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Ultrasound Measurements Are Useful to Estimate Hot Carcass Weight of Nellore Heifers Under Different Supplementation Strategies

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Abstract: The use of non-invasive methods can contribute to the development of predictive models for measuring carcass yield (CY) and hot carcass weight (HCW) in domestic ruminants. In this study, in vivo measurements of subcutaneous fat thickness (SFT) and ribeye area (REA) were performed on 111 Nellore heifers using ultrasound imaging. The animals were managed in crop–livestock integrated systems with different supplementation levels (SL). Four multiple regression equations were developed to estimate CY and HCW, using five predictor variables: SFT, REA, REA per 100 kg of body weight (REA100), live weight (LW), and SL. For the CY prediction models, when ultrasound measurements (SFT, REA, and REA100) were considered, the generated equations showed low R^2 and concordance correlation coefficient (CCC) values, indicating low predictive capacity for this trait. For HCW, the predictor variables stood out due to their high R^2 values. Additionally, the equation based solely on ultrasound measurements achieved a CCC greater than 0.800, demonstrating high predictive capacity. Based on these results, it can be concluded that ultrasound-derived measurements are effective for generating useful models to predict HCW. Thus, it will be possible to estimate the amount of carcass that will be produced even before the animals are sent to slaughterhouses.

Keywords: beef cattle; multiple regression; prediction; ribeye area; subcutaneous fat thickness

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1. Introduction

The possibility of measuring carcass weight and quality through morphometric measurements [1,2] or in vivo ultrasound imaging [3], without the need for comparative slaughters, ensures both the acquisition of accurate data and animal welfare. Ultrasound measurements, such as subcutaneous fat thickness (SFT) and ribeye area (REA), are already used as phenotypes in animal breeding programs. Additionally, they show a positive correlation with other traits that directly impact productive efficiency, such as dry matter intake, hot carcass weight, and age at puberty in cattle [4,5]. This reinforces the potential of ultrasound in selecting more efficient animals, assisting in the early identification

of genetically superior individuals. Moreover, ultrasound allows for the assessment of genotype–environment interactions, as carcass traits are influenced by external factors such as nutrition [6]. Thus, this tool enables a more precise approach in selecting animals adapted to different production systems. Finally, the use of ultrasound in the selection process contributes to identifying and choosing animals with superior carcass traits, benefiting both genetic improvement and productive efficiency [7].

Non-destructive measurements also demonstrate high potential for generating reliable predictive models, as highlighted by Gurgel et al. [8] and Montoya-Santiyanes et al. [9]. These authors found that biometric traits correlate with live weight and carcass cuts, favoring the selection of robust equations. In this context, measurements like SFT and REA are strong candidates as predictor variables, as they correlate with key traits such as carcass yield (CY) and hot carcass weight (HCW) [10].

For predictive models to be practically useful, the selected variables must meet farmers' demands. CY is used as an indicator to assess productive efficiency under various sexual conditions, genetic groups, and feeding management of domestic ruminants [11,12]. Meanwhile, HCW determines the gross income of beef cattle farmers [13]. The use of tools to measure CY and HCW during the finishing phase enables producers to identify animals ready for slaughter and predict the value they will receive for them.

Beyond predicting carcass yield and weight, these tools contribute to evaluating different dietary strategies for grazing animals. In tropical pastures, often characterized by low nutritional quality, farmers use supplementation to enhance animal performance [14,15]. Supplementation changes the composition of weight gain in animals by reducing the size and weight of abdominal viscera, especially the liver and gastrointestinal tract. Consequently, the prediction of CY and HCW using ultrasound imaging may vary depending on the nutritional management adopted.

Therefore, the hypothesis is that in vivo ultrasound measurements, such as SFT and REA, can be an efficient predictor for CY and HCW of Nellore heifers even though they are managed under different supplementation strategies. Thus, the objective of this study was to identify and select simple equations to estimate CY and HCW in Nellore females under varying nutritional management conditions.

2. Materials and Methods

2.1. Description of the Animals and Experimental Design

A total of 111 Nellore heifers, with an average age of 20 months, were used in this study. The animals had access to pasture during the dry season (March to September) in a crop–livestock integrated system, with a grazing period of 78 days in 2020 and 72 days in 2023. The experimental area was in Montes Claros de Goiás, Brazil. The region presents an average annual rainfall of 1532 mm, 87% of which occurs between October and March, resulting in the average water deficit lasting four to five months during the year [16].

The animals were assigned to experimental groups, each subjected to a specific supplementation strategy during the grazing period. Three supplementation strategies were evaluated: mineral supplement (0.03% of live weight—LW), protein–energy supplementation (0.5% of LW), and high-intake supplementation (1.5% to 1.8% of LW). The experiment followed a randomized complete block design, in which each block consisted of three paddocks (replicates), and each experimental unit received its respective treatment. The total experimental area was 13.90 ha, subdivided into nine paddocks, each covering 1.54 ha.

The composition of the protein–energy supplement was as follows: corn (76%), soybean meal (15.2%), urea (3.5%), and mineral supplement (5.3%). The high-intake supplement contained corn (88.1%), soybean meal (9.0%), urea (1.1%), and mineral supplement (1.7%).

The high-intake supplements were formulated according to the animals' requirements to achieve an average daily carcass gain of 1 kg. The animals were gradually adapted to the diet. The high-intake supplementation group received 0.5% of LW during the first week, 0.75% of LW in the second week, 1% of LW in the third week, 1.5% of LW from the fourth week until 60 days of grazing, and 1.8% of LW for the remainder of the grazing period. Table 1 presents the chemical composition of each level of protein–energy supplementation.

