Prediction of pasture intake by beef cattle in tropical conditions

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Abstract
Forage intake is the most important factor for beef cattle raised on pasture, as it is the basis of the diet. Thus, knowing the variables that affect this parameter can help supplementation programs. Thus, a meta-analytic study was conducted to develop and evaluate models for the prediction of pasture dry matter intake (DMIpasture) by beef cattle in tropical conditions. Eight hundred four individual observations of DMIpasture were used, taken from 23 studies through analysis of mixed models, including the study as a random effect. To evaluate the accuracy and precision of the new models proposed as well as for the models of Azevedo et al. (2016) and Minson and McDonald (1987), an independent databank with 87 means from treatments of 21 experiments (n = 888 animals) was used. Three prediction models were adjusted: model I (animal information), model II (animal information + supplement), and model III (animal information + supplement + pasture). The proposed models presented similarity for the average square root of the prediction error. The inclusion of the predictive variables for supplementation (supplement dry matter intake − DMIsupplement − % of the body weight and crude protein intake through supplement) with the variables for the animal (BW0.75 and average daily gain) and of the pasture (% of crude protein) in model III improved accuracy and precision and provided higher determination and correlation coefficients, and agreement than the other proposed models. Similarly, it was found to be more accurate and precise than the equations of Azevêdo et al. (2016) and Minson and McDonald (1987), which presented lower precision. The DMIpasture for beef cattle in tropical conditions is more accurate and precise when the information for the animal, supplement, and pasture is included.

Keywords Meta-analysis · Modeling · Tropical pasture · Supplementation

Introduction
Production systems in pasture present difficulties in terms of the formulation of diet due to the complexity of predicting pasture intake and consequently, the quality of the material consumed. In this sense, the formulation of these diets has occurred empirically. According to Azevêdo et al. (2016), the greater part of the nutrients in the beef cattle diet are used to supply the requirements of maintenance while a small portion contributes toward weight gain. Therefore, small negative changes in feed intake caused interference in the efficiency of production processes with a consequent reduction in growth rates and reproductive efficiency.

Determining the DMIpasture precisely is not an easy task. Coleman et al. (1999) affirms that intake is altered as a function of both the quality and the physical characteristics of the forage, as well as due to the physiological state of the animal. In addition to these related factors, intake by cattle can be influenced by the use, or not, of dietary supplements,
varying according to the nutritional level and composition of the available food. If a given model does not adequately estimate the DMI$_{\text{pasture}}$ of an animal, these factors can compromise the productive process, leading to liabilities for the producer and even rendering the agricultural activity unfeasible, as the prediction of consumption is an essential prerequisite for productive and economic responses to be correctly estimated and imposed (Souza et al., 2014).

However, most models to estimate the DMI of beef cattle such as the National Research Council (NRC), Agricultural and Food Research Council (AFRC), Cornell Net Carbohydrate and Protein System (CNCPS), and BR-Corte (https://brcorte.com.br/livro2016en) are adjusted with data from animals in confinement using variables related to the animal, such as the body weight (BW) and average daily gain (ADG). However, the variables that influence intake in systems based on pasture are more heterogeneous than in confinement, which explains the need to develop new models to be applied for animals raised on pasture and to include the variables related to the animal and their diet. According to Poppi (1996), the adjustment of prediction equations using food data can improve the accuracy of predictions.

Therefore, our hypothesis is that more complete equations, which include variables associated with the animal, supplements and pasture, better predict the DMI$_{\text{pasture}}$. As such, we sought to develop and evaluate predictive models for DMI$_{\text{pasture}}$ for beef cattle.

**Material and methods**

**Data bank and development of models**

The dataset used to formulate the predictive models was obtained from individual observations reported in 23 studies carried out under tropical conditions between 2006 and 2019, totaling 104 means of treatment that represented 804 sample animals (growth or finishing). The criteria adopted for inclusion of data in the set were as follows: (1) experiments carried out under tropical conditions; (2) cattle fed using different feeding management systems and different production levels; (3) individual measures of DMI; (4) estimate of DMI$_{\text{pasture}}$ using external and internal markers; (5) adequate description of the animals: BW, DMI, ADG, experimental diets: ingredients and chemical composition. The data used were from Zebu cattle (male and female).

