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Influence of season of birth and sex on wight gain in Nelore calves in tropical systems

[Influência da sazonalidade de nascimento e do sexo no desenvolvimento ponderal de bezerros da raça Nelore em sistemas tropicais]

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Abstract: The productive performance of beef cattle is influenced by the interaction of genetic and environmental factors. The aim was to evaluate the impact of seasonality, sex and birth weight on the weight development of 483 Nelore cattle. A five-year retrospective longitudinal survey was carried out, analyzing the data using ANOVA, Tukey's test, Pearson's correlation and Random Forest. The results indicated that calves born in the rainy season had higher birth weights, regardless of gender. Sexual dimorphism was more expressive in weaning weight and yearling weight during the rainy season, where males were significantly heavier. Weaning weight, rather than birth weight, was consolidated as the main predictor of subsequent performance, with strong positive correlations with yearling and yearling weights. The analysis of relative importance confirmed that environmental influence (period) is more critical in the early stages, while sex becomes progressively more decisive. It is concluded that management should aim to optimize weaning weight, as this is the most robust indicator of future performance in production systems in tropical regions.

Keywords: cattle; growth; sexual dimorphism; interaction; weight.

Resumo: O desempenho produtivo de bovinos de corte é influenciado pela interação de fatores genéticos e ambientais. Objetivou-se avaliar o impacto da sazonalidade, do sexo e do peso ao nascimento no desenvolvimento ponderal de 483 bovinos Nelore. Foi realizado um levantamento longitudinal retrospectivo de cinco anos, analisando os dados por meio de ANOVA, teste de Tukey, correlação de Pearson e Random Forest. Os resultados indicaram que bezerros nascidos no período chuvoso apresentaram maior peso ao nascer, independentemente do sexo. O dimorfismo sexual foi mais expressivo no peso ao desmame e ao ano durante a estação chuvosa, onde os machos foram significativamente mais pesados. O peso ao desmame, e não o ao nascimento, consolidou-se como o principal preditor do desempenho subsequente, com fortes correlações positivas com os pesos ao ano e ao sobreano. A análise de importância relativa confirmou que a influência ambiental (período) é mais crítica nas fases iniciais, enquanto o sexo se torna progressivamente mais determinante. Conclui-se que o manejo deve visar à otimização do peso ao desmame, pois este é o indicador mais robusto para o desempenho futuro em sistemas de produção em regiões tropicais.

Palavras-chave: bovinos; crescimento; dimorfismo sexual; interação; peso.

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1. Introduction

Brazilian cattle production plays a prominent role in global livestock agriculture, with a herd estimated at 197 million head in 2023, reflecting remarkable growth and more than doubling its production since 1970 [1, 2]. This substantial output has established Brazil as one of the world's leading beef producers and exporters [3, 4], highlighting the importance of beef cattle production as one of the country's main agricultural sectors.

Given Brazil's continental dimensions and predominantly tropical location, climatic variability requires cattle breeds to exhibit high adaptability and performance under these conditions [5]. The zebu breed Nelore, originally from India, meets these requirements. Its superior adaptability results from an evolutionary process that selected alleles associated with heat tolerance, providing optimized thermoregulatory capacity characterized by a lower metabolic rate and greater ability to dissipate heat to the environment [6, 7].

In addition to adaptability, rapid body weight development is a trait of considerable zootechnical importance. Animals that reach slaughter weight at an early age contribute substantially to reducing production costs [8, 9]. Productive performance in cattle results from the interaction between genetic and environmental factors. Genotype-by-environment interaction (G×E) occurs when different genotypes respond differently to environmental variation, directly affecting traits such as growth, reproduction, and feed efficiency [10]. Among genetic factors, sex, birth weight, weaning weight, and daily weight gain are particularly important, whereas environmental factors include management practices and climatic and nutritional conditions [11, 12].

Sex exerts a substantial influence on growth because, under similar environmental conditions, males tend to be approximately 10 % heavier than females, directly affecting carcass composition and tissue distribution [13]. This influence is particularly evident during the finishing phase, as heifers generally enter this stage at lower body weights, whereas bulls are characterized by greater feed efficiency and higher weight gains, [14,15]. These differences directly affect management decisions, requiring producers to consider productive characteristics and market demands while adjusting feeding strategies according to sex to achieve an optimal balance between slaughter weight and carcass quality.