Table 1. Chemical composition of protein–energy supplements.

Item	0.5% of Live Weight	1.8% of Live Weight
Acid detergent fiber (%)	3.71	3.47
Neutral detergent fiber (%)	5.60	6.35
Starch (%)	52.39	62.46
Crude fiber (%)	1.74	2.91
Lignin (%)	17.48	18.13
Crude protein (%)	24.09	14.08
Acid detergent insoluble protein (%)	0.070	0.490
Neutral detergent insoluble protein (%)	0.630	0.890
Ether extract (%)	2.15	3.12
Ash (%)	9.43	4.89
Total digestible nutrients (%)	79.75	84.35
Digestible energy (Mcal kg^{-1})	3.68	3.73
Metabolizable energy (Mcal kg^{-1})	3.13	3.31
Net energy for gain (Mcal kg^{-1})	1.44	1.59
Net energy for maintenance (Mcal kg^{-1})	2.11	2.09

The mineral supplement used had the following composition: calcium (18.56%), phosphorus (5.69%), magnesium (1.07%), potassium (5.69%), sodium (14.75%), sulfur (1.16%), and chloride (22.32%).

2.2. Description of Experiment Implementation and Management Practices Adopted

In the livestock phase of the crop–livestock integrated system, Zuri guinea grass (*Megathyrsus maximus* cv. BRS Zuri) was established by sowing it after soybean (*Glycine max*) harvest. Sixty days after the soybean harvest, the grass-based animal production phase began each year. Pre-grazing, the Zuri guinea grass pastures exhibited, on average, 80 cm in height, 2.00 Mg ha^{-1} of forage mass availability, 15.20% crude protein (CP), 56.30% neutral detergent fiber (NDF), 36.23% acid detergent fiber (ADF), 61.93% NDF digestibility over 48 h, and 4.59% lignin.

In 2020, 63 females with an initial average weight of 281 $\pm$ 1.69 kg were managed. In 2023, 48 females were used, with an average weight of 298 $\pm$ 3.09 kg. Each animal was identified with an ear tag before the start of the grazing phase.

The grazing method used was continuous stocking, with a fixed initial stocking rate defined for each treatment annually, adjusted based on forage availability and supplementation provided to each group. Thus, all groups began with the same stocking rate per treatment, and animals were removed from paddocks only when there was a reduction in forage availability, i.e., when a forage mass value close to 1.00 Mg ha^{-1} was measured in the paddock.

In 2020, the initial animal distribution was organized as follows (Table 2): five animals per paddock for the mineral, seven animals per paddock for the 0.5% of LW, and nine animals per paddock for the 1.5% to 1.8% of LW. In 2023, four animals per paddock were managed for the mineral, five animals per paddock for 0.5% of LW, and seven animals per paddock for 1.5% to 1.8% of LW. Each paddock was equipped with a trough providing an area of 50 cm $animal^{-1}$, where the animals had access to the supplement, and each experimental unit was provided with a water trough to ensure a continuous water supply.

Table 2. Number of animals per supplementation strategy.

Groups	Years	
	2020	2023
Mineral	15	12
0.5% of LW	21	15
1.8% of LW	27	21

LW: live weight; 0.5% of LW: protein–energy supplementation at 0.5% of LW; 1.8% of LW: protein–energy supplementation at 1.8% of LW.

2.3. Measurement of Parameters Considered in the Model

During the entire grazing period, the animals were weighed at the beginning and end of the trial with intermediate weighing every 28 days. Before each weighing, animals were subjected to a 12 h fasting period. During the weighing procedure, in vivo ultrasound readings were also performed to assess body composition (obtaining one measurement per characteristic per animal). After restraining the animal in the chute, the ultrasound application site was identified by palpation and properly cleaned to ensure better image resolution. The images were obtained between the 12th and 13th ribs, in the Longissimus thoracis et lumborum muscle, allowing the measurement of SFT (mm) and REA (cm^2), as well as REA adjusted for 100 kg of BW (REA100, cm^2 100 kg^{-1}), as illustrated in Figure 1.

