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Supplementation in the last third of pregnancy in Nellore cows: calf performance and economics of the post-weaning phase

Suplementação no terço final da gestação de vacas Nelore: desempenho do bezerro e economicidade da fase de cria

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Highlights

Concentrate protein supplementation (CPS) is safe and efficient for fetal programming.
CPS for Nellore cows in the last third of pregnancy does not affect calf performance.
CPS in the last trimester of pregnancy provides viable post-weaning economic indices.

Abstract

The objective of this study was to assess the economics of the post-weaning phase and performance of Nellore calves born to dams that received protein concentrate supplementation during the final trimester of pregnancy. This research was organized into two phases: Phase I entailed a 90-day supplementation period for the dams in the last third of their pregnancy, and Phase II spanned from the birth of the calves to their weaning at 240 days. Twenty multiparous Nellore cows, subjected to fixed-time artificial insemination (FTAI), were divided into two groups: unsupplemented (US) and supplemented (SP), each

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comprising 10 animals. Statistical analysis was performed using an analysis of variance and the F-test with a significance level set at 0.05, within a completely randomized design. Among the parameters examined, only the total feed cost (US = BRL41.09 vs. SP = BRL112.22, P = 0.0001), effective operating cost (US = BRL872.51 vs. SP = BRL943.64, P = 0.0001), total operating cost (US = BRL925.51 vs. SP = BRL951.64, P = 0.0001), and total cost (US = BRL925.51 vs. SP = BRL996.64, P = 0.0001) were significantly affected by protein concentrate supplementation during the last third of pregnancy. Therefore, it can be concluded that while protein concentrate supplementation in the final stages of pregnancy does not influence the performance or morphological traits of calves, it does lead to increased feed and labor expenses. However, these increases do not negatively impact economic viability rates.
Key words: Internal rate of return. Net present value. Postweaning phase. Visual score.

Resumo

Objetivou-se avaliar a economicidade da fase de cria e desempenho dos bezerros oriundos de vacas Nelore submetidas à suplementação concentrada proteica no terço final da gestação. O estudo foi dividido em duas fases. Fase I, 90 dias de suplementação das matrizes no terço final da gestação; Fase II, do nascimento ao desmame (240 dias) dos bezerros. Foram utilizadas 20 vacas Nelore multíparas a partir de inseminação artificial em tempo fixo (IATF), sendo divididas em dois grupos com 10 animais SS=Vacas não suplementação e CS=Vacas Suplementadas. Os dados foram interpretados estatisticamente por análise de variância e Teste F a 0,05 de probabilidade, em delineamento inteiramente casualizado. Entre as variáveis estudadas, apenas o custo total com alimentação (SS=R$41,09 e CS=R$112,22, P=0,0001), custo operacional efetivo (SS=R$872,51 e CS=R$943,64, P=0,0001), custo operacional total (SS=R$925,51 e CS=R$951,64, P=0,0001), custo total (SS=R$925,51 e CS=R$996,64, P=0,0001) foram influenciadas pela suplementação concentrada proteica no terço final da gestação. Desta forma, conclui-se que a suplementação concentrada proteica no final da gestação não influencia o desempenho e características morfológicas dos bezerros; eleva os custos com alimentação e mão de obra, porém, sem impactar negativamente os índices de viabilidade econômica.
Palavras-chave: Escore visual. Fase de cria. Taxa interna de retorno. Valor presente líquido.

Introduction

The livestock cycle and its stages are constantly subject to the fluctuating prices of inputs and services on both national and international levels (Cooke et al., 2020; Trejo-Pech et al., 2022). This variability necessitates a dynamic and periodic optimization of financial resources to uphold sustainable economic planning on farms (Martins et al., 2022; Semchechem et al., 2021). This is especially true during the post-weaning phase, as it can directly impact later production stages (Greenwood & Bell, 2019; Mccabe et al., 2019; Santana et al., 2023).

Nutritional strategies during the last third of pregnancy, known as fetal programming, are essential for the development of the fetus and its future productive performance (Caton et al., 2020; Cappellozza et al., 2021). This is particularly true in tropical pastoral systems, where nutritional supplementation when strategically applied represents a promising technology to provide nutrients in adequate quantity and quality during forage shortages /or even in cases of intensified farming (Delevatti et al., 2019; Klein et al., 2020; Webb et al., 2019).

When examining calf performance traits and body conformation, genetic influences play a significant role (Oliveira et al., 2021; Soares et al., 2023). Additionally, external factors, particularly maternal nutrition during pregnancy, have a notable impact. Key variables such as birth weight, growth rate, body composition, early sexual development, and muscular development are crucial in selecting animals that are well-adapted to various tropical agricultural systems and environments (Negreiros et al., 2022).

From a financial perspective, it is important to consider how nutritional supplementation can affect dietary expenses and productivity per area (Romanzini et al., 2020). Accounting for the economic and nutritional flow in relation to the performance of calves from fetal programming is essential for selecting efficient animals for specific market segments and ensuring the reproductive success and productivity of dams in future cycles (Martins et al., 2022; Souza et al., 2022).

Given this backdrop, our study aims to investigate the effects of protein concentrate supplementation for Nellore cows during the last third of pregnancy on the performance of their calves and economic viability up to weaning.

