dioxide equivalents (CO_2e), using the 100-year global warming potential of methane, as recommended by the IPCC:

$$\Delta CO_{2e} = \Delta CH_4 \times GWP_{CH_4}$$

where GWP_{CH_4} corresponds to the global warming potential of methane (28 kg CO_2e/kg CH_4).

3. Results and Discussion

3.1. Initial Investment and Cash Flow Structure

The estimated initial outlay for the adoption of the project (Table 3) totaled US$146,482.00. The three largest expenditures were concentrated in the items "Biological assets/Herd," which accounted for 44% of the total, physical infrastructure, representing 28%, and equipment for animal handling and production, corresponding to 22% of the initial costs.

Table 3. Description of the items that comprise the initial investment (US dollars).

Fixed investment	Quantity	Unit value (U$S)	Total value (U$S)
1- Physical infrastructure			
Milking parlor	1	4,892.94	4,892.94
Input storage shed	1	34,037.88	34,037.88
Wooden corral	1	1,701.89	1,701.89
Subtotal			40,632.72

2- Biological assets / Herd (number of cows)			
Number of dairy cows	30	2,127.37	63,821.02
Subtotal			63,821.02
3- Handling and livestock equipment			
Concrete feed bunk (18 meters)	1	765.85	765.85
Water troughs	4	138.07	552.26
Tractor	1	21,273.67	21,273.67
Milking machines	1	4,254.73	4,254.73
Milk coolers	1	4,680.21	4,680.21
Subtotal			31,526.73
4- Equipment for planting and pasture establishment			
Seed drill	1	4,680.21	4,680.21
Plow	1	736.07	736.07
Leveling harrow	1	1,063.68	1,063.68
Hoe	1	21.27	21.27
Backpack sprayer	1	143.20	143.20
Subtotal			6,644.43
5- Other			
Land factor remuneration (18 hectares)	18	96.10	1,729.73
Vehicle (Saveiro 2005 / 2 doors)	1	2,127.37	2,127.37
Subtotal			3,857.10
Total			**146,482.00**

Source: Research data (2025).

It should be noted that the initial investments considered refer to the full implementation of the production structure, assuming the absence of any pre-existing assets. Thus, although the main focus of this study is to evaluate the feasibility of using yeast in the feeding of dairy cows, it is necessary to include installation costs, such as herd acquisition, physical infrastructure, and equipment, since disregarding these expenditures would tend to compromise the reliability of the results by failing to adequately represent the real context of adoption of the analyzed system.

After determining the initial outlay, the annual cash flow was projected, with its detailed breakdown presented in Table 4.

Table 4. Cash flow (US dollars) for the use of yeast in the feeding of dairy cows.

Description	Year 0	Year 1-9	Year 10
1- Total revenue	**0.00**	**108,899.89**	**108,899.89**
Milk sales revenue	0.00	98,000.00	98,000.00
Culled cows sales (heads)	0.00	3,820.75	3,820.75
Male calves sales (heads)	0.00	7,079.14	7,079.14
2- Costs and expenses	**0.00**	**76,843.52**	**76,843.52**
Yeast	0.00	3,945.95	3,945.95
Silage and hay	0.00	24,648.28	24,648.28
Concentrates	0.00	24,648.28	24,648.28
Fuel and lubricants	0.00	1,055.41	1,055.41
Inseminations	0.00	95.73	95.73
Veterinary drugs	0.00	1,659.35	1,659.35
Salaries and charges	0.00	5,309.44	5,309.44
Outsourced services	0.00	1,372.50	1,372.50
Taxes (FUNRURAL)	0.00	1,937.06	1,937.06
Electricity	0.00	893.49	893.49

Maintenance and repairs	0.00	1,464.82	1,464.82
Insurance on fixed capital	0.00	1,098.61	1,098.61
Depreciation	0.00	8,714.59	8,714.59
3- Operating profit	0.00	**32,056.37**	**32,056.37**
4- Income tax	0.00	**5,989.49**	**5,989.49**
5- Depreciation	0.00	8,714.59	8,714.59
5. Operating cash flow	0.00	34,781.47	34,781.47
6. Fixed investment	- 146,482.00	0.00	0.00
7. Working capital investment	- 31,396.93	0.00	31,396.93
8. Free cash flow	- 177,878.93	34,781.47	66,178.40

Source: Research data (2025).