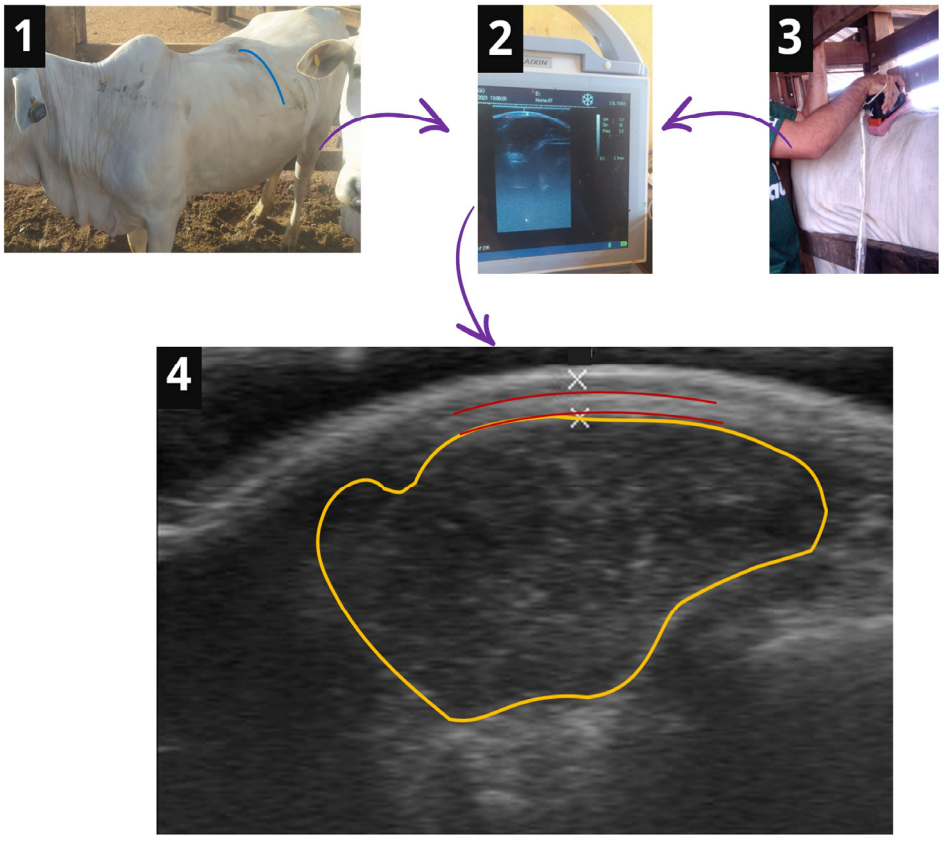

Figure 1. Steps to perform the reading of ribeye area (REA) and subcutaneous fat thickness (SFT): (**1**)—Image positioning: The blue line indicates the boundary for obtaining images, positioned between the 12th and 13th ribs. (**2**)—Processing monitor: Used for viewing and processing the obtained images. (**3**)—Probe in the correct position: The probe must be properly positioned for efficient scanning of the desired areas. (**4**)—Visual highlights: Red lines with markers "×" indicate the SFT, while the yellow contour outlines the REA.

To obtain this information, the following procedures were adopted: REA and SFT images were captured using the KX5600 Full Digital B-Mode Ultrasound Scanner (Xuzhou, Jiangsu, China), equipped with a 17.2 cm linear probe and a 3.5 MHz frequency. To ensure the proper coupling of the transducer to the animal's body, a silicone couplant combined with vegetable oil was applied to the back, contributing to image clarity. Subsequently, the images were saved and analyzed manually by an expert using ImageJ software, version 1.52u.

In the software used, the images for identifying REA and SFT were analyzed following the appropriate parameters. REA was delineated through precise manual demarcations, respecting the anatomical boundaries of the muscles visible in the ultrasound, such as the Quadratus lumborum, Musculus intercostalis, Longissimus costarum, and Spinalis dorsi. The manual execution of these markings was essential to ensure the accuracy and standardization of the measurements, guaranteeing the reliability of the obtained results. Subsequently, the data obtained from each animal were recorded in electronic spreadsheets.

After weighing and ultrasound scanning, all animals were sent to a commercial slaughterhouse under State Sanitary Inspection (Iporá, Brazil). At the time of slaughter, HCW (kg) and CY (%) were recorded, calculated based on the LW obtained at the end of the experimental grazing period.

2.4. Statistical Analysis

All data analysis procedures were performed using R software, version 4.4.0 [17]. Initially, data from animals with outliers or missing information were removed, resulting in a final dataset of 106 observations (each observation represents one animal).

The data obtained for the evaluated traits were expressed as means for each experimental group. The complete dataset was presented in terms of mean, maximum, minimum, and standard deviation.

Before performing the regression analyses, 70% of the data from each evaluated group were randomly selected for model development, while the remaining 30% were reserved for the validation process. To predict CY and HCW, four multiple regressions were tested ($Y_{ij} = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_2 \ldots \beta_n \times X_n + \varepsilon_{ij}$). In the models used, Y_{ij} represents the observed values of CY or HCW; β_0 is the equation intercept; $\beta_1, \beta_2 \ldots \beta_n$ are the equation parameters; $X_1, X_2 \ldots X_n$ are the predictor variables (SFT, LW, SL, REA e REA100); and ε_{ij} represents the random error for a specific observation *ij*. The lm function in R [17] was used to estimate the equation parameters. All equations included measurements obtained in vivo ultrasound measures (SFT, REA, and REA100). However, three equations also evaluated the effect of additional predictors such as LW and supplementation level (SL), the latter defined based on the proportion of LW: 0.03% for SM, 0.5% for 0.5 LW, and 1.8% for 1.8 LW.

Predictor variables were distributed across the equations as follows: Equations (1) and (5)—SFT, LW, SL, REA, and REA100; Equations (2) and (6)—SFT, SL, REA, and REA100; Equations (3) and (7)—SFT, LW, REA, and REA100; Equations (4) and (8)—SFT, REA, and REA100. This organization allowed for the evaluation of the isolated and combined impact of these variables on the prediction of the studied responses.

In the validation stage, the models generated with 70% of the database were applied to the remaining 30% (validation data), using the ultrasound, CY, and HCW measurements from this set for evaluation. Additionally, the coefficient of determination (R^2) and root mean square error (RMSE) were calculated for all equations. During the validation process, observed and predicted results were plotted as graphs, and the practical utility of the prediction models was assessed using the concordance correlation coefficient (CCC) calculated with the R package DescTools [18]. When the CCC is between 0.21 and 0.40, it indicates

a reasonable predictive capacity; between 0.41 and 0.60, it indicates moderate predictive capacity; between 0.61 and 0.80, it indicates substantial predictive capacity; and between 0.81 and 1.00, it indicates precise predictive capacity [19].

3. Results

3.1. Descriptive Analysis of Parameters Used in the Models

The 1.8% LW level exhibited high mean values for HCW and CY (Table 3). Likewise, this supplementation level also stood out in ultrasound characteristics (SFT, REA, and REA100).