Material and Methods

Location and CEUA approval

The research was conducted from August 2019 to September 2020 at Uberlândia Farm, situated in the municipality of Parnaguá, within the cerrado biome of Piauí, Brazil. The region experiences a tropical seasonal sub-humid dry climate (Aw) as per the Köppen classification. A 20-ha area planted with Massai grass (*Panicum maximum* cv. Massai) and creeping rivergrass (*Echinochloa polystachya*), partitioned into eight paddocks, served as the study site. The Ethics Committee on the Use of Animals (CEUA) at the State University of Piauí (UESPI) granted approval for the research under authorization no. 0033/2017.

Experimental period and animals

The study involved Nellore dams that were identified, weighed, treated for ecto- and endo-parasites, and inseminated using fixed-time artificial insemination (FTAI). An intravaginal progesterone-releasing device (CIDR) was inserted and 2 mg estradiol benzoate were administered on Day 0. On Day 8, the CIDR was removed and 150 μg prostaglandin F2α and 1 mg estradiol cypionate were injected. Artificial insemination was performed 48-56 h after the removal of the CIDR. Initially, 20 cows/cattle with an average initial body weight of 493 ± 43.54 kg, of 3rd to 5th parities, with body condition scores (BCS) ranging from 5 to 6 (1 to 9 scale) (Richards et al., 1986), were selected. A 15-day adaptation period to the supplementation regimen was conducted prior to the experiment, which was subsequently divided into two phases. Phase I comprised the entirety of the last third of pregnancy (90 days), during which 10 dams received protein concentrate supplementation, resulting in two groups: 10 unsupplemented and 10 supplemented.

The protein concentrate supplement was provided daily during Phase I, at 10h00, using uncovered, communal plastic troughs designed for double access, with 65 cm of linear space per animal to promote even supplement consumption. The formulation of the concentrate adhered to Valadares et al. (2016) guidelines and Normative Instruction 12 of 2004 of the Ministry of Agriculture, Livestock, and Supply (MAPA) (Instrução Normativa 12/2004), which defines the minimum supplement characteristics for cattle (Table 1). The supplementation rate was set at 0.5 kg cow^{-1} day^{-1} (1 g kg BW^{-1}), aiming to maintain a BCS between 5 and 6.

Table 1
Proportion of ingredients in the supplement and physicochemical composition of simulated grazing and supplement

Proportion of ingredients in the supplement		
Ingredients (%)		(g kg^{-1} DM)
Soybean meal		790
Ground corn		100
*Mineral salt		110
Physicochemical composition		
	Simulated grazing	Protein concentrate
Dry matter (g kg^{-1})	431	892
Mineral matter (g kg^{-1} DM)	121	144
Organic matter (g kg^{-1} DM)	879	856
Crude protein (g kg^{-1} DM)	86	488
NDFap (g kg^{-1} DM)	759	321
Acid detergent fiber (g kg^{-1} DM)	524	130
Lignin (g kg^{-1} DM)	82	35
Ether extract (g kg^{-1} DM)	34	34
Non-fibrous carbohydrates (g kg^{-1} DM)	241	679
Total digestible nutrients (g kg^{-1} DM)	520	759

*Calcium 190-165 g kg^{-1}, phosphorus 60 g kg^{-1}, sodium 107 g kg^{-1}, sulfur 12 g kg^{-1}, magnesium 5000 mg kg^{-1}, cobalt 107 mg kg^{-1}, copper 1300 mg kg^{-1}, iodine 70 mg kg^{-1}, manganese 1000 mg kg^{-1}, selenium 18 mg kg^{-1}, zinc 4000 mg kg^{-1}, fluorine 600 mg kg^{-1}. NDFap - neutral detergent fiber corrected for ash and protein.

Phase II took place during the postpartum period, beginning at birth and continuing until the calves were weaned at 240 days. The newborns were identified, weighed, and provided with the appropriate nutritional and health care. Subsequently, a random selection of 20 dams was made based on the sex of their calves, comprising 10 unsupplemented and 10 supplemented groups. This selection aimed to negate the influence of calf sex on treatment outcomes, maintaining a balance of five males and five females per treatment group. Both groups were granted unrestricted access to mineral salt and water, ensuring an ad libitum intake (Adaptation, Phases I and II) (Tables 2 and 3).

Table 2
Pasture characteristics and components of the forage

Variable	Dry	Dry/Rainy	Rainy	Rainy/Dry
Dry matter (t ha^{-1})	5.4	3.2	5.0	5.4
Potentially digestible dry matter (%)	70.9	74.2	74.2	64.5
DMApd (t ha^{-1})	3.8	2.4	3.7	3.5
Leaf (t DM ha^{-1})	0.4	0.6	1.1	0.9
Stem (t DM ha^{-1})	2.2	2.0	1.8	2.0
Mineral matter[4] (t DM ha^{-1})	2.7	0.5	2.1	2.6
Leaf/Stem	0.2	0.3	0.7	0.6

DMApd - potentially digestible dry matter availability.