Annual revenue totaled US$108,899.89, resulting from milk sales (90%), the sale of culled cows (3.5%), and male calves (6.5%), in accordance with the recommendations described by Vaz et al., (2023). The commercialization of these animals (culled cows and males) is a relevant practice in dairy production, as it contributes significantly to the composition of total farm revenue (Amaral-Phillips & King, 2023), thereby reducing exclusive dependence on milk revenue, which is characterized by high price volatility.

Total costs and expenses were estimated at US$76,843.52, with feed being the main component of the cost structure, representing approximately 69% of the total. This result is expected due to the high cost of conventional ingredients in dairy production, given the elevated nutritional requirements of cows for maintenance, production, and reproduction (Barceló-Villalobos et al., 2025; Reed et al., 2017). Feed expenditures were estimated based on costs for silage and hay (US$24,648.28), concentrates (US$24,648.28), and yeast (US$3,945.95).

Although yeast does not replace other feed inputs, its use occurs in a complementary manner, contributing to improved digestive efficiency and nutrient utilization of the diet with a relatively low financial impact, accounting for approximately 5% (US$3,945.95) of total feed costs, which were estimated at US$53,242.51. This positive effect is supported by the studies of Xiang et al. (2025) and Zhang et al. (2024), which indicate that yeast supplementation promotes significant increases in milk production, reinforcing its potential as an economically viable nutritional strategy.

In addition to feed expenditures, which represent the largest share of total costs, expenses related to depreciation (US$8,714.59) and wages and payroll charges (US$5,309.44) also stand out, reflecting, respectively, the importance of fixed capital and labor for the operation of the production system. Other operating costs (including veterinary medicines, outsourced services, maintenance and repairs, electricity, taxes, insurance, and insemination) individually represent smaller shares of total costs; however,

they are essential for the continuous operation of the activity and, for this reason, were incorporated into the economic analysis, similarly to the study conducted by Vaz et al., (2023).

The analysis of operating profit, adjusted for depreciation, made it possible to evaluate the cash-generation capacity of the system, while the consideration of fixed investments and working capital allowed the estimation of free cash flow. Taking together, these results reinforce the importance of an integrated approach to the economic analysis of dairy production, highlighting that system viability depends not only on cost levels but also on the combination of productive efficiency, revenue diversification, and sound financial management.

3.2. Economic Feasibility Analysis

The evaluation of the project's feasibility was based on several investment analysis indicators (NPV, IRR, MIRR, PI, B/C, DPBP, and EAV), the results of which are presented in Table 5.

Table 5. Results of the economic indicators.

Economic indicator		Economic results
NPV	Net Present Value	US$ 97,154.11
IRR	Internal Rate of Return	12.39%
MIRR	Modified Internal Rate of Return	8.91%
PI	Profitability Index	US$ 1.45
B/C ratio	Benefit–Cost Ratio	US$ 1.28
DPBP	Discounted Payback Period	7.5 years