Table 3. Descriptive analysis of the database from Nellore heifers under different supplementation strategies in crop–livestock integrated production systems.

Item	N	SFT (mm)	LW (kg)	HCW (kg)	CY (%)	REA (cm^2)	REA100 (cm^2 100 kg^{-1})
		Means followed by the standard error for each experimental group					
Mineral	24	4.28 ± 0.129	357.29 ± 5.51	174.21 ± 2.36	48.83 ± 0.405	53.71 ± 2.00	15.06 ± 0.554
0.5 of LW	35	4.63 ± 0.087	355.00 ± 5.48	178.74 ± 2.44	50.41 ± 0.255	56.18 ± 1.84	15.84 ± 0.471
1.8 of LW	47	4.82 ± 0.105	358.32 ± 4.44	188.24 ± 2.13	52.62 ± 0.359	57.73 ± 1.15	16.18 ± 0.344
Minimum	106	2.60	304.00	154.50	42.92	36.08	10.49
Mean	106	4.63	356.99	181.93	51.04	56.36	15.83
Maximum	106	6.60	450.00	230.00	58.22	82.09	22.30
Standard deviation	106	0.673	30.43	15.10	2.58	9.52	2.62

N: number of observations. SFT: subcutaneous fat thickness. LW: live weight. HCW: hot carcass weight. CY: carcass yield. REA: ribeye area. REA100: ribeye area per 100 kg of body weight; 0.5 of LW: protein–energy supplementation at 0.5% of LW; 1.8 LW: protein–energy supplementation at 1.8% of LW.

3.2. Prediction Equations for Carcass Yield

In the evaluation of CY prediction equations (Table 4), the multiple regression that considers all predictor variables (Equation (1)) showed the highest R^2 and the lowest RMSE compared to the other equations used. Excluding LW (Equation (2)) promoted a reduction in R^2.

Table 4. Prediction equations for carcass yield (%) of Nellore heifers under different supplementation strategies in integrated production systems.

	Equation	*p*-Value	R^2	RMSE
Equation (1)	$CY = 22.30 + 0.317 \times SFT + 0.063 \times LW + 1.87 \times SL - 0.557 \times REA + 2.15 \times REA100$	<0.001	0.557	2.29
Equation (2)	$CY = 44.98 + 0.220 \times SFT + 1.95 \times SL - 0.161 \times REA + 0.769 \times REA100$	<0.001	0.544	2.32
Equation (3)	$CY = 2.59 + 1.18 \times SFT + 0.106 \times LW - 0.760 \times REA + 3.02 \times REA100$	<0.001	0.355	2.45
Equation (4)	$CY = 40.31 + 1.07 \times SFT - 0.091 \times REA + 0.686 \times REA100$	<0.001	0.319	2.50

CY: carcass yield. SFT: subcutaneous fat thickness. LW: live weight. SL: supplement level based on the proportion of live weight. REA: ribeye area. REA100: ribeye area per 100 kg of body weight. *p*-value: probability of a significant effect. R^2: coefficient of determination. RMSE: root mean square error.

3.3. Prediction Equations for Hot Carcass Weight

The multiple regression used to predict HCW, including all predictor variables (Equation (5)), resulted in the highest R^2 value (Table 5). When only the ultrasound measurements are used (Equation (8)), the model shows a reduction in R^2 and an increase in RMSE.

Table 5. Prediction equations for hot carcass weight (kg) of Nellore heifers under different supplementation strategies in integrated production systems.

	Equation	*p*-Value	R^2	RMSE
Equation (5)	HCW = −70.34 + 1.05 × SFT + 0.649 × LW + 6.91 × SL − 1.46 × REA + 5.76 × REA100	<0.001	0.820	17.68
Equation (6)	HCW = 162.04 + 0.060 × SFT + 7.73 × SL + 2.59 × REA − 8.48 × REA100	<0.001	0.780	17.37
Equation (7)	HCW = −142.85 + 4.23 × SFT + 0.807 × LW − 2.20 × REA + 8.94 × REA100	<0.001	0.737	18.36
Equation (8)	HCW = 143.60 + 3.44 × SFT + 2.87 × REA − 8.80 × REA100	<0.001	0.673	18.11

HCW: hot carcass weight. SFT: subcutaneous fat thickness. LW: live weight. SL: supplement level based on the proportion of live weight. REA: ribeye area. REA100: ribeye area per 100 kg of body weight. *p*-value: probability of a significant effect. R^2: coefficient of determination. RMSE: root mean square error.

3.4. Validation of the Prediction Equations for Carcass Yield and Weight

The equations used to predict CY showed that the multiple regression involving all predictor variables (Equation (1)) and the equation excluding LW (Equation (2)) presented a CCC indicating low predictive capacity (Table 6). When examining the relationship between the points of the predicted and observed results, it is observed that they are not close, indicating low accuracy in the CY prediction estimate (Figure 2).

Table 6. Concordance correlation coefficient of the prediction equations for carcass yield and hot carcass weight of Nellore heifers under different supplementation strategies in integrated production systems.

Items	CY	HCW
Equations (1) and (5)	0.629	0.904
Equations (2) and (6)	0.621	0.859
Equations (3) and (7)	0.303	0.674
Equations (4) and (8)	0.254	0.801

CY: carcass yield (Equations (1), (2), (3) and (4)). HCW: hot carcass weight (Equations (5), (6), (7) and (8)).