Table 3
Variations in the weight and body condition score of cows during the last third of pregnancy and during the post-weaning stage

Variable	Treatment		SD
	Unsupplemented	Supplemented	
$VCBW_{LT}$ (kg)	-9.375	-5.300	18.58
$VCBW_{PW}$ (kg)	-34.750	-17.800	25.62
$VCBCS_{LT}$ (score)	0.187	0.100	1.04
$VCBCS_{PW}$ (score)	-0.718	-0.275	0.95

SD - standard deviation; $VCBW_{LT}$ - variation in cow body weight in the last third of pregnancy; $VCBW_{PW}$ - variation in cow body weight in the post-weaning phase; $VCBCS_{LT}$ - variation in cow body condition score in the last third of pregnancy; $VCBCS_{PW}$ - variation in cow body condition score in the post-weaning phase.

Assessment of performance and Body structure, Earliness, and Muscularity (BEM)

The assessment of calf performance during this phase involved weighing the calves at three key points: at birth, at 120 days, and at weaning (240 days). These measurements enabled the calculation of the average daily gain (ADG), BCS on a 1 to 9 scale, and other pertinent data for economic analysis.

$$\text{ADG kg.day}^{-1} = \left(\frac{(\text{FW}-\text{IW})}{\text{T}}\right),$$

where FW = final weight in kg; IW = initial weight in kg; and T = time in days.

At the 120-day mark, evaluations were conducted on the morphological traits of the calves, as adapted from Koury et al. (2010). Three qualified and trained personnel assessed body structure (B), earliness (E), and muscularity (M), assigning scores on a scale from 1 to 6 based on:

- Body structure: meat quantity on the carcass, with scores determined by visual inspection. This attribute is influenced by the size and muscularity level of the animal;
- Earliness: a score reflecting the capacity of the animal to attain a minimum carcass fat level at a lower live weight. Indicators of earlier maturation include deeper ribs, an expansive rib cage, a filled-out silhouette, a heavier groin, and the onset of subcutaneous fat deposition, primarily at the base of the tail. Conversely, taller, slimmer, and excessively lean animals are typically later maturing;
- Muscularity: overall muscle development, focusing on areas such as the forearm, shoulder, loin, rump, and particularly the hindquarters.

Economic evaluation

The economic viability of the technology was examined through a marginal analysis of both phases. This involved collating experimental data on revenues and direct costs, leading to calculations of revenue minus feed cost (RMFC) and the marginal rate of return (MRR) (Evans, 2005; Perrin et al., 1988).

An economic analysis of the complete system (Phases I and II) was undertaken incorporating operational costs, depreciation, and interest, alongside a 10% administrative fee. The cost of capital over time was assessed using the net present value (NPV) as a measure of treatment efficiency relative to interest rates of 6%, 10%, and 12% per month. In addition, the internal rate of return (IRR) was calculated for investment analysis.

$$\text{NPV} = \frac{\sum(\text{Cash flows})}{(1+\text{i})^{\text{n}}} - \text{Initial investment},$$

where i = discount rate, or the weighted average cost of capital; ∑(Cash flows) = sum of all net operating cash flows of the project; and n = period.

By establishing a cash flow comparison of costs and benefits, the monthly gross revenues were calculated. These were then adjusted using the current value coefficients at a set monthly rate of 1%, resulting in updated monthly gross revenues. Summing these updated figures provided the NPV for each treatment, allowing their comparison.

Statistical analyses

The experimental design employed was a completely randomized design, encompassing two treatments and ten replicates each. The data were analyzed using ANOVA and the F test at a significance level of 5%, utilizing the PROC GLM procedure within the SAS® Academic OnDemand statistical software (Sas Institute Inc., Cary, NC, USA; accessible at: https://www.sas.com/en_us/software/on-demand-for-academics.html.

The statistical model applied in the analysis was as follows:

$$Y_{ij} = \mu + \tau_j + \varepsilon_{ij},$$

where y_{ij} = observed value of the response variable for treatment i in its replicate j; μ = overall mean of the treatment means; τ_i = effect of treatment i on the observed value y_{ij}; e_{ij} = experimental error associated with the observed value y_{ij}.

Results and Discussion

Calf body weight at birth, average daily gain, body condition score (BCS), body weight at weaning, ratio of calf body weight to cow weight at weaning, body structure (B), earliness (E), and muscularity (M) were unaffected (P>0.05) by the supplementation of dams with protein concentrate in the last third of gestation (Table 4). This outcome may be attributed to the limited direct impact of nutritional supplementation during gestation considering the phase, nutrient type, supplement type, and supplied quantity on body weight at birth (BWB) (Moriel et al., 2020, 2021; Palmer et al., 2022). However, the influence might vary in different stages, such as the transition to post-weaning and subsequent phases (Costa et al., 2022).

Table 4
Performance and BEM of calves from dams supplemented in the last third of pregnancy

Variable	Treatment		CV%	P-value
	Unsupplemented	Supplemented		
BWB (kg)	39.089	39.140	15.15	0.9921
ADG (kg day^{-1})	0.591	0.632	15.02	0.3651
BCS (score)	7.15	6.53	12.81	0.1466
BWW (kg)	180.929	190.820	10.57	0.5693
CaBW/CoBW (%)	39.20	39.50	14.75	0.9039
Body structure (score)	3.86	3.58	18.02	0.3935
Earliness (score)	3.69	3.36	16.43	0.2478
Muscularity (score)	3.56	3.48	19.78	0.8112

BEM - body structure, earliness, and muscularity; CV% - coefficient of variation; BWB - body weight at birth; ADG - average daily gain; BCS - body condition score; BWW - body weight at weaning; CaBW/CoBW - calf body weight relative to cow body weight at weaning.