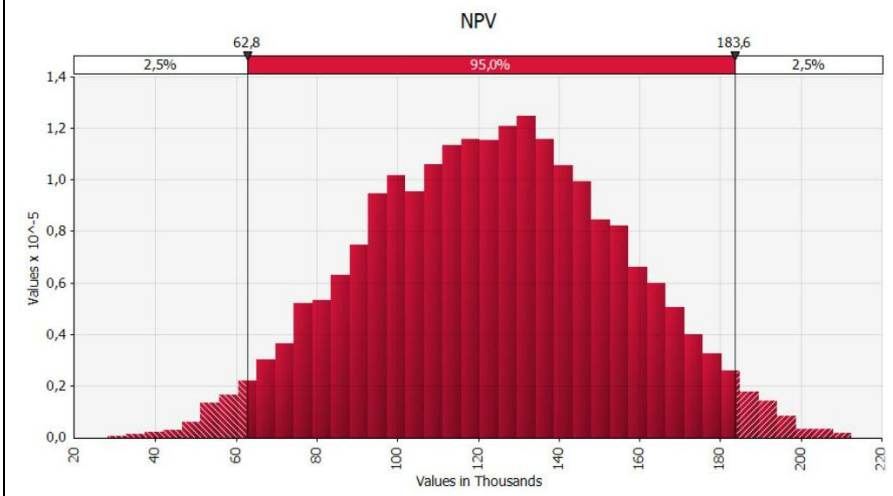
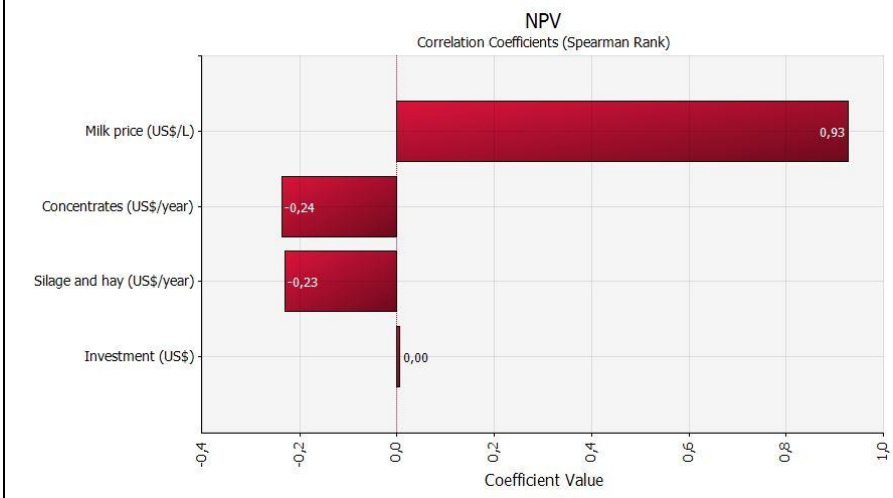
Source**:** Prepared by the authors (2025).

The Net Present Value (NPV) obtained was US$97,154.11, indicating an economic surplus, as the generation of net value over the analyzed period was positive. This result shows that discounted future benefits exceed the costs involved, thereby confirming the project's feasibility, in accordance with the premises described by Ross et al. (2019) and Assaf Neto (2020).

The project's IRR and MIRR were estimated at 12.39% and 8.91%, respectively, demonstrating profitability, since these rates are higher than the estimated cost of capital for the project (6.43%). This feasibility is further supported by the Profitability Index (PI) and the Benefit–Cost ratio (B/C), which reached values of 1.45 (PI) and 1.28, respectively. The discounted payback period (DPBP) was estimated at 7.5 years,

indicating project feasibility, as the identified investment recovery period is shorter than the project's useful life (T = 10 years).Finally, the project was subjected to Monte Carlo simulation and sensitivity analysis (Figure 2) in order to evaluate its economic robustness and its ability to remain viable over time.

Figure 2. Monte Carlo simulation and sensitivity analysis.

Monte Carlo simulation	
Sensitivity analysis	

Source: Research data (2025).

The Monte Carlo simulation showed that the Net Present Value (NPV) remained predominantly positive across the iterations, with a high probability of values above zero. This result indicates that, even when considering uncertainties associated with the economic variables of the model, the project demonstrates economic feasibility.

Sensitivity analysis revealed that the project's economic viability is strongly influenced by milk price, showing a high positive correlation (0.93). This indicates that even small variations in the price per liter of milk have a significant impact on system

profitability, highlighting the importance of strategies aimed at ensuring stable or predictable milk prices.

In contrast, costs related to concentrates and to silage and hay showed moderate negative correlations (−0.24 and −0.23, respectively), indicating that increases in these expenses reduce the NPV, although to a lesser extent than the effect of milk price. In addition, it was found that the investment variable and the cost of yeast had no significant effect on NPV values.

Based on the results discussed, it can be inferred that the use of yeast in the feeding of dairy cows represents, from an economic standpoint, an important investment to be considered by dairy producers, and that its sustainability depends primarily on efficient revenue management and control of the most sensitive operating costs.

3.3. Evaluation of Environmental Benefits

Table 6 presents the estimated methane (CH_4) production of dairy cows under the different treatments. For methane production expressed per animal per day, per animal per year, g CH_4 per total milk produced (365 days), and g CH_4 per kg of ECM (365 days), animals that consumed liquid yeast residue, regardless of crude protein level, showed lower methane production compared with diets without liquid yeast residue.