When measuring the CCC of the predicted and observed data for HCW, it is observed that Equations (5), (6) and (8) generate estimated values with high accuracy (Table 6). Simultaneously, the deviation points between the predicted and observed data (Figure 3A,B,D) are close to the observed results in all four equations, reinforcing the high accuracy of the generated estimates. When analyzing Equation (7), the removal of the SL effect reduces the CCC value.

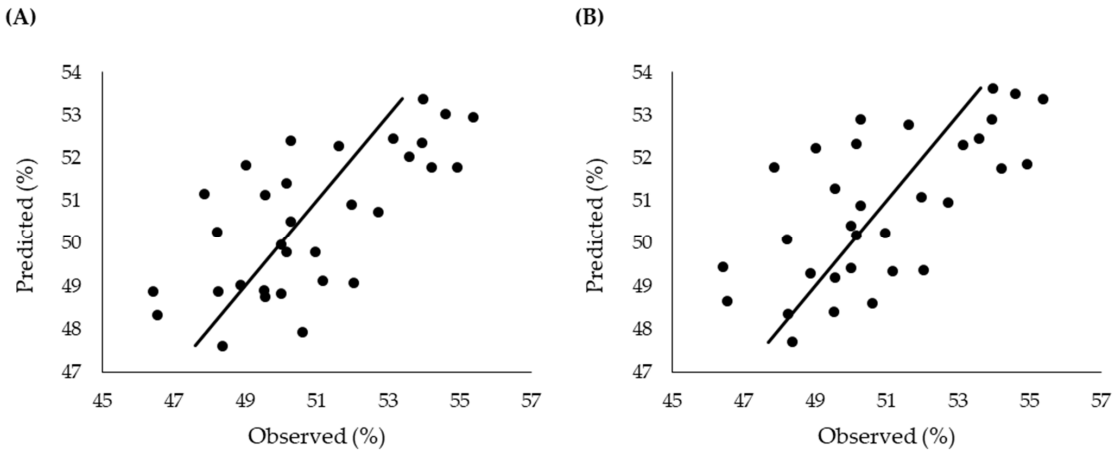

Figure 2. *Cont.*

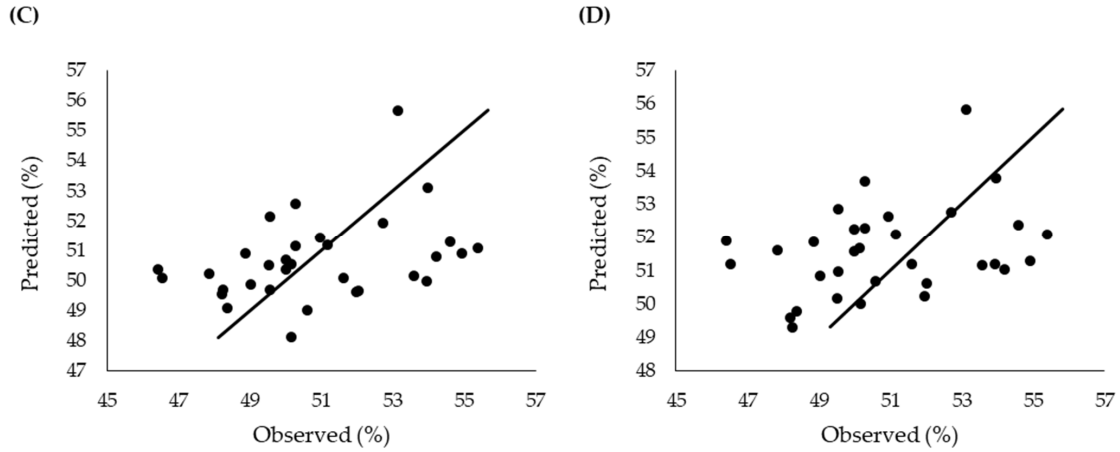

Figure 2. Relationship between predicted and observed results for carcass yield of Nellore heifers under different supplementation strategies in integrated production systems. Predicted values are represented by the solid line, while observed data are represented by black circles. (**A**): Equation (1); (**B**): Equation (2); (**C**): Equation (3); (**D**): Equation (4).