The experiments included in the data bank for the elaboration of the models were conducted at different times of the year (dry, dry–wet transition, wet and wet-dry transition). They were carried out using a completely randomized design. The pastures were divided into different paddocks with watering fountain and covered feeders, and a wide variety of treatments, using different supplement amounts and compositions.

The supplementation of the animals used in the database was standardized as a function of the percentage of BW ranging from 0.25 to 1.41% of the BW, provided daily once a day, with the leftovers being weighed to calculate the daily intake. The descriptive statistics (average, median, maximum, and standard deviation) for all the variables used in the development of the predictive equations for DMI$_{\text{pasture}}$ are found in Table 1.

For the inclusion of the independent variables into the model, the Pearson correlation coefficient (Table 3) was determined. For the variable to remain in the model, the procedure of elimination of non-significant independent variables ($P > 0.05$) was applied, with the reduced models that best explained the evaluated dependent variable being kept (Neter et al., 1990). The observations that presented studentized residuals larger than 2.5 or smaller than −2.5 were discarded from the data bank used for the formulation of the models.

The development of the proposed prediction models was adjusted through analysis of mixed models (Littell et al., 2006), including the study as a random effect and the factors associated with animal, supplement, and pasture as fixed effects. The software RStudio version 3.6.2 was used to perform the analyses. This adjustment of the models appears as a tool to express the trend in the behavior of DMI$_{\text{pasture}}$ (dependent variable) in relation to independent variables. It basically works like trying to get a function from data from two or more variables.

### Table 1 Descriptive statistics of the data set used to develop models to predict DMI$_{\text{pasture}}$ by beef cattle under tropical conditions

| Item                  | Mean    | Median | Minimum | Maximum | SD    |
|-----------------------|---------|--------|---------|---------|-------|
| BW, kg                | 294.50  | 281.8  | 80.0    | 590.0   | 99.3  |
| BW$^{0.73}$, kg       | 70.41   | 68.67  | 26.75   | 119.71  | 18.2  |
| ADG, kg/day           | 0.40    | 0.40   | −0.22   | 1.11    | 0.24  |
| Intake                |         |        |         |         |       |
| DMI$_{\text{total}}$, kg/day | 5.70    | 5.42   | 1.67    | 12.03   | 2.04  |
| DMI$_{\text{pasture}}$, kg/day | 4.99    | 4.70   | 1.35    | 11.52   | 1.90  |
| CPI$_{\text{supplement}}$, kg/day | 0.21    | 0.19   | 0.00    | 1.19    | 0.17  |
| DMI$_{\text{supplement}}$, kg/day | 0.70    | 0.62   | 0.00    | 3.66    | 0.59  |
| DMI$_{\text{supplement}}$, % BW | 0.25    | 0.23   | 0.00    | 1.41    | 0.13  |
| Pasture (%)           | 8.15    | 8.10   | 4.23    | 12.66   | 2.15  |
| CP                    | 64.65   | 65.00  | 59.54   | 73.37   | 3.37  |

$n^1$ number individual observations, $SD$ standard deviation
**Evaluation in the models**

To evaluate the accuracy and precision of the proposed models, as well as for the models of Azevêdo et al. (2016) (https://br.corte.com.br/livro2016en) and Minson and McDonald (1987), an independent data bank was used, with 87 observations (means of treatments) originating from 21 experiments carried out under tropical condition (n = 888 animals) composed of male and female (Zebu cattle), following the same selection criteria for data selection to adjust the equations (Table 2).

A literature research was carried out using the data bank of (Web of Science https://login.webofknowledge.com), PubMed (https://www.ncbi.nlm.nih.gov/pubmed), Google Scholar (http://www.scholar.google.com), Scielo (https://scielo.org/), using search terms including the following: “nutritional assessment,” “beef cattle,” “dry matter intake,” “tropical pasture,” “grazing supplementation,” “supplementation level.”

