Short communication: Development and evaluation of predictive models of body weight for crossbred Holstein-Zebu dairy heifers

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ABSTRACT

Equations to predict body weight (BW) of crossbred Holstein-Zebu dairy heifers were developed and compared with current models (Heinrichs et al. for Holsteins, United States; Reis et al. for crossbred Holstein-Zebu, Brazil). The data set was constructed from 150 measurements of BW (320 ± 107 kg) and biometric measurements such as heart girth (HG, 161 ± 19.5 cm), withers height (WH, 126 ± 11.0 cm), and hip height (HH, 132 ± 11.3 cm) of heifers from 5 commercial dairy producers in the southern Amazon region in Brazil. The data were evaluated using mixed nonlinear models with herd as a random effect. Three nonlinear equations were fitted: $BW \text{ (kg)} = 0.00058 \cdot HG \text{ (cm)}^{2.6135}$; $BW \text{ (kg)} = 0.000618 \cdot HG \text{ (cm)}^{2.7362}$; and $BW \text{ (kg)} = 0.000196 \cdot HH^{2.8793}$. An independent database was constructed to evaluate the models from 38 treatment means of 4 feeding trials: BW 258 ± 54.3 kg, HG 142.5 ± 11.8 cm, WH 113.2 ± 6.0 cm, and HH 118.7 ± 9.1 cm (mean $\pm$ SD). The evaluations were based on the relationship between observed and predicted values of BW by linear regression, root mean square prediction error (RMSPE), and concordance correlation coefficient analysis. Only the proposed model using HG accurately predicted observed BW, with bias (observed – predicted) of 4.83 kg and RMSPE of 5.41% of observed BW (87.7% of random error). The models using WH and HH failed to accurately predict observed BW, with a bias of –3.06 and 72.02 kg, and RMSPE of 9.40% of observed BW (75.2% of random error and 23.1% of systematic error) and 30.81% of observed BW (81.2% of mean bias). Additionally, the models of Heinrichs and Reis used for comparison did not predict BW accurately, with a bias of 19.32 and 29.37 kg and RMSPE of 9.08% of observed BW (68.4% of mean bias and 31.4% of random error) and 12.58% of observed BW (81.9% of mean bias). The largest concordance correlation coefficient of the

proposed HG-nonlinear model (0.930), compared with the models of Heinrichs and Reis of 0.845 and 0.708, confirmed the greater accuracy and precision of the new equation to predict BW in crossbred Holstein-Zebu dairy heifers.

Key words: body growth, meta-analysis, modeling

Short Communication

Body weight measurements are essential in growing systems for dairy heifers to determine nutritional requirements and feeding, breeding, health, and reproductive management. However, the adoption of BW measurement by farmers remains a challenge. Surveys performed in several dairy regions in Brazil have demonstrated that fewer than 10% of dairy farmers weigh their heifers, due to the low availability of scales on farms (Diagnóstico da Pecuária Leiteira do Estado de Minas Gerais, 2005; Diagnóstico da Cadeia Produtiva do Leite do Estado de Mato Grosso, 2011). Thus, a feasible alternative would be to provide an indirect, fast, and low-cost method able to estimate BW of heifers on commercial herds.

Biometrics measurements such as heart girth (HG), withers height (WH), hip height (HH), and body length represent an alternative to estimate BW (Davis et al., 1961). Some predictive equations have been developed for Holsteins in the United States (Heinrichs et al., 1992) and for crossbred Holstein-Zebu in Brazil (Reis et al., 2008) that are able to assess the BW through biometric measurements. However, these models were empirically developed, which means their accuracy and precision are population dependent. Furthermore, the models proposed by Heinrichs et al. (1992) and Reis et al. (2008) have not been evaluated using an independent data set, which could make their full acceptance and recommendation questionable.