Regarding variables B, E, and M, the existing literature on the evaluation of these characteristics in calves from fetal programming is sparse. Nevertheless, these traits are extensively considered in programs designed for the identification of early animals (Carreño et al., 2019; Vargas et al., 2020), as well as by associations and commercial farms aiming to shape the profile of Nellore cattle to meet the evolving demands of the local, regional, and national markets (Calil et al., 2022; Soares et al., 2023).

This can be corroborated by Mattos et al. (2023), who, in a study conducted with 598 male and 728 female Nellore calves, observed a positive (moderate to high) correlation of B (r=0.67 and 0.63), E (r=0.47 and 0.50), and M (r=0.68 and 0.64) with the daily weight gain and weaning weight of the calves. This finding confirms that this technique can be used in calves for the classification and selection of Nellore cattle. Evaluating the genetic correlation of frame size with B, E, and M in Nellore animals around 490 days old, Barro et al. (2023) discovered a positive genetic correlation of frame size with B (0.62 ± 0.07), but a negative correlation with E and M (-0.50 ± 0.08 and -0.34 ± 0.09, respectively). A likely explanation for these divergent correlations may be related to the variable itself since, after body weight, B physiologically precedes and serves as a foundation for the visual evaluation of E and M (Abreu et al., 2018; Oliveira et al., 2021; Paterno et al., 2017).

The lack of significant effects (P>0.05) of gestational supplementation on calf performance and morphological scores (Table 4) could be related to the inherent maternal capabilities of Zebu dams (maternal ability and cow-calf relationships) (Jensen et al., 2024; Sanz et al., 2024), which might account for the observed body weight loss and reduction in BCS during pregnancy, especially in the pre-weaning phase (Table 3) among non-supplemented cows. Despite this, their calves showed comparable development and performance (P>0.05) to those of supplemented cows (Table 4).

Additionally, the availability and composition of forage (Table 2) might have played a role in the observed calf performance outcomes (Table 5) and the potential mitigation of weight loss in cows (Table 4). The progressive increase in potentially digestible dry matter and leaf availability, and consequent higher leaf/stem ratio are forage characteristics that particularly benefit young animals during the transition from pre-ruminant to ruminant stages (Smith et al., 2021).

Table 5
Performance and BEM of calves from dams supplemented in the last third of pregnancy

Variable	Treatment		CV%	P-value
	Unsupplemented	Supplemented		
Total costs				
TRC (BRL animal^{-1})	41.094	34.826	17.46	0.0614
TFC (BRL animal^{-1})	41.094	112.226	8.15	0.0000
VC (BRL animal^{-1})	771.094	764.826	0.85	0.0614
EOC (BRL animal^{-1})	872.514	943.646	0.72	0.0000
TOC (BRL animal^{-1})	880.514	951.646	0.71	0.0000
TC (BRL animal^{-1})	925.514	996.646	0.68	0.0000
$Cost_{@}$ (BRL @$^{-1}$)	158.623	169.032	10.47	0.2209
$Cost_{kg}$ (BRL kg^{-1})	5.287	5.634	10.47	0.2209
Economic indices				
GRSC (BRL animal^{-1})	2047.500	2095.333	10.62	0.6537
RMFC (BRL animal^{-1})	2006.406	1983.170	10.97	0.8259
GR (BRL animal^{-1})	2047.500	2095.333	10.62	0.6537
NM (BRL animal^{-1})	1121.986	1098.687	19.72	0.8259
EOC/TC (%)	94.273	94.681	0.040	0.4825
EOC/GR (%)	42.725	45.725	10.48	0.1930
FC/EOC (%)	88.375	89.251	0.09	0.4825
Economic viability				
IRR (%)	1.21	1.10	19.09	0.3031
NPV 6% (BRL animal^{-1})	115.256	104.169	20.14	0.3031
NPV 10% (BRL animal^{-1})	111.256	100.169	20.90	0.3031
NPV 12% (BRL animal^{-1})	109.256	98.169	21.31	0.3031

CV% - coefficient of variation; TRC - total roughage cost; BRL - Brazilian real (currency); TFC - total feed cost of; VC - variable cost; EOC - effective operating cost; TOC - total operating cost; TC - total cost; $Cost_{@}$ - cost per arroba (1 @ = 15 kg of animal); $Cost_{kg}$ - cost per kilogram; GRSC - gross revenue from the sale of one calf; RMFC - revenue minus feed costs; GR - gross revenue; NM - net margin; EOC/TC - ratio of effective operating cost to total cost; EOC/GR - ratio of effective operating cost to gross revenue; FC/EOC - ratio of feed cost to effective operational cost; IRR - internal rate of return; NPV- net present value.

As for cost variables, economic indicators, and economic viability, only the total feed cost (TFC), effective operating cost, total operating cost (TOC), and total cost were significantly affected (P<0.05) (Table 5) (Figure 1). The observed increase in costs between treatments was anticipated due to factors such as raw material acquisition, storage, processing, and supplementation, which contribute to the escalation of the mentioned expenses. Therefore, TFC and TOC stand out as important parameters for the preliminary assessment of supplementation strategies. Nonetheless, as discussed later, other variables are also important for marginal analysis and financial assessment.