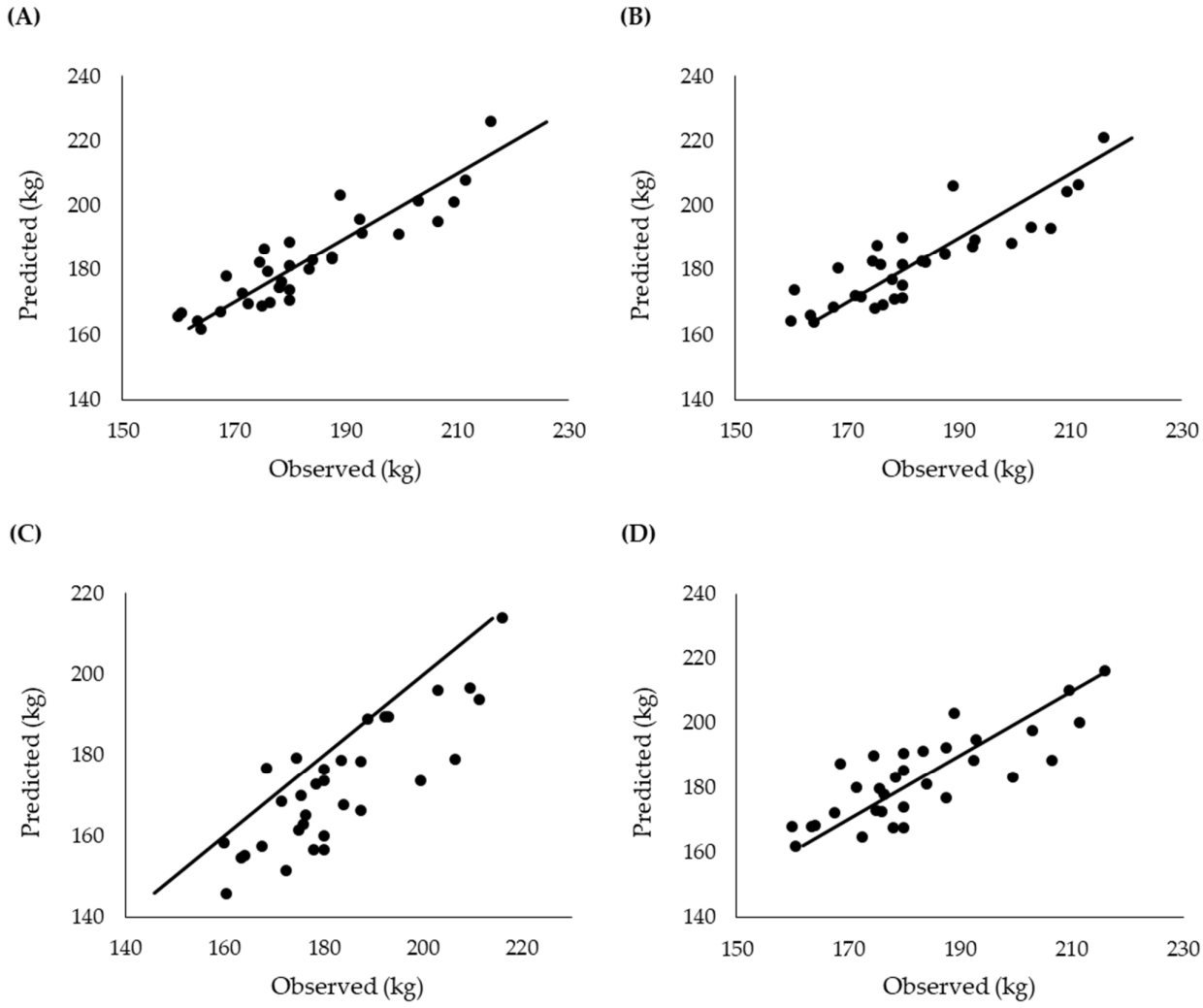

Figure 3. Relationship between predicted and observed results for the hot carcass weight of Nellore heifers under different supplementation strategies in integrated production systems. Predicted values are represented by the solid line, while observed data are represented by black circles. (**A**): Equation (5); (**B**): Equation (6); (**C**): Equation (7); (**D**): Equation (8).

4. Discussion

Pasture-based animal production in tropical climates faces natural limitations of forage resources, as the predominant crops are C4 plants, which have low levels of minerals, proteins, and energy in their chemical composition. To enhance animal production in grazing environments, beef cattle producers use supplements (mineral and protein–energy) to address pasture deficiencies [15–20].

In this context, when predicting the characteristics of pasture-based animal production, it is important to include management-related measures as a source of variation or predictor variable in the prediction equations, as was the case in this study, which considered the level of supplement used for each experimental scenario. In this scenario, the amount of supplement provided plays a crucial role, directly influencing productive outcomes. When offered at high levels, such as 1.5% to 1.8% of LW, a significant improvement in carcass quality was seen as expected [21,22].

The use of SFT, REA, and REA100 measurements to estimate CY resulted in equations with R^2 ranging from low to moderate. Additionally, the low accuracy of CY equations based on in vivo ultrasound measurements may be associated with the weak to moderate correlations between variables, which reduces the effectiveness of ultrasound-derived traits as robust predictors.

Another relevant factor concerns pre-slaughter procedures, such as the fasting period for solids and liquids, which can influence carcass components [23], compromising the accuracy of the generated equations. Additionally, the inclusion of other in vivo variables, such as LW, and management conditions represented by SL did not significantly contribute to generating more accurate and robust predictive models for estimating CY.

For HCW equations, it was observed that even with the removal of LW and SL, the use of SFT, REA, and REA100 variables resulted in models with R^2 ranging from moderate to high (Equation (8)). Similarly, CCC values indicate a strong association between observed and predicted values, reinforcing the reliability and robustness of the models generated for different variable combinations. According to Tedeschi [24] and Buonaiuto et al. [25], CCC values above 0.800 indicate excellent accuracy.

When using prediction equations, field technicians and agricultural producers should consider the RMSE. In CY models, where R^2 values range from weak to moderate, RMSE values remain relatively stable across equations. This suggests that the predictive performance of CY models may be limited, especially if RMSE represents a large proportion of the observed variability. In HCW equations, the inclusion of all predictor variables increases R^2 and reduces RMSE, indicating an improvement in predictive accuracy.

The performance observed in this study indicates that the proposed HCW equations have potential for practical applications, such as estimating carcass weight before sending animals for slaughter or even for animals that will be used for reproduction. This prediction allows beef cattle producers to estimate in advance the amount of carcass that will be produced, generating more accurate expectations regarding financial returns. In this way, it is possible to estimate net profit and assess the mitigation of fixed and variable costs. Additionally, the equations generated for HCW offer cattle farmers greater flexibility in deciding the ideal time for marketing the animals, as they will be able to estimate the amount of carcass produced by each animal before slaughter.

Another important aspect of using ultrasound images is the speed of obtaining information, ensuring that routine herd management activities are not compromised. In addition, SFT measurement can also assist in verifying carcass quality, as it allows for inferring carcass finishing and checking compliance with slaughterhouse standards.