Birth weight is a multifactorial trait influenced by both genetic inheritance and environmental conditions and is of considerable interest because of its positive genetic correlation with later body weights [12, 16, 17]. Calves with excessive birth weights may be predisposed to varying degrees of dystocia, resulting in fetal distress and metabolic and respiratory acidosis, with adverse effects on subsequent development [18]. Conversely, low birth weight is associated with reduced energy reserves, impaired thermoregulatory capacity, and increased perinatal mortality [19-21].

Environmental factors also exert significant effects on animal development throughout various stages of life. Brazil's location within the tropical zone results in a well-defined climatic seasonality characterized by dry and rainy periods, directly affecting forage quantity and quality. Depending on the season, these variations may either favor or impair fetal development in pregnant Nelore cows [22,23]. Strategic planning of the calving season allows the nutritional requirements of both cows and calves to be synchronized with forage availability throughout the year while accounting for environmental and management conditions that vary across regions of the country [24, 25].

The complexity involved in understanding and controlling these multiple factors highlights the need for research aimed at improving predictability within beef production systems by identifying productive markers and indicators that support management decisions. Therefore, this study evaluated the effects of sex, birth weight, and seasonality on the body weight development of Nelore cattle, hypothesizing that these factors influence growth differently throughout the animals' developmental stages.

2. Material and methods

2.1 General description

This study was conducted using data obtained from a private farm located in the municipality of Arraias, Tocantins, Brazil. The study was based on a retrospective longitudinal survey of records collected over a five-year period (2020–2024). A total of 483 purebred Nelore cattle were included as experimental units, comprising 238 males and 245 females. All animals were electronically identified to ensure traceability and the reliability of data collection.

All animals remained clinically healthy throughout the study period and were managed according to their production category. Individual animals were monitored from birth, and body weight measurements were recorded at four stages: birth, weaning, yearling, and post-yearling. Body weights were measured in kilograms (kg) using an electronic scale.

The effect of seasonality on body weight development was evaluated according to the rainfall pattern of the macroregion where the animals were raised. Seasons were classified as rainy (higher precipitation) or dry (lower precipitation) based on regional climatic conditions. To ensure data comparability, identical weighing protocols were adopted across both seasons. Therefore, regional climatic characteristics should be considered when replicating this study in other locations.

This study consisted exclusively of a retrospective analysis of previously existing secondary data and did not involve direct animal contact, intervention, or experimental manipulation. According to the Brazilian Arouca Law (Law No. 11,794/2008) and the guidelines established by the National Council for the Control of Animal Experimentation (CONCEA), studies based solely on existing records do not require prior review or approval by an Animal Use Ethics Committee (CEUA).

2.2 Statistical analysis

This field experiment was carried out under a completely randomized design (CRD). The study was conducted using data obtained from a retrospective observational dataset comprising records previously collected from Nelore cattle evaluated for body weight performance traits. Because historical records were used, animals were not randomly assigned to the evaluated groups, and comparisons were therefore based on the observational structure of the available data.

Initially, the assumptions required for analysis of covariance (ANCOVA) were assessed. Residual normality was evaluated using the Shapiro–Wilk test, and homogeneity of variances was assessed using Bartlett's test. However, the covariate birth weight did not significantly affect the response variables and was therefore not retained in the model as an adjustment factor.

Subsequently, analysis of variance (ANOVA) was performed to evaluate the main effects of sex (male and female), seasonal period (rainy and dry), and their interaction on body weight traits. When a significant interaction was detected, simple effects were examined according to the ANOVA results.

Multiple comparisons among means were performed using Tukey's honestly significant difference (HSD) test on ranked data (semiparametric approach). The use of this procedure was justified by the number of means compared, the observed coefficients of variation, and compliance with the underlying assumptions of the analyses.

Pearson's correlation analyses were also conducted among body weights recorded at birth, weaning, yearling, and post-yearling stages. Correlations were evaluated separately according to sex and seasonal period. Correlation coefficients were presented using correlograms and scatterplots to facilitate visualization and interpretation of the relationships among variables.

The relative importance of biometric, reproductive, and environmental variables was assessed using the Random Forest machine-learning algorithm. Variable importance was quantified using the percentage increase in mean squared prediction error (incMSE), which estimates the individual contribution of each predictor variable. Because the objective was to estimate the relative importance of predictor variables in explaining variation in the response variable rather than to develop a predictive model for future observations, the Random Forest model was fitted using the complete dataset and internally validated through bootstrap sampling performed by the algorithm.

All statistical analyses were performed using R software [26], version 4.4.2, with the aid of the packages: randomForest [27], multcomp [28], emmeans [29], ggplot2 [30], RColorBrewer [31], dplyr [32], multcompView [33], and AgroR [34].