The evaluation of accuracy and precision of the models developed and of those already in the available literature (Table 3) were realized by way of analyses of simple linear regression of the observed (Y) and predicted (X) values, using the following procedures: graphic analysis of the observed versus predicted values, coefficient of determination, MSPE (mean square prediction error), RMSPE (root MSPE), and CCC (concordance correlation coefficient) analyses using the Model Evaluation System (College Station, TX; http://nutritionmodels.tamu.edu/mes.html), as described by Tedeschi (2006).

The MSPE was broken down into three sources of error: (1) errors due to bias, the most accurate model is the one with an average bias close to the value 0; (2) errors due to the deviation of the regression between the observed and predicted values being different from 1; and (3) random error. The random error represents the error that is unexplained by the model (Bibby and Toutenburg, 1977). The MSPE is frequently used to verify the accuracy of the model. According to Wilks (2006), by elevating the individual differences to the square root, it always becomes positive, where MSPE = 0 indicates a perfect prediction.

In addition to the MSPE, RMSPE is commonly used to express the accuracy of the results, with the advantage that it presents values for the error in the same dimensions of the analyzed variable. The values were expressed in kg/day and in % of the observed DMI_pasture and their confidence interval by error type I of 5%, according to the proposal of Vieira (2017).

The CCC was divided into correlation coefficient, indicating the ρ and the factor of bias correction, indicating the

### Table 2 Descriptive statistics of the data set used to evaluate models to predict DMI_pasture by beef cattle under tropical conditions

| Item           | Mean  | Median | Minimum | Maximum | SD   |
|----------------|-------|--------|---------|---------|------|
| BW, kg         | 268.1 | 255.40 | 125.00  | 448.5   | 70.46|
| BW<sup>0.75</sup>, kg | 65.83 | 63.89  | 37.55   | 97.46   | 12.93|
| ADG, kg/day    | 0.53  | 0.52   | 0.09    | 0.97    | 0.20 |
| Intake         |       |        |         |         |      |
| DMI<sub>total</sub>, kg/day | 5.95  | 5.75   | 3.02    | 9.91    | 1.74 |
| DMI<sub>pasture</sub>, kg/day | 4.81  | 5.01   | 1.44    | 9.27    | 1.70 |
| CPI<sub>supplement</sub>, kg/day | 0.22  | 0.20   | 0.00    | 0.75    | 0.18 |
| DMI<sub>supplement</sub>, kg/day | 0.88  | 0.82   | 0.00    | 4.08    | 0.82 |
| DMIBW<sub>supplement</sub>—% | 0.32  | 0.30   | 0.00    | 1.55    | 0.27 |
| DMIBW<sub>supplement</sub>—kg/d  |       |        |         |         |      |
| Pasture (%)    |       |        |         |         |      |
| CP             | 8.14  | 7.9    | 4.3     | 13.3    | 2.26 |
| NDF            | 64.57 | 65.20  | 52.13   | 84.30   | 8.87 |

<sup>n</sup> treatment mean, SD standard deviation

### Table 3 Pearson’s correlation coefficients for the relationships between the explanatory variables in the dataset used to develop the models

| Item           | BW<sup>0.75</sup> | ADG    | DMI<sub>total</sub> | DMI<sub>pasture</sub> | CPI<sub>supplement</sub> | DMI<sub>supplement</sub> | DMIBW<sub>supplement</sub> | CP<sub>pasture</sub> | NDF<sub>pasture</sub> |
|----------------|-------------------|--------|---------------------|-----------------------|--------------------------|--------------------------|-------------------------|-------------------|---------------------|
| BW, kg         | 0.990*            | -0.125 | 0.752*              | 0.747*                | 0.161                    | 0.201*                   | -0.137                  | -0.346*           | 0.327*              |
| BW<sup>0.75</sup>, kg | -0.131           | 0.756* | 0.749*              | 0.168                 | 0.207*                   | -0.135                   | -0.345*                  | 0.327*            |                    |
| ADG, kg/day    |                   |        | 0.086               | 0.036                 | 0.177*                   | 0.181*                   | 0.220*                  | 0.378*            | -0.187*            |
| DMI<sub>total</sub>, kg/day | 0.957*         | 0.364* | 0.383*              | 0.109                 | 0.075                    | 0.171                    | 0.167                   | 0.032*            |                    |
| DMI<sub>pasture</sub>, kg/day | 0.100           |        | 0.099               | -0.162                | -0.050                   | 0.167                    | 0.053                   | 0.032*            |                    |
| CPI<sub>supplement</sub>, kg/day | 0.932*             |        | 0.849*              | 0.098                 | 0.039                    | 0.053                   | 0.064                   | 0.064             |                    |
| DMI<sub>supplement</sub>, kg/d  | 0.895*            |        |                    |                       |                         |                         |                         | 0.663*            |                    |