As a preliminary result, the use of ultrasound images (SFT, REA, and REA100) demonstrates high potential as a predictive variable for estimating HCW in Nelore females man-

aged in pastures established in integrated systems. However, further studies are needed to validate the applicability of these equations in commercial herds, considering the effect of sexual condition and genetic group. Females, intact males, and crossbred animals between *Bos taurus* and *Bos taurus* indicus exhibit significant variations in carcass conformation and weight [26].

For the efficient application of the equations presented in this study, it is essential to consider environmental factors, as the evaluated models include management variables such as the amount of supplement provided, regardless of the source used (mineral or protein–energy). Additionally, the type of pasture should also be taken into account. In the present study, data were obtained in a crop–livestock integration system, where cultivated pastures have higher nutritional value compared to monoculture pastures cultivated in the offseason in tropical climate regions. Therefore, the generated models, especially those aimed at determining HCW, are specific to this production system. Under conventional conditions, with tropical monoculture pastures during the offseason, even with supplementation, it would be unlikely to form a similar dataset for animals managed under grazing conditions.

5. Conclusions

The models generated for CY do not exhibit practical applicability for Nellore heifers raised in integrated production systems. On the other hand, when analyzing the equation generated to estimate HCW using the validation model, it not only demonstrated high practical applicability but also produced precise and accurate predictions. Based on this, it is possible to determine HCW in live beef cows raised on pastures in integrated systems using ultrasound measurements, LW, and nutritional management (SL), which can aid in the decision-making process for marketing animals to slaughterhouses.

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Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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References

1. Castillo-Sanchez, L.E.; Canul-Solís, J.R.; Pozo-Leyva, D.; Camacho-Perez, E.; Lugo-Quintal, J.M.; Gurgel, A.L.C.; Santos, G.T.; Ítavo, L.C.V.; Chay-Canul, A.J. Prediction of Live Weight in Beef Heifers Using a Body Volume Formula. *Arq. Bras. Med. Vet. Zootec.* **2022**, *74*, 1127–1133. [CrossRef]
2. Gurgel, A.L.C.; Dos Santos Difante, G.; Neto, J.V.E.; Ítavo, L.C.V.; Ítavo, C.; Costa, C.M.; Dos Santos, G.T.; Chay-Canul, A.J. Prediction of weaning weight in Santa inês lambs using the body volume formula. *Trop. Anim. Health Prod.* **2022**, *55*, 29. [CrossRef]
3. Camacho-Pérez, E.; Lugo-Quintal, J.M.; Tirink, C.; Aguilar-Quiñonez, J.A.; Gastelum-Delgado, M.A.; Lee-Rangel, H.A.; Roque-Jiménez, J.A.; Garcia-Herrera, R.A.; Chay-Canul, A.J. Predicting carcass tissue composition in Blackbelly sheep using ultrasound measurements and machine learning methods. *Trop. Anim. Health Prod.* **2023**, *55*, 300. [CrossRef] [PubMed]
4. Silva Neto, J.B.; Peripolli, E.; da Costa e Silva, E.V.; Espigolan, R.; Neira, J.D.R.; Schettini, G.; Costa Filho, L.C.C.; Barbosa, F.B.; Macedo, G.G.; Brunes, L.C.; et al. Genetic correlation estimates between age at puberty and growth, reproductive, and carcass traits in young Nelore bulls. *Livest. Sci.* **2020**, *241*, 104266. [CrossRef]
5. Pereira, L.S.; Brunes, L.C.; Baldi, F.; Carmo, A.S.; Soares, B.B.; Magnabosco, V.; Eifert, E.C.; Magnabosco, C.U. Genetic association between feed efficiency, growth, scrotal circumference, and carcass traits in Guzerat cattle. *Trop. Anim. Health Prod.* **2023**, *55*, 132. [CrossRef]
6. Zuim, D.M.; Bignardi, A.B.; Pereira, R.J.; Boligon, A.A.; Piccoli, M.L.; Roso, V.M.; Carvalheiro, R.; Santana, M.L. Genotype by Environment Interaction in Ultrasound Carcass Traits and Growth of Hereford and Braford Cattle. *Cienc. Rural* **2024**, *54*, e20230198.
7. Marestone, B.S.; Torres Junior, R.A.A.; Silva, L.O.C.; Menezes, G.R.O.; Muniz, C.A.S.D.; Ribeiro, E.L.A. Genetic Parameters for Traditional and Novel Ultrasound Carcass Traits in Nellore Cattle. *Trop. Anim. Health Prod.* **2022**, *54*, 34. [CrossRef]
8. Gurgel, A.L.C.; Difante, G.d.S.; Emerenciano Neto, J.V.; Araújo, C.G.F.; Costa, M.G.; Ítavo, L.C.V.; Araujo, I.M.M.d.; Costa, C.M.; Santana, J.C.S.; Ítavo, C.C.B.F.; et al. Prediction of Carcass Traits of Santa Inês Lambs Finished in Tropical Pastures through Biometric Measurements. *Animals* **2021**, *11*, 2329. [CrossRef]
9. Montoya-Santiyanes, L.A.; Chay-Canul, A.J.; Camacho-Pérez, E.; Rodríguez-Abreo, O. A novel model for estimating the body weight of Pelibuey sheep through Gray Wolf Optimizer algorithm. *J. Appl. Anim. Res.* **2022**, *50*, 635–642. [CrossRef]
10. Moura, J.R.F.; Ítavo, L.C.V.; Gurgel, A.L.C.; Ítavo, C.C.B.F.; de Nadai Bonin Gomes, M.; Longhini, V.Z.; Chay-Canul, A.J. Prediction models of carcass characteristics from non-castrated Nellore cattle finished in the feedlot system under tropical conditions. *Trop. Anim. Health Prod.* **2023**, *55*, 427. [CrossRef]
11. Rodrigues, V.C.; de Andrade, I.F.; de Freitas, R.T.; Bressan, M.C.; Teixeira, J.C. Rendimentos Do Abate E Carcaça De Bovinos E Bubalinos Castrados E Inteiros. *R. Bras. Zootec.* **2003**, *32*, 663–671. [CrossRef]
12. Niwa, M.V.G.; Ítavo, L.C.V.; Ítavo, L.C.V.; Ítavo, C.C.B.F.; Gomes, M.N.B.; Longhini, V.Z.; Cunha, C.S.; Dias, A.M.; Difante, G.S.; Vedovatto, M.; et al. Fiber sources on performance and carcass and meat characteristics of feedlot Nellore young bulls. *J. Anim. Physiol. Anim. Nutr.* **2024**, *109*, 1–9.
13. Alves, K.d.A.; de Lima, J.A.M.; Costa, M.R.G.F.; da Silva, T.C.; Brito, C.d.L.; Gomes, M.L.R.; Pereira Filho, J.M.; de Oliveira, J.P.F.; do Nascimento, R.R.; Bezerra, L.R. Effect of Replacing Corn with Cactus Pear on the Performance and Carcass Traits and Meat Quality of Feedlot Finished Lambs. *Ciênc. Anim. Bras.* **2023**, *24*, e-75322E.
14. Detmann, E.; Valente, E.E.L.; Batista, E.D.; Huhtanen, P. An evaluation of the erformance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. *Livest. Sci.* **2014**, *162*, 141–153. [CrossRef]
15. Silva, C.S.; Euclides, V.P.B.; Montagner, D.B.; Araújo, I.M.M.; Difante, G.S.; Orrico, M.A.P., Jr. Effects of different supplements on performance of steers grazing Mombaça guinea grass (*Megathyrsus maximus*) during the dry period. *Trop. Grassl. Forrajes Trop.* **2022**, *10*, 44–51. [CrossRef]
16. Cardoso, M.R.D.; Marcuzzo, F.F.N.; Barros, J.R. Classificação Climática de Köppen-Geiger para o Estado de Goiás e o Distrito Federal. *ACTA Geográfica* **2014**, *8*, 40–55. [CrossRef]
17. R Core Team. R: A Language and Environment for Statistical Computing. 2024. Available online: https://www.R-project.org/ (accessed on 10 September 2024).
18. Signorell, A.; Aho, K.; Alfons, A.; Anderegg, N.; Aragon, T.; Arppe, A.; Baddeley, A.; Barton, K.; Bolker, B.; Borchers, H.W. DescTools: Tools for Descriptive Statistics. R Package Version 0.99.44. Available online: https://cran.r-project.org/package=DescTools (accessed on 25 October 2024).
19. Lin, L.K. A concordance correlation coefficient to evaluate reproducibility. *Biometrics* **1989**, *45*, 255–268. [CrossRef]
20. Bitencourt, L.P.; Montagner, D.B.; Marino, C.T.; Difante, G.D.S.; Euclides, V.P.B.; Neves, A.P.; Gomes, R.D.C. Short-term protein-energy supplementation at weaning or in the transition of dry-rainy season on performance of Nellore calves kept on Mombaça or Marandu grasses. *Rev. Bras. Zootec.* **2023**, *52*, e20210192. [CrossRef]
21. Silva, R.d.M.; Pereira Filho, J.M.; da Silva, A.L.N.; Cezar, M.F.; Silva, A.M.d.A.; Oliveira, N.S. The Effect of Supplementation on the Tissue Composition of the Commercial Cuts of Cross-bred F1 (boer × SPRD) Finished in Native Pasture. *R. Bras. Zootec.* **2010**, *39*, 1353–1358. [CrossRef]