3. Results

Birth weight (kg) did not differ significantly between male and female Nelore calves. However, when seasonal periods were compared within each sex, calves born during the rainy season exhibited higher birth weights than those born during the dry season, regardless of sex (Figure 1A).

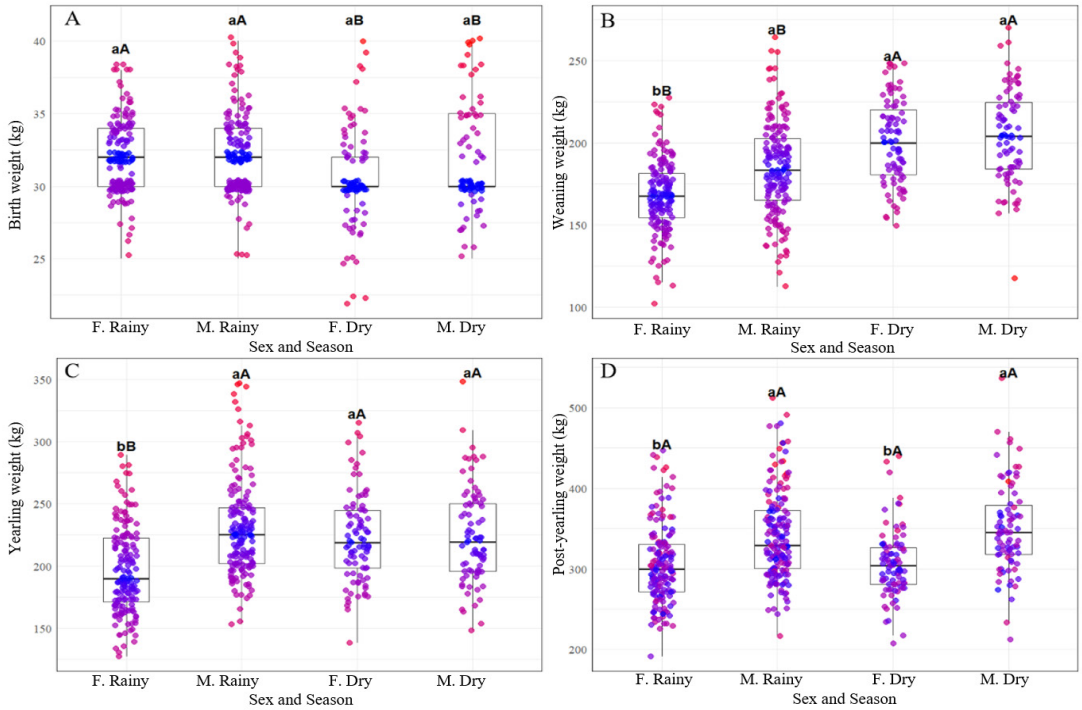

Figure 1. Body weight distribution (kg) across birth (A), weaning (B), yearling (C), and post-yearling (D) of Nelore cattle according to sex (F = female; M = male) and season (dry and rainy). Means were compared using Tukey's ranked HSD test ($P < 0.05$). *Means followed by the same lowercase letter within a season and the same uppercase letter within a sex do not differ according to Tukey's ranked HSD test at $P < 0.05$.

For weaning weight (kg), males born during the rainy season were significantly heavier than females, demonstrating the greater growth potential of male animals. In contrast, no significant differences between sexes were observed during the dry season. When the effect of season was evaluated within each sex, animals weaned during the dry season exhibited greater weights than those weaned during the rainy season (Figure 1B).

For yearling weight (kg), the pattern of greater body weight in males was again observed during the rainy season, with males presenting significantly higher values than females. However, no significant sex-related differences were detected during the dry season, suggesting that environmental conditions reduced the expression of sexual dimorphism. Regarding the effect of season within each sex, females raised during the dry season exhibited greater yearling weights than those raised during the rainy season. In contrast, males showed similar yearling weights regardless of season, indicating recovery from the lower weaning weights observed during the rainy season (Figure 1B, C).

For post-yearling weight (kg), males were significantly heavier than females in both seasons, confirming the expected pattern of greater weight gain in male animals. No significant seasonal effect was observed within either sex, suggesting that animals achieved similar post-yearling performance regardless of environmental conditions (Figure 1D).