Table 6. Emission, intensity, and mitigation of enteric methane (CH_4) in dairy cows fed diets with different protein levels, with or without yeast supplementation

Diet	CH_4 (kg/head/year)	ΔCH_4 (kg/head/year)	CH_4 (kg/head/day)	ΔCH_4 (kg/head/day)	CH_4 total/milk (365 d)	ΔCH_4 total/milk (365 d)	CH_4 intensity (Kg CH_4/Kg^{-1} ECM) (365d)	ΔCH_4 intensity (Kg CH_4/Kg^{-1} ECM) (365d)
High protein								
Without yeast	134.39	-	0.37	-	18.98	-	19.56	-
With yeast	123.13	11.26	0.34	0.03	17.06	1.92	16.90	2.66
Avoided impact (CO_2e	-	315.3	-	0.84	-	53.8	-	74.5
Low protein								
Without yeast	133.64	-	0.37	-	17.62	-	18.01	-
With yeast	128.85	4.79	0.35	0.02	16.80	0.82	16.70	1.31
Avoided impact (CO_2e)	-	134.1	-	0.56	-	23.0	-	36.7

ECM= energy-corrected milk (3.5%)

ΔCH_4 = methane emission reduction calculated as the difference between scenarios without and with yeast supplementation within each protein level.

Avoided climate impact (CO_2e) was calculated from the CH_4 reduction associated with yeast inclusion at each protein level, using a global warming potential of 28 for methane (IPCC AR5, 100-year horizon).

The reduction of enteric methane (CH_4) production is a central aspect of dairy cattle systems, from both environmental and productive perspectives. Ruminants are widely recognized as a significant source of CH_4 emissions, a gas with high global warming potential, and its formation in the rumen represents a pathway of energy loss, accounting for approximately 2 to 12% of the gross energy intake (FAO, 2023). Therefore, nutritional strategies that enhance energy use efficiency, with the potential to reduce CH_4 formation, have been extensively investigated.

In the present study, estimates obtained through predictive models indicated lower CH_4 emissions in diets containing liquid yeast residue, both in absolute terms and relative to milk production. However, as no statistical analysis was performed for these variables, these results should be interpreted as indicative trends rather than statistically confirmed differences. Nevertheless, these findings suggest a potential improvement in energy utilization efficiency, as reduced methane production is associated with lower energy losses and a greater potential for redirecting this energy toward milk synthesis. The evaluation of emission intensity (CH_4 per unit of milk produced) supports this interpretation, indicating that yeast supplementation may contribute to more environmentally efficient production systems.

Although ruminal parameters were not directly evaluated in the present study, the literature suggests that yeast supplementation may indirectly influence CH_4 production through modulation of ruminal fermentation. Proposed mechanisms include stabilization of ruminal pH, stimulation of lactate-utilizing microorganisms, and improved fiber digestibility, all of which may alter volatile fatty acid production patterns and hydrogen dynamics in the rumen. In particular, competition for hydrogen between metabolic pathways, such as methanogenesis and acetogenesis, is frequently cited as a key determinant of CH_4 production (Ogunade et al., 2019). However, these mechanisms should be interpreted with caution in the context of this study, as they were not directly measured.

Additionally, it is important to consider that even in the absence of substantial reductions in absolute CH_4 production, improvements in animal performance may result in lower emissions per unit of product, reflecting enhanced environmental efficiency. This effect has been reported in previous studies with yeast supplementation, in which

improvements in digestibility and animal performance offset variations in total methane production (Ogunade et al., 2019).

Finally, it should be emphasized that CH_4 emission estimates presented in this study were derived from predictive models based on productive parameters and were not obtained from direct animal measurements. Therefore, the results should be interpreted as indicating the mitigation potential of liquid yeast residue supplementation, and further experimental studies are required to confirm these effects under practical production conditions.

Table 7 presents the estimated effect of yeast inclusion on CH_4 emissions, regardless of dietary protein level. Based on predictive model outputs, yeast supplementation was associated with an estimated reduction of approximately 8.02 kg CH_4 per head per year, 0.8 kg per head per day, and 1.98 g per kg of ECM (365 days), compared to diets without supplementation. When expressed as CO_2 equivalent (CO_2e), this corresponds to an estimated mitigation of 224.6 kg per head per year, 0.84 kg per head per day, 38.36 g per total milk produced, and 55.44 g per kg of ECM.