<sup>BM</sup> body weight, <sup>BW<sup>0.75</sup></sup> metabolic body weight, ADG average daily gain, DMI<sub>total</sub> total dry matter intake, DMI<sub>pasture</sub> pasture dry matter intake, CPI<sub>supplement</sub> crude protein intake through the supplement, DMI<sub>supplement</sub> supplement dry matter intake, DMIBW<sub>supplement</sub> pasture dry matter intake (% BW), CP<sub>pasture</sub> crude protein from pasture, NDF<sub>pasture</sub> neutral detergent fiber pasture

*Significant (P < 0.05)
bias, coefficient estimate (ρ—precision) and Cb values varied from 0 to 1, with values close to 1 indicating greater precision and exactitude (Lin, 1989; King and Cinchillini, 2001; Liao, 2003). The descriptive statistics (average, median, minimum, maximum, and standard deviation (SD)), for all the variables used in the predictive equations of the DMI

**Results**

**Data bank**

The data bank used to develop (Table 1) and evaluate (Table 2) the models of the DMI_pasture represented an ample range of the characteristics of the beef cattle and the diets used. In addition, the dataset was representative of beef cattle systems fed on pasture with concentrated supplementation during the growing phases of the animals, with the objective of increasing weight gain and reducing slaughter age. The descriptive statistics of the animals and the diets used were close, indicating that the two subsets were adequate (Tables 1 and 2) for model development and evaluation. The same evaluation process was applied in the models already published.

**Predictive models**

In the three models proposed for DMI_pasture, the variables associated with the animal, the supplements, and pasture (Table 4) were adjusted (P < 0.05). In model I, the metabolic body weight (BW^{0.75}) and ADG were adjusted (P < 0.05). In model II, in addition to the variables of model I, information related to the supplement (DMI_{supplement} - % BW) and CPI_{supplement} (kg/day) was adjusted (P < 0.05). In model III, the variables from model II as well as information related to pasture (% of CP) were adjusted (P < 0.05).

The NDF presented a low correlation with DMI of pasture and did not present significance while eliminating the non-significant independent variables. For this reason, we did not include it for model fitting. The effect of the study was considered as random in all the models, since according to St-Pierre (2001), when it is included in the analyses, the equations generated become more precise. The effect of breed, sex and their interactions were tested, however significance (P > 0.05) was not observed in the analyses. Therefore, separate models were not proposed.

The proposed models I (animal) and III (animal + supplement + pasture) presented non-significant results for the line’s intercept and slope (P > 0.05) (Table 5). However, model II (animal + supplement), presented significance for the line’s intercept and slope (P < 0.05).

**Evaluation of the models**

The new models proposed were able to explain between 45 to 52% (R^2) of the variability between the predicated and observed values (Table 5). Model I presented the second lowest average bias for prediction (underestimated in 0.10 kg/day, Table 5, Figs. 1 and 2), lowest accuracy (ρ = 0.68), and precision (Cb = 0.85), leading to the lowest CCC (0.58). Additionally, it presented the lowest MSPE (1.37), and similar (P > 0.05) RMSPE (24.32% of observed DMI_pasture) in comparison with models II and III. The decomposition of the MSPE, indicated that this model presented a larger part of the uncorrelated errors, since the absence of correlation accounted for by random errors was 96.73% and the average bias was only responsible for 0.68% of the prediction errors.