Among females born during the dry season, weaning weight showed significant positive correlations with both yearling and post-yearling weights, indicating that superior performance at weaning tended to be maintained during subsequent growth stages. This relationship was even more pronounced between yearling and post-yearling weights, suggesting that animals with superior yearling performance generally maintained this advantage at the post-yearling stage (Figure 2A). According to Cohen's classification, correlations between weaning weight and subsequent weights were moderate (r = 0.30–0.49), whereas the correlation between yearling and post-yearling weights was strong (r > 0.50).

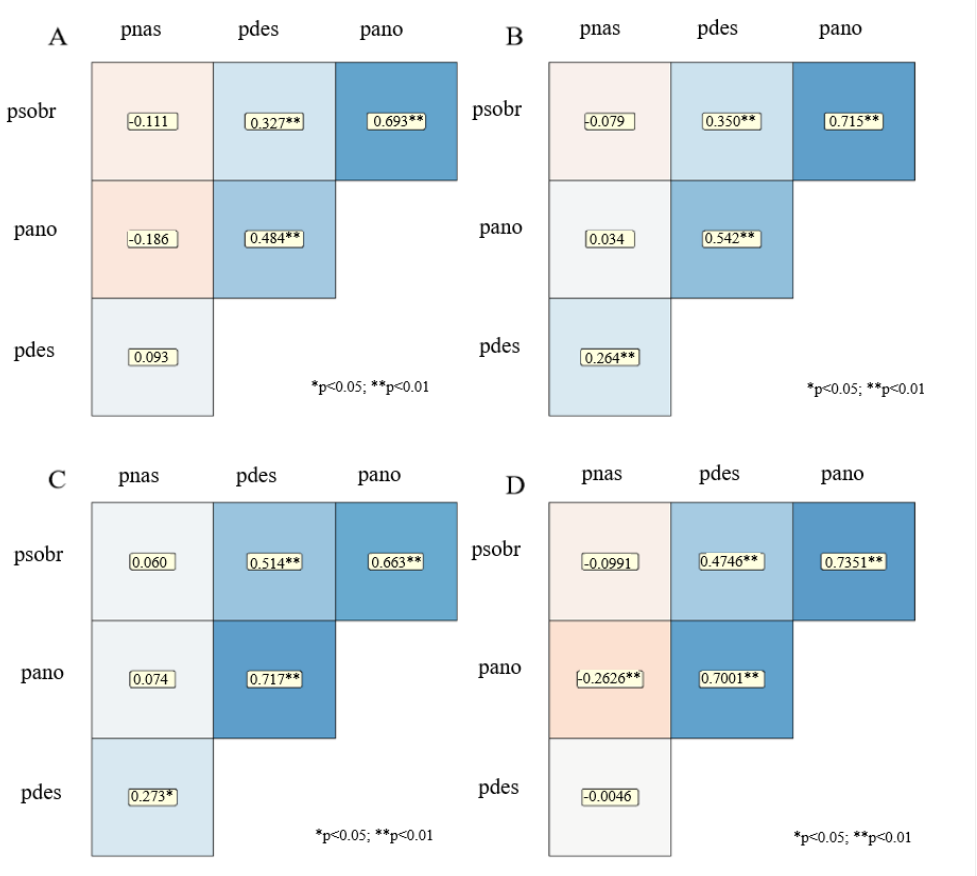

Figure 2. Pearson's correlation coefficients among birth, weaning, yearling, and post-yearling weights (kg) of Nelore cattle: females born during the dry season (A), females born during the rainy season (B), males born during the dry season (C), and males born during the rainy season (D). Description of abbreviations: psobr (yearling weight), pano (yearling weight), pdes (weaning weight), pnas (birth weight).

In contrast, birth weight showed negative coefficients with both yearling and post-yearling weights in females born during the dry season, although these correlations were not significant. Despite the lack of statistical significance, this pattern suggests that females with higher birth weights may exhibit lower performance during subsequent growth stages under these conditions (Figure 2A).

For females born during the rainy season, weaning weight was positively and significantly correlated with both yearling and post-yearling weights, reinforcing the importance of early performance for subsequent growth. The strongest association was observed between yearling and post-yearling weights (Figure 2B).

Birth weight showed only a weak but significant correlation with weaning weight and was not significantly associated with either yearling or post-yearling weights. These findings indicate that, in females born during the rainy season, birth weight exerts limited influence on later growth stages (Figure 2B).

Among males born during the dry season, weaning weight was strongly correlated with both yearling and post-yearling weights. Likewise, the correlation between yearling and post-yearling weights was particularly strong, indicating consistency in growth performance after weaning (Figure 2C).