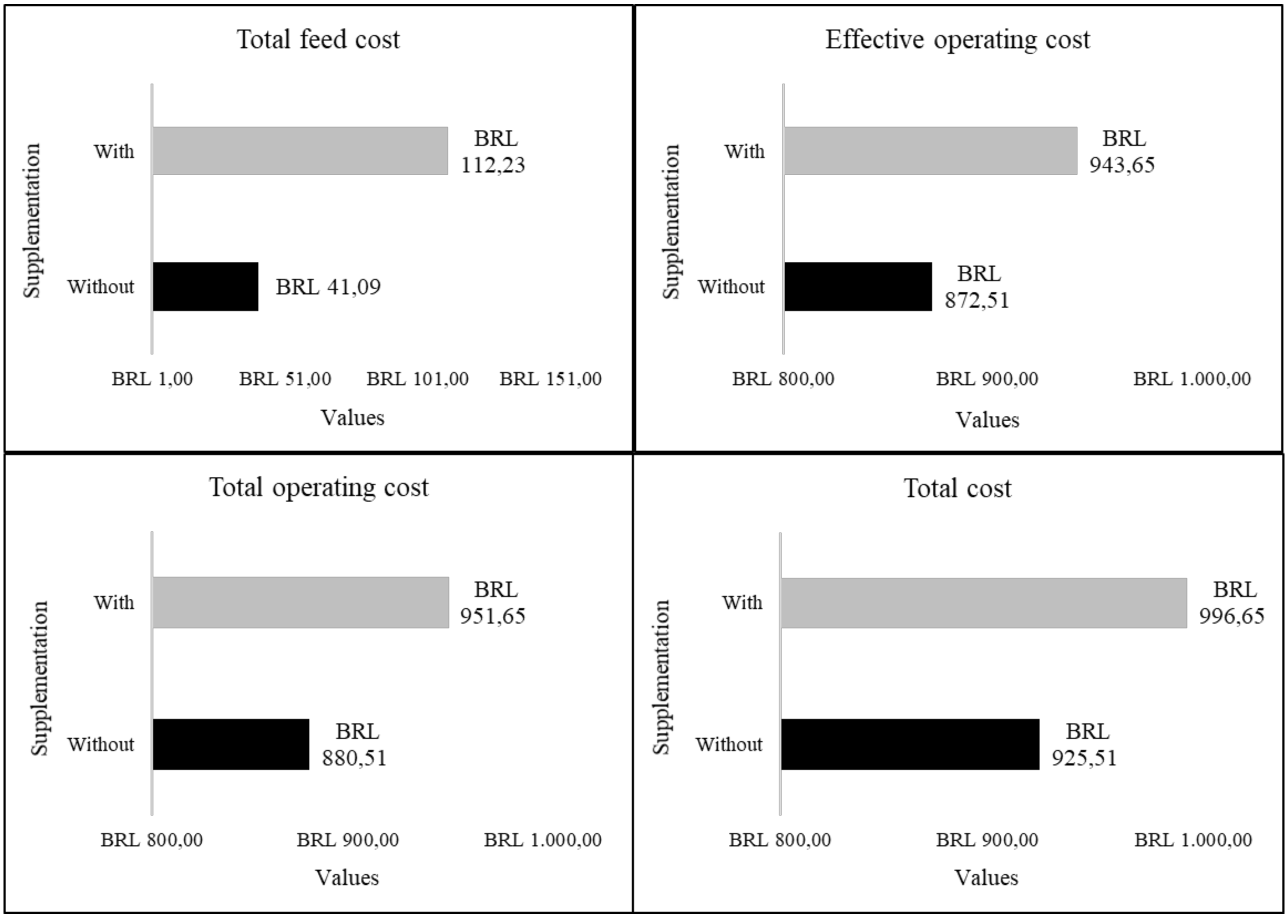

Figure 1. Costs as a function of the use or non-use of protein concentrate supplement in the last third of pregnancy.

Although unaffected by gestational supplementation (P>0.05), metrics such as revenue from the sale of one calf, revenue minus feed cost, gross revenue, and net margin remained positive (Table 5). This indicates that the high costs associated with the adoption of a technology do not necessarily render a production phase or system financially inviable. Indeed, factors like average daily gain and weaning weight are typically positively influenced by nutritional strategies, leading to the production of heavier and more lucrative animals during favorable selling periods (Portes et al., 2020; Romanzini et al., 2020; Oliveira et al., 2021; Semchechem et al., 2021).

Every financial operation is directly dependent upon both internal and external variables, with interest rates being the primary external factor. These rates are, in turn, influenced by the prevailing local economic and temporal conditions (Trejo-Pech et al., 2022). In this study, neither the net present value (NPV) nor the internal rate of return (IRR) was significantly affected by supplementation (P>0.05) (Table 5), with both treatments yielding positive averages, indicating financial viability with more attractive values at a discount rate of 6%.

In a study conducted between 2012 and 2014, comparing three pasture-based rearing systems with nutritional supplementation, Garcia et al. (2017) identified an ideal rate of 4% per year for IRR and NPV. In a 2011 trial with heifers, Peres et al. (2015) achieved better results (NPV and IRR) with a rate of 6% per year. Evaluating the supplementation system in heifers, Silva et al. (2019) noted an ideal annual discount rate similar to the aforementioned, although in 2016, under specific experimental conditions, a 4% rate yielded the best NPV and IRR values.