Model II presented the lowest average bias (0.08 kg/day), as well as intermediary precision (Bc = 0.84), and accuracy (ρ = 0.71), presenting the second best CCC (0.60) in comparison with models I and III. In the process of partition of the MSPE, it presented the lowest participation of the random error (93.71%) and the lowest error associated

**Table 4 Models for predicting DMI_pasture (kg/day) by beef cattle under tropical conditions**

| Models | Equations |
|--------|-----------|
| Azevêdo et al. (2016)\(^1\) | DMI = -1.912 + (0.900 × DMI_{supplement}) + (0.094 × BW^{0.75}) + (1.070 × ADG) − (1.395 × ADG^2) |
| Minson and McDonald (1987)\(^2\) | DMI = (1.185 + (0.00454 × BW) − (0.0000026 × BW^2) + (0.315 × ADG))^2 |
| Models proposed | |
| Model I\(^2\) | DMI_pasture = 0.055 + (0.069 × BW^{0.75}) + (0.304 × ADG) |
| Model II\(^2\) | DMI_pasture = 0.387 + (0.065 × BW^{0.75}) + (0.399 × ADG) − (1.164 × DMIBW_{supplement}) + (1.199 × CPI_{supplement}) |
| Model III\(^2\) | DMI_pasture = -1.510 + (0.067 × BW^{0.75}) + (2.997 × ADG) − (1.110 × DMIBW_{supplement}) + (1.143 × CPI_{supplement}) |

\(^1\) Adjusted with data DMI_total

\(^2\) Adjusted with data DMI_pasture, BW = body weight (kg), BW^{0.75} = metabolic BW (kg), ADG = average daily gain (kg/day), DMIBW_{supplement} = supplement dry matter intake (% BW); CPI_{supplement} = crude protein intake through the supplement (kg/day); CPI_pasture = crude protein from pasture (% DM)
with average bias (0.53%). However, it presented a significant effect ($P < 0.05$), for the line’s intercept and slope, indicating that there was no similarity between the observed $\text{DMI}_{\text{pasture}}$ and that predicted by the model.

Model III presented a prediction bias similar to that of model I (underestimated by 0.10 kg/day), higher $\rho$ (0.72), and $Cb$ (0.98) leading to higher CCC (0.63). It obtained the lowest MSEP (1.23), and similar ($P > 0.05$) RMSPE (23.07% of the observed $\text{DMI}_{\text{pasture}}$) in comparison with models I and II. With the decomposition of the MSEP, it was found that this model presented a greater part of the non-correlated errors, given that the lack of correlation accounted for by the random error was 95.59% and the average bias was only responsible for 0.88% of the prediction error.

The model proposed by Azevêdo et al. (2016) estimated $\text{DMI}_{\text{pasture}}$ with greater average bias (−0.290 kg/day), lower CCC (0.52), $\rho$ (0.53), and $Cb$ (0.98) and higher ($P \leq 0.05$) RMSPE (33.98% of the observed $\text{DMI}_{\text{pasture}}$) than the models proposed. It presented a significant result ($P < 0.05$) for the intercept and slope of the line, indicating a difference between the observed and predicted. For the model proposed by Minson and McDonald (1987) observed higher average bias (−0.790 kg/day), lower $\rho$ (0.65) and $Cb$ (0.78) that led to lower CCC (0.50). Additionally, it presented higher ($P \leq 0.05$) RMSPE (29.73% of the observed $\text{CDM}_{\text{pasture}}$) than the models proposed.

### Discussion

The prediction of $\text{DMI}_{\text{pasture}}$ is complex and dependent on various factors. Coleman et al. (1999) found that the $\text{DMI}_{\text{pasture}}$ varies as a function of the quality and physical characteristics of the forage and is inherent to the physiological state of the animal, as well as to environmental conditions, that can cause a reduction in consumption. In this manner, the interactions to be considered as estimates for prediction are more complex than for animals fed in a feedlot system (Azevêdo et al., 2016).

In the data evaluated, there was no significance for sex class and pasture NDF. Two possible explanations for sex class may be related to dietary energy density and female body fat. When animals receive energy rich diets, the predominant mechanism of regulation of the DMI is physiologically based (Mertens, 1987), in this case, consumption increases with the reduction of the energy density of the diet, until it occurs ruminal repletion effect.