Table 7. Enteric methane emissions and avoided CO_2-equivalent (CO_2e) emissions associated with yeast supplementation in the diet of dairy cows, regardless of protein level.

Diets	CH_4/head/year	CH_4/head/day	g CH_4/total milk (365d)	g CH_4/Kg ECM milk (365d)
Without yeast	134.02	0.37	18.30	18.78
With yeast	125.99	0.34	16.93	16.80
Reduction (Δ)	8.02	0.03	1.37	1.98
Avoided impact (CO_2e)	224.6	0.84	38.36	55.44

The values presented are the average of the estimated emissions from diets with high and low crude protein content. The reduction in methane emissions (Δ) was calculated as the difference between scenarios with and without yeast supplementation to isolate the additive's effect, regardless of dietary protein level. CO_2-equivalent emissions were calculated using a Global Warming Potential (GWP) of 28 for CH_4, according to IPCC AR5.

The reduction in methane emissions associated with the inclusion of liquid yeast residue resulted in an estimated decrease in carbon dioxide equivalent (CO_2e) emissions, highlighting the potential of this strategy to mitigate the environmental impact of dairy production systems. Considering the high global warming potential of CH_4 relative to carbon dioxide, even moderate reductions in methane emissions may lead to meaningful decreases in CO_2e.

In the present study, yeast supplementation was associated with an estimated mitigation of 224.6 kg CO_2e per head per year, along with consistent reductions when values were expressed daily and per unit of product. These findings suggest that the inclusion of yeast may contribute to improved environmental efficiency of the production system, as indicated by lower greenhouse gas emissions per kilogram of energy-corrected milk (ECM) produced.

Thus, the inclusion of liquid yeast residue in the diet of dairy cows shows potential as a strategy to mitigate greenhouse gas emissions. However, the results should be interpreted with caution, as they are based on estimates derived from predictive models rather than direct measurements or inferential statistical analyses. Nevertheless, these findings reinforce the relevance of nutritional strategies aligned with the increasing demand for more efficient and sustainable production systems.

4. Conclusion

Under the configurations analyzed, the project proved to be feasible, as all the tools applied met the acceptance criteria. The results obtained were: NPV (US$ 97,154.11), IRR (12.39%), MIRR (8.91%), Profitability Index (US$ 1.45), Benefit–Cost Ratio (US$ 1.28), and Discounted Payback Period (7.5 years). From an environmental perspective, it was found that the inclusion of liquid yeast residue directly contributed to a reduction in CO_2e emissions, demonstrating that yeast use made it possible to avoid the emission of 224.6 kg of CO_2e per head per year.

Based on these results, the use of yeast is identified as a relevant strategy for dairy producers, as it promotes greater feed efficiency and generates both economic and environmental benefits, thereby contributing to the sustainability of agricultural activity. As a practical contribution, this study advances the existing literature, which typically focuses on the effects of yeast on animal performance, by adopting an integrated approach that analyzes the economic impacts of the implementation process from its initial phase and incorporates the environmental dimension into the evaluation, thus providing more robust support for decision-making in the sector.

5. Study limitations

This study presents some limitations that should be considered when interpreting the results. Enteric methane (CH_4) emissions were estimated using predictive models based on animal performance parameters rather than direct measurements under

experimental conditions. Therefore, the reported values reflect theoretical scenarios and are subject to the assumptions and simplifications inherent to the applied models. In addition, no inferential statistical analysis was performed for the emission estimates, which limits the interpretation of the results as statistically significant differences among treatments.

Another relevant aspect is that the evaluation was conducted considering only lactating cows, without including other animal categories within the production system, thereby restricting the extrapolation of the results to the whole-farm level. Thus, the findings should be interpreted as indicative of the mitigation potential associated with the inclusion of liquid yeast residue, and further experimental studies are required to validate these results under practical production conditions.

6. Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

7. Funding

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8. Data Availability Statement

The data and materials supporting the findings of this study are available from the corresponding author upon reasonable request..

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