Given the above results, it is understood that the annual discount rate directly influences the investment analysis and profitability of the production system. When linked to the opportunity cost of capital, as it increases, it tends to directly dilute the NPV and IRR, making the investment less attractive (Peres et al., 2015). The annual discount rate is a key factor in this analytical approach, playing a pivotal role in assessing the profitability of the production system and, more importantly, in making investment decisions.

Because it is based on and offset by the opportunity cost of capital, this variable suggests that investments are viable in scenarios with higher interest rates, such as 10% and 12% annually (Table 5), thus encouraging producers and investors to remain engaged in the production chain. The present study demonstrated that even with these elevated rates, the investment remained viable. However, despite the viability of these rates, 6% provided the most attractive values for IRR and NPV (Table 5), making it the best rate.

Despite the scarcity of studies specifically addressing the economic implications of gestational nutritional supplementation during the post-weaning phase, it is evident that technology adoption costs primarily affect the budget in the short and medium terms. This necessitates careful planning and assessment by producers to ensure the viability and successful execution of the project.

Conclusion

Supplementation with protein concentrate at the end of pregnancy does not affect the performance or morphological traits of calves; it does elevate feed costs but does not adversely affect economic viability indices.

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References

Abreu, L. R. A., Martins, P. G. M. A., Mota, L. F. M., Ferreira, T. A., Ribeiro, V. M. P., Villela, S. D. J., Merlo, F. A., & Pires, A. V. (2018). Genetic correlations between body weight, scrotal circumference and visual evaluation scores in Bos indicus cattle. *Animal Science Journal, 89*(9), 1223-1229. doi: 10.1111/asj.12972

Barro, A. G., Marestone, B. S., dos S, E. R., Ferreira, G. A., Vero, J. G., Terto, D. K., de, C. A., & Bridi, A. M. (2023). Genetic parameters for frame size and carcass traits in Nellore cattle. *Tropical Animal Health and Production, 55*(2). doi: 10.1007/s11250-023-03464-z

Calil, Y. C. D., Ribera, L. A., Anderson, D. P., & Koury, W. Fo. (2022). Purebred Nellore Prices in Brazil: morphological, genetic, physical, and market factors in auctions. *Journal of Agricultural and Resource Economics, 47*(3), 529-543. doi: 10.22004/ag.econ.313308

Cappellozza, B. I., Bohnert, D. W., Reis, M. M., Van Emon, M. L., Schauer, C. S., Falck, S. J., & Cooke, R. F. (2021). Influence of amount and frequency of protein supplementation to ruminants consuming low-quality cool-season forages: efficiency of nitrogen utilization in lambs and performance of gestating beef cows. *Journal of Animal Science, 99*(6), 1-10. doi: 10.1093/jas/skab122

Carreño, L. O. D., Conceição Pessoa, M. da, Espigolan, R., Takada, L., Bresolin, T., Cavani, L., Baldi, F., Carvalheiro, R., Albuquerque, L. G. de, & Fonseca, R. da. (2019). Genome association study for visual scores in nellore cattle measured at weaning. *BMC Genomics, 20*(1), 1-9. doi: 10.1186/s12864-019-5520-9

Caton, J. S., Crouse, M. S., McLean, K. J., Dahlen, C. R., Ward, A. K., Cushman, R. A., Grazul-Bilska, A. T., Neville, B. W., Borowicz, P. P., & Reynolds, L. P. (2020). Maternal periconceptual nutrition, early pregnancy, and developmental outcomes in beef cattle. *Journal of Animal Science, 98*(12), 1-10. doi: 10.1093/JAS/SKAA358

Cooke, R. F., Daigle, C. L., Moriel, P., Smith, S. B., Tedeschi, L. O., & Vendramini, J. M. B. (2020). Cattle adapted to tropical and subtropical environments: Social, nutritional, and carcass quality considerations. *Journal of Animal Science, 98*(2), 1-14. doi: 10.1093/jas/skaa014.

Costa, T. C., Lourenço, P. E. C., Souza, R. O., Lopes, M. M., Araújo, R. D., Santos, M. M., Luciano, L. P., Massensini, J. D., Chalfun, L. L. H., Rennó, L. N., Sampaio, C. B., Veroneze, R., Paulino, P. V. R., Gionbelli, M. P., & Duarte, M. S. (2022). Ruminal undegradable protein enriched diet during late gestation of beef cows affects maternal metabolism and offspring's skeletal muscle development. *Animal Feed Science and Technology, 291*(115400), 1-12. doi: 10.1016/j.anifeedsci.2022.115400

Delevatti, L. M., Romanzini, E. P., Koscheck, J. F. W., Ross de Araujo, T. L. da, Renesto, D. M., Ferrari, A. C., Barbero, R. P., Mulliniks, J. T., & Reis, R. A. (2019). Forage management intensification and supplementation strategy: Intake and metabolic parameters on beef cattle production. *Animal Feed Science and Technology, 247*(2018), 74-82. doi: 10.1016/j.anifeedsci.2018.11.004

Evans, E. (2005). *Marginal Analysis: An Economic Procedure for Selecting Alternative Technologies/ Practices.* https://edis.ifas.ufl.edu

Garcia, F. Z., Carvalho, C. A. B., Peres, A. A. C., Malafaia, P., & Souza, P. M. (2017). Análise da viabilidade econômico-financeira de sistemas de cria em gado de corte: estudo de múltiplos casos. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 69*(4), 1030-1038. doi: 10.1590/1678-4162-9194