Birth weight showed a significant positive correlation with weaning weight, suggesting that, among males born during the dry season, heavier calves at birth tended to maintain a moderate performance advantage until weaning. However, no significant correlations were observed between birth weight and either yearling or post-yearling weights, indicating limited predictive value for later growth stages (Figure 2C).

For males born during the rainy season, weaning weight was positively and significantly correlated with both yearling and post-yearling weights, demonstrating that performance at weaning is a key determinant of subsequent growth. The association between yearling and post-yearling weights was the strongest observed among all variable combinations, indicating that animals with superior yearling performance generally maintained this advantage through the post-yearling stage (Figure 2D).

Birth weight showed a weak but significant negative correlation with yearling weight in males born during the rainy season, suggesting that heavier calves at birth tended to exhibit lower yearling weights under these conditions (Figure 2D).

Season was the main predictor of weaning weight, accounting for 40.76 % of the relative importance, followed by sex (24.37 %) and birth weight (18.10 %). These results indicate that environmental factors exert a marked influence on animal performance during the early stages of development. For yearling weight, weaning weight was the most important predictor (34.33 %), demonstrating a strong relationship between early growth and subsequent performance. Sex, season, and birth weight also contributed substantially, with relative importance values ranging from 17 % to 23 %, indicating that both animal-related and environmental factors continue to influence performance at this stage (Table 1).

To assess the relative importance of biometric, reproductive, and environmental variables in the predictions, the Random Forest machine-learning algorithm was applied. The dataset was partitioned into training (70 %) and testing (30 %) subsets. Model fitting was performed using the training dataset with repeated 10-fold cross-validation for model tuning and internal hyperparameter selection. Predictive performance was subsequently evaluated using the testing dataset, which was not included in the training process. Variable importance was quantified using the percentage increase in mean squared prediction error (incMSE), allowing the individual contribution of each predictor variable to be assessed.

Table 1. Relative importance (%) of predictor variables for estimating weaning, yearling, and post-yearling weights, based on the percentage increase in mean squared prediction error (%IncMSE) obtained from the Random Forest model.

Predictor	Relative importance (%)		
	Weaning weight	Yearling weight	Post-yearling weight
Season	34.116	27.103	17.85
Sex	63.083	24.962	27.469
Weaning weight	24.904	17.785	3.384
Yearling weight		63.049	19.479
Post-yearling weight	-		66.430
	-	-	

For post-yearling weight prediction, yearling weight was the most important predictor (32.70 %), followed by sex (31.08 %) and weaning weight (20.18 %). The contributions of season (16.09 %) and birth weight (6.69 %) were comparatively lower, suggesting that previous body weights and sex become increasingly important determinants of performance as animals progress through later stages of development (Table 1).

4. Discussion

Sexual dimorphism is a phenomenon in which males and females of the same species differ in behavior, body size, and/or physical characteristics [35,36]. In cattle, this pattern is well documented, with males generally exhibiting superior growth performance due to greater muscle deposition and feed efficiency, largely driven by hormonal factors, particularly testosterone [37–38]. This pattern was clearly observed for weaning and yearling weights, especially during the rainy season, when more favorable environmental conditions likely allowed greater expression of the genetic growth potential of male animals (Figure 1B, C).

The relationship between heat distribution and exchange between the animal and its environment should be considered not only as an aspect of adaptability, from a physiological perspective, cutaneous receptors transmit information to thermoregulatory centers, particularly the hypothalamus, which, upon detecting an increase in body temperature, triggers mechanisms such as vasodilation, sweating, and panting [39]. These responses represent an adaptive challenge and result in additional energy expenditure to restore homeostasis.

When animals are exposed to temperatures above the upper critical limit of their thermal comfort zone, blood flow is redirected to peripheral tissues and respiratory rate increases. This response reduces feed conversion efficiency because energy that would otherwise be allocated to muscle tissue deposition (anabolism) is diverted to maintaining homeostasis through thermoregulatory processes [40].

Birth weight is an important trait to evaluate because it can be strongly influenced by both environmental and genetic conditions. When evaluated solely in relation to sexual dimorphism, no significant differences in birth weight were observed between sexes (Figure 1A). This result may

be explained by the fact that, during the initial stages of development, birth weight is more strongly influenced by maternal and environmental factors than by the sex of the newborn calf [41,42]. When birth weight was evaluated according to season (dry and rainy periods), animals born during the rainy season exhibited greater birth weights (Figure 1A). This finding is consistent with previous studies, which attributed these differences to improved nutritional conditions of pregnant cows during this period, positively influencing the intrauterine environment and fetal growth, both of which play important roles in animal development and productive performance [22, 43, 44].