It is observed in model III (Table 4) that the increase in the CP content of the pasture promotes an increase in the DMI. This behavior may be indicating the predominance of physical regulation of consumption over physiological regulation (Conrad et al., 1964), since the correlation between CP and NDF of the pasture was high and negative (Table 3), indicating physical limitations. Thus, pasture

| Model | Observed $\text{DMI}_{\text{pasture}}$ (Y), kg/day | Predicted $\text{DMI}_{\text{pasture}}$ (X), kg/day | Mean bias (Y – X), kg/day | Intercept | $P$ (H0, $\beta_0=0$) | Slope | $P$-Value (H0, $\beta_1=1$) | $R^2$ | MSEP, kg×kg | Root MSEP, kg/day | Partition of MSEP, % |
|-------|-----------------------------------------------|-----------------------------------------------|----------------------------|-----------|---------------------|-------|--------------------------|-------|----------------|------------------|---------------------|
| Model I | 4.81                                           | 4.81                                           | 0.10                        | −0.8965   | 0.2172              | 1.2111 | 0.1638                   | 0.45  | 1.37            | 1.17             | 68.08               |
| Model II | 4.71                                           | 4.73                                           | 0.08                        | −1.4215   | 0.0460              | 1.3181 | 0.0326                   | 0.51  | 1.28            | 1.13             | 53.03               |
| Model III | 4.81                                           | 4.71                                           | −0.29                       | −0.9563   | 0.1407              | 1.2255 | 0.0962                   | 0.52  | 1.23            | 1.11             | 88.00               |

$MSEP$ mean squared error of prediction, $CCC$ concordance correlation coefficient, $\rho$ correlation coefficient estimate (precision), $Cb$ bias correction factor (accuracy)
quality can limit the higher consumption of males, due to the ruminal repletion effect. Another explanation for sex class may be related to the possibility that females have not reached enough body fat to cause reductions in food intake. Due to their earlier fat deposition than males, they would cause greater secretion of leptin by adipocytes, a hormone that has been correlated with reductions in intake (Nkrumah et al., 2005). There is no significance of pasture NDF related to the high correlation between pasture NDF and pasture CP. If the NDF were maintained, even with the analysis of variance indicating non-significance, we could be assuming the risk of having collinear variables in the model.

When analyzing the coefficient of determination provided by the models proposed for the DMI \textsubscript{pasture}, it was found that they did not present high values. However, it would be wrong to say that a non-elevated $R^2$ indicates low correlation between the predicted and observed values, given that this relation can be curvilinear (Tedeschi, 2006). In these cases, submitting the data to further analysis, to verify the accuracy and precision between the predicted and observed values becomes necessary.
In this context, it was found that models I and III presented close results without difference for RMSPE, indicating that both models are adequate to predict the DMI_{pasture}. Despite model II had lower average bias than models I and III, it presented an intercept different to zero and the slope was different from the unity, and indicates that the relationship between observed and predicted DMI_{pasture} was not adequate. Therefore, its use is not recommended.

In addition to the RMSPE, other measures have been employed to evaluate the models, since the evaluation should be based on diverse measures that evaluate precision, accuracy and adequacy. The CCC, which is an index of reproducibility, simultaneously considers the exactitude and precision of the model. In this context, model III presents better adjustment to estimate the DMI_{pasture} given that it showed higher CCC than the other models.

Generally, model I provided acceptable prediction for DMI_{pasture}. However, given that this model was similar to Model III for average bias and RMSPE, but presented lower CCC, its utilization was limited. Therefore, the hypothesis that the use of more complete models, which include variables associated with the animal, supplements and pasture, better predicts the DMI_{pasture} was confirmed. By presenting the proximity of the RMSPE with model I, higher CCC and lower average bias, model III can be considered the most adequate for prediction of DMI_{pasture}.