22. Menezes, B.M.; da Silva, D.G.; de Menezes Bisneto, B.M.; Bettencourt, A.F.; Pias, G.M.; dos Santos Pinho, A.P.; Isola, J.V.V.; Baungratz, A.R.; Paulo Macedo, V. Carcass and meat characteristics of Dorper x Santa Ines lambs finished in pasture, silvopastoral system, and feedlot. *Semin. Ciênc. Agrár.* **2021**, *42*, 4039–4058. [CrossRef]
23. Schettino, D.N.; Cançado, S.V.; Baião, N.C.; Lara, L.J.C.; Figueiredo, T.C.; Santos, W.L.M. Efeito Do Período De Jejum Pré-abate Sobre O Rendimento De Carcaça De Frango De Corte. *Arq. Bras. Med. Vet. Zootec.* **2006**, *58*, 918–924. [CrossRef]
24. Tedeschi, L.O. Assessment of the adequacy of mathematical models. *Agric. Syst.* **2006**, *89*, 225–247. [CrossRef]
25. Buonaiuto, G.; Cavallini, D.; Mammi, L.M.E.; Ghiaccio, F.; Alberto Palmonari, A.; Formigoni, A.; Visentin, G. The accuracy of NIRS in predicting chemical composition and fibre digestibility of hay-based total mixed rations. *Ital. J. Anim. Sci.* **2021**, *20*, 1730–1739. [CrossRef]
26. UFV, DZO. *BR-CORTE: Tabela Brasileira de Exigências Nutricionais*, 3rd ed.; UFV, DZO: Viçosa, Brazil, 2016; Volume xviii, p. 327.

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