Greenwood, P. L., & Bell, A. W. (2019). Developmental programming and growth of livestock tissues for meat production. *Veterinary Clinics of North America: Food Animal Practice, 35*(2), 303-319. doi: 10. 1016/j.cvfa.2019.02.008

Instrução Normativa 12/2004, de 02 de dezembro de 2004 (2004). Regulamento técnico sobre fixação de parâmetros das características mínimas dos suplementos destinados a bovinos. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-pecuarios/alimentacao-animal/arquivos-alimentacao-animal/IN12.2004.pdf

Jensen, E. H., Neave, H. W., Bateson, M., & Jensen, M. B. (2024). Maternal behavior of dairy cows and suckling behavior of dairy calves in different cow-calf contact conditions. *Journal of Dairy Science, 107*(8), 6090-6103. doi: 10.3168/jds.2023-24291

Klein, J. L., Adams, S. M., Moura, A. F. de, Alves, D. C., Fº., Maidana, F. M., Brondani, I. L., Cocco, J. M., Rodrigues, L. D. S., Pizzuti, L. A. D., & Silva, M. B. da. (2020). Productive performance of beef cows subjected to different nutritional levels in the third trimester of gestation. *Animal, 15*(2), 100089. doi: 10.1016/j.animal.2020.100089

Koury Filho, W., Galvão de Albuquerque, L., Forni, S., Ii de Vasconcelos Silva, J. A., Yokoo, M. J., & Mello de Alencar, M. (2010). Estimativas de parâmetros genéticos para os escores visuais e suas associações com peso corporal em bovinos de corte. *Revista Brasileira de Zootecnia, 39*(5), 1015-1022. doi: 10.1590/ S1516-35982010000500011

Martins, M. M., Spolador, H. F. S., & Njuki, E. (2022). Production environment and managerial techniques in explaining productivity growth in Brazilian beef cattle production. *Agribusiness, 38*(2), 371-385. doi: 10.1002/agr.21722

Mattos, T. F. de A., Mattos, P. de Q. R., Barbero, M. M. D., & Barbero, R. P. (2023). Correlations between performance and morphological traits of beef calves. *Brazilian Journal of Agricultural and Enviromental Sciences, 1*(1), 1-13. doi: 10.5281/zenodo.10382563

Mccabe, S., Prendiville, R., Evans, R., O'connell, N. E., & Mchugh, N. (2019). Effect of cow replacement strategy on cow and calf performance in the beef herd. *Animal, 13*(3), 631-639. doi: 10.1017/S1751731118001660

Moriel, P., Palmer, E. A., Harvey, K. M., & Cooke, R. F. (2021). Improving beef progeny performance through developmental programming. *Frontiers in Animal Science, 2*(728635), 1-14. doi: 10.3389/fanim.2021.728635

Moriel, P., Vedovatto, M., Palmer, E. A., Oliveira, R. A., Silva, H. M., Ranches, J., & Vendramini, J. M. B. (2020). Maternal supplementation of energy and protein, but not methionine hydroxy analog, enhanced postnatal growth and response to vaccination in Bos indicus-influenced beef offspring. *Journal of Animal Science, 98*(5), 1-12. doi: 10.1093/jas/skaa123

Negreiros, M. P., Peripolli, E., Espigolan, R., Londoño-Gil, M., Rodriguez, J. D., Brunes, L., Magnabosco, C. U., Guimarães, N. C., Sainz, R. D., Pereira, A. S. C., Lobo, R. B., & Baldi, F. (2022). Selection criteria for frame score and its association with growth-, reproductive-, feed efficiency- and carcass-related traits in Nellore cattle. *Animal Production Science, 62*(16), 1551-1562. doi: 10.1071/AN22054

Oliveira, M. H. V. de, Silva, J. A. I. de V., Faria, R. A. da S., Paiva, J. T. de, Malheiros, J. M., Correia, L. E. C. dos S., Albuquerque, L. G., & Gaya, L. de G. (2021). Genetic evaluation of weaning weight and udder score in Nellore cattle. *Livestock Science, 244*(104400), 1-5. doi: 10.1016/j.livsci.2021.104400

Palmer, E. A., Vedovatto, M., Oliveira, R. A., Ranches, J., Vendramini, J. M. B., Poore, M. H., Martins, T., Binelli, M., Arthington, J. D., & Moriel, P. (2022). Timing of maternal supplementation of dried distillers grains during late gestation influences postnatal growth, immunocompetence, and carcass characteristics of Bos indicus -influenced beef calves. *Journal of Animal Science, 100*(2), 1-17. doi: 10.1093/jas/skac022

Paterno, F. M., Buzanskas, M. E., Koury, W., Fº., Lôbo, R. B., & Queiroz, S. A. (2017). Evaluation of body weight and visual scores for genetic improvement of Nelore cattle. *Tropical Animal Health and Production, 49*(3), 467-473. doi: 10.1007/s11250-016-1215-2

Peres, A. A. C., Santos, A. A., Carvalho, C. A. B., & Brandalise, N. (2015). Financial analysis of production systems for heifers on brachiaria brizantha "xaraés" pasture supplemented with mineral mixture. *Archivos de Zootecnia, 64*(246), 123-130. doi: 10.21071/az.v64i246.386

Perrin, R., Winkelmann, D., Moscardi, E., & Anderson, J. (1988). *From Agronomic Data to Farmer Recommendations: An Economics Training Manual.* CIMMYT.