Animals of both sexes born during the dry season exhibited greater weaning weights than those born during the rainy season (Figure 1B). This pattern may be related to compensatory growth, a phenomenon observed in mammals and birds in which animals subjected to a period of nutritional restriction sufficient to depress normal growth subsequently exhibit growth rates above normal once the restriction is removed and adequate nutrition is restored [45,46]. In addition, intensified management practices frequently adopted during the dry season to mitigate nutritional deficiencies may have contributed to this performance. The importance of environmental conditions, particularly during the early stages of development [47, 48], is further supported by the finding that season of birth was the most influential predictor of weaning weight (40.76 %), followed by sex (24.37 %) and birth weight (18.10 %), as shown in Table 1.

Correlation analyses demonstrated that weaning weight was positively and significantly associated with both yearling and post-yearling weights across all groups evaluated, highlighting its potential as a key indicator of future animal performance. These associations reinforce the influence of early development on subsequent stages of growth [24, 49-51].

Toral et al. [52] while investigating genotype-by-environment interactions affecting growth traits in Nelore cattle in Mato Grosso do Sul, reported that calves born at the beginning of the rainy season generally exhibited lower birth weights, which negatively affected weaning weight. However, the authors also highlighted that these animals tended to exhibit compensatory growth before weaning due to the greater availability of high-quality forage and more favorable environmental conditions during this period.

In contrast, birth weight showed weak or nonsignificant correlations with post-yearling weight and was negatively correlated with yearling weight in males born during the rainy season [yearling weight ($r = -0.186$) and post-yearling weight ($r = -0.111$)]. According to Holland and Odde [18], weak correlations in cases of higher birth weights may increase the risk of dystocia, resulting in fetal distress and metabolic and respiratory acidosis, which can adversely affect subsequent development.

As shown in Figure 1D, post-yearling weight was strongly associated with sexual dimorphism, with males exhibiting greater weight gain than females. Similar physiological relationships have been reported by Biffani et al. [53]. Likewise, Euclides Filho, Rosa, and Figueiredo [54] observed that male calves were, on average, approximately 1.60 kg heavier at birth than females. Furthermore, Yilmaz and Bayram [55], reported a positive correlation between gestation length and birth weight, which may explain the greater birth weights commonly observed in males, as they have longer gestation periods.

Although environmental seasonality (Figure 2) and growth stage influenced animal performance, birth weight showed no significant relationship with post-yearling weight and had low relative importance as a predictor (6.69 %; Table 1). This trend is consistent with previous studies reporting greater influence of factors associated with later stages of development on animal growth performance [55, 56].

Regarding the correlation analyses, sex played an increasingly significant role in body weight performance as animals progressed through the growth stages, becoming the second most important predictor of post-yearling weight (31.08 %). This finding reinforces the effect of sexual dimorphism on weight gain, as previously discussed and widely reported in the literature [13–15]. In contrast, the influence of environmental conditions (season) decreased as animals advanced through the production phases, indicating that environmental effects tend to be more pronounced during the early stages of life. Management practices adopted on the farm, particularly nutritional and environmental welfare strategies, may have contributed to mitigating the impact of environmental conditions on animal performance [23, 38, 57].

Overall, the results highlight the importance of early postnatal development for subsequent growth performance. Environmental conditions associated with birth season were closely related to body weight development, while weaning weight emerged as an important indicator of future performance. In addition, sexual dimorphism exerted a progressively greater influence throughout development, favoring greater weight gain in males.

5. Conclusion

In conclusion, body weight performance of Nelore cattle is influenced by birth season and early developmental conditions in the Cerrado biome of southern Tocantins State. Among the variables evaluated, weaning weight proved to be a more robust predictor of future performance than birth weight, which appears to be more strongly affected by maternal influences.

Conflict of interest statement

The authors declare no conflict of interest.

Data availability statement

The complete dataset supporting the results of this study was published in the article itself.

Author contributions

Conceptualization: Sampaio, H.S.; Data Curation: Marques Filho, W.C.; Methodology: Coutinho, W.B.G. and Gomes, A.L;Writing (revision and editing): Dias, N.C.C. and Silva, A.G.

Generative AI use statement

The authors did not use generative Artificial Intelligence tools or technologies in the creation or editing of any part of this manuscript.

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