Although the equation proposed by Azevêdo et al. (2016) had been developed using observation of beef cattle raised on pasture, the quality of its prediction for the DMI_{pasture} was inferior to that of the new models proposed and to the equation of Minson and McDonald (1987). Additionally, this model presented a significant result for the line’s intercept and slope ($P < 0.05$), being found to be inadequate for the prediction of DMI_{pasture}. However, it is worth noting that this equation was developed to estimate the total DMI and not just DMI_{pasture}, which may have led to a lower predictive capacity and a significant result for the line’s intercept and slope ($P < 0.05$), indicating a lack of adequacy between the predicted and observed DMI_{pasture}.

The equation proposed by Minson and McDonald (1987) did not adequately estimate DMI_{pasture}. Despite the intercept between the predicted and observed DMI_{pasture} values not being different from zero and the slope not being different from the unity, this equation explained 41% of the variation of the DMI_{pasture} and overestimated intake by 16.4%. Additionally, it presented a lower CCC and little participation by the random error during the partition of the MSPE of all the adjusted models.

This lower predictive capacity can be associated with the non-inclusion of the variables related to the supplements and pasture consumed by the animals. This fact may have diminished the quality of the prediction, which is similar to what was observed for the proposed model I, which only included variables related to the animal, and which also presented a lower predictive capacity than the more complete model containing variables related to the animal, supplement and pasture. Thus, it is necessary to constantly update and validate the knowledge generated in the research, so that the largest number of sources of variation can be known and evaluated in the consumption prediction models (Valadares Filho et al. 2016).
Heat stress can cause a reduction in the intake of the animals leading to a negative impact on performance (West, 2003). However, due to the majority of the studies published not reporting variables related to climatic conditions, its inclusion in the adjustment of the models, which could improve the prediction, was not possible. However, when the environmental conditions are outside the zone of thermal comfort due to an increase in air temperature or the temperature-humidity index, the DMI_{pasture} and efficiency of feeding drop significantly (West, 2003).

Through the results obtained, it is possible to observe the greater complexity of the factors that affect the DMI in beef cattle systems based on pasture, in addition to the greater challenge in predicting this variable under these conditions. This demonstrates that there are other factors in addition to those evaluated in this study that should be identified and added to future prediction models, such as climate data, including photoperiod, relative humidity and temperatures, according to NRC (2000) is the range in which there is no impact on consumption is between 15 and 25 °C, and for Zebu animals this range can reach 35 °C (Silva, 2008).

Two main factors that help to explain the greater difficulty in predicting DMI_{pasture} can be highlighted: (1) the greater complexity of the factors that affect ingestion, such as availability of forage, and the structural and morphogenetic characteristics of the pasture, (Stobs, 1973; Carvalho et al., 2007); (2) difficulties in measuring the DMI_{pasture} under grazing conditions due to the grazing tests frequently not taking the selection of the diet into account, as well as the representativity of the pasture sample effectively consumed by the animals (Lopes, 2008).

The selectivity of the animal can negatively influence the DMI_{pasture} since the animal uses a greater part of its time searching for better quality food (Cosgrove, 1997). Further, when the animal encounters some type of limitation in grazing on the pasture and/or low availability of pasture, there is an increase in the chew rate and grazing time, which ends up interfering in the DMI_{pasture}, a variable which is also complex when included in the predictive models, where a set of easily obtainable input information will increase the practical utility of the model (Gregorini et al., 2009).

**Conclusion**

The new models proposed presented greater accuracy and precision for the prediction of pasture dry matter intake than the models of Azevêdo et al. (2016) and Minson and McDonald (1987). Therefore, it is recommended to use model III, which includes information about the animal, supplement, and pasture. Despite resulting in a similar prediction bias to models I and II, model III showed greater precision and accuracy in its results, providing higher correlation and agreement coefficients and lower MSPE.

**Author contribution** The study was designed by EHBKM, ASO, and GAF. Formal analysis and investigation: GAF. Statistical analyses: GAF and CVA. Writing—original draft preparation: GAF. Writing—review and editing: EHBKM and KAKM.

**Data Availability** The data that support the results of this study are available from the corresponding author upon reasonable request.

**Code availability** Not applicable.

**Declarations**

**Ethics approval** Not applicable.

**Consent to participate** Not applicable.

**Conflict of interest** The authors declare no competing interests.

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