Portes, J. V., Menezes, G. R. O., MacNeil, M. D., Silva, L. O. C. da, Gondo, A., & Braccini, J., Neto. (2020). Selection indices for

Nellore production systems in the Brazilian Cerrado. *Livestock Science, 242*(104309), 1-8. doi: 10.1016/j.livsci.2020.104309

Richards, M. W., Spitzer, J. C., & Warner, M. B. (1986). Effect of varying levels of postpartum nutrition and body condition at calving on subsequent reproductive performance in beef cattle. *Journal of Animal Science, 62*(2), 300-306. doi: 10.2527/jas1986.622300x

Romanzini, E. P., Barbero, R. P., Reis, R. A., Hadley, D., & Malheiros, E. B. (2020). Economic evaluation from beef cattle production industry with intensification in Brazil's tropical pastures. *Tropical Animal Health and Production, 52*(5), 2659-2666. doi: 10.1007/s11250-020-02304-8

Santana, M. L., Bignardi, A. B., Pereira, R. J., Oliveira, G. A., Jr., Freitas, A. P., Carvalheiro, R., Eler, J. P., Ferraz, J. B. S., Cyrillo, J. N. S. G., & Mercadante, M. E. Z. (2023). Genotype by prenatal environment interaction for postnatal growth of nelore beef cattle raised under tropical grazing conditions. *Animals, 13*(2321), 1-25. doi: 10.3390/ani13142321

Sanz, A., Blanco-Penedo, I., Quintans, G., & Álvarez-Rodríguez, J. (2024). Mother-offspring bonding revisited: A blueprint for the future of beef cattle farming. *Applied Animal Behaviour Science, 277*(106346), 1-10. doi: 10.1016/j.applanim.2024.106346

Semchechem, R., Pértile, S. F. N., Simonelli, S. M., Canozzi, M. E. A., Cunha, L. F. C. da, Fº., Zamboti, M. L., Zundt, M., Santos, M. D. dos, El Memari, A. C., Neto, & Almeida Rego, F. C. de. (2021). Relationship among productive and economic variables of beef cattle in Brazil. *Ciência Rural, 51*(4), 1-7. doi: 10.1590/0103-8478cr20190841

Silva, P. H. F., Carvalho, C. A. B., Malafaia, P., Garcia, F. Z., Peres, A. A. C., Souza, P. M., Barbero, R. P., & Ferreira, R. L. (2019). Análise bioeconômica de períodos de suplementação proteico-energética na estação seca para novilhas Nelore em pastagem diferida de Urochloa decumbens. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 71*(3), 1058-1066. doi: 10.1590/1678-4162-10511

Smith, W. B., Galyean, M. L., Kallenbach, R. L., Greenwood, P. L., & Scholljegerdes, E. J. (2021). Understanding intake on pastures: how, why, and a way forward. *Journal of Animal Science, 99*(6), 1-17. doi: 10.1093/jas/skab062

Soares, B. B., Brunes, L. C., Baldi, F. S., Carmo, A. S. do, Narciso, M. G., Magnabosco, V. S., Sainz, R. D., & Magnabosco, C. U. (2023). Association of visual scores with reproductive traits in Nelore cattle using Bayesian Inference. *Ciência Animal Brasileira, 24*(e-75081E), 1-11. doi: 10.1590/1809-6891v24e-7508 1E

Souza, F. M., Lopes, F. B., Rosa, G. J. M., Fernandes, R. da S., Magnabosco, V. S., & Magnabosco, C. U. (2022). Genetic selection of Nellore cattle raised in tropical areas: Economic indexes and breeding decisions risks. *Livestock Science, 265*(105098), 1-9. doi: 10.1016/j.livsci.2022.105098

Trejo-Pech, C. J. O., Bruhin, J., Boyer, C. N., & Smith, S. A. (2022). Profitability, risk and cash flow deficit for beginning cow-calf producers. *Agricultural Finance Review, 82*(1), 1-19. doi: 10.1108/AFR-05-2020-0065

Valadares, S. C. Fo., Costa e Silva, L. F., Gionbelli, M. P., Rotta, P. P., Marcondes, M. I., Chizzotti, M. L., Prados, L. F. (2016). *Exigências Nutricionais de Zebuínos Puros e Cruzados BR-CORTE,* (3a. ed.), Viçosa.

Vargas, G., Schenkel, F. S., Brito, L. F., Neves, H. H. de R., Munari, D. P., Lucia, L. G., & Carvalheiro, R. (2020). Genomic regions associated with principal components for growth, visual score and reproductive traits in Nellore cattle. *Livestock Science, 233*(103936), 1-9. doi: 10.1016/j.livsci.2020.103936

Webb, M. J., Block, J. J., Funston, R. N., Underwood, K. R., Legako, J. F., Harty, A. A., Salverson, R. R., Olson, K. C., & Blair, A. D. (2019). Influence of maternal protein restriction in primiparous heifers during mid- and/or late-gestation on meat quality and fatty acid profile of progeny. *Meat Science, 152*, 31-37. doi: 10.1016/j.meatsci.2019.02.006