Thus, the objectives were (1) to develop equations to predict BW of dairy crossbred Holstein-Zebu heifers through the use of biometrics measurements, and (2) to evaluate the adequacy of the proposed predictive models compared with the models of Heinrichs et al. (1992) and Reis et al. (2008) using an independent database.

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Table 1. Descriptive statistics of the data sets used to develop and evaluate model predictions of BW in dairy heifers

Body measurement	Mean	Minimum	Maximum	Median	SD
Development (n = 150) ¹					
BW, kg	319.6	86.0	605.0	333.0	107.2
Heart girth, cm	161.2	110.0	200.0	166.0	19.5
Withers height, cm	126.2	90.0	149.0	128.0	11.0
Hip height, cm	131.7	96.0	150.0	134.0	11.3
Evaluation (n = 38) ²					
BW, kg	257.8	146.9	347.4	257.9	54.3
Heart girth, cm	142.5	118.0	159.6	143.7	11.8
Withers height, cm	113.2	100.8	123.2	113.4	6.0
Hip height, cm	118.7	116.6	129.6	113.2	9.1

¹One hundred fifty heifers in 5 herds.²Miranda et al. (1999); Guimarães (2009); Vidaurre, (2009); Santos et al. (2010).**Table 2.** Solution for fixed effects of nonlinear equations for predicting BW in crossbred and Holstein dairy heifers from body measurements¹

Model	Biometric measurement	Equation	P-value	AIC	BIC	S _{xy}
[1]	Heart girth (HG)	BW = 0.00058·HG ^{2.6135}	<0.001	1,398.6	1,397.0	0.96
[2]	Withers height (WH)	BW = 0.000618·WH ^{2.7362}	<0.001	1,561.7	1,560.1	0.90
[3]	Hip height (HH)	BW = 0.000196·HH ^{2.8793}	<0.001	1,505.5	1,503.9	0.89

¹AIC = Akaike information criterion; BIC = Bayesian information criterion; S_{xy} = correlation coefficient between predicted and observed values.

The data set of BW and biometrics measurements was obtained from 150 crossbred Holstein-Zebu dairy heifers from 5 commercial dairy herds in the south Amazon region in Brazil (Table 1). The main biometric

measurements taken were HG, WH, and HH, as described by Heinrichs and Lammers (1998).

Three nonlinear equations (allometric) were fitted in an attempt to predict BW from HG, WH, and HH. Sta-

Table 3. Analysis of regression between observed (Y) and predicted (X) values of BW for various models used for Holstein and crossbred Holstein-Zebu dairy heifers

Item ¹	Model ²					
	Model [1] (HG)	Model [2] (WH)	Model [3] (HH)	H1	H2	Reis
Y, kg of BW	257.84	257.84	257.84	257.84	257.84	257.84
X, kg of BW	253.00	260.93	185.82	238.52	263.47	228.47
Intercept (β_0)	1.34	-89.40	-147.06	22.84	42.81	27.81
P-value ($H_0: \beta_0 = 0$)	0.908	0.002	<0.001	0.039	0.027	0.017
Slope (β_1)	1.014	1.330	2.180	0.985	0.816	1.007
P-value ($H_0: \beta_1 = 1$)	0.763	0.002	<0.001	0.738	0.012	0.884
R ²	0.936	0.833	0.809	0.935	0.799	0.928
Mean bias (Y - X)	4.84	-3.06	72.02	19.32	-5.60	29
MSEP, kg × kg	194.30	588.40	6,319.7	545.24	668.84	776.44
Root MSEP, % of BW observed	5.41	9.41	30.83	9.05	10.03	12.59
Partition of MSEP, %						
Squared bias	12.05	1.63	82.08	68.41	4.74	81.97
Systematic error	0.24	23.15	9.92	0.17	3.64	0.468
Random error	87.71	75.22	8.00	31.43	91.63	17.56
CCC (0 to 1)	0.930	0.850	0.241	0.845	0.878	0.708
ρ (0 to 1)	0.935	0.913	0.899	0.904	0.886	0.826
C _b (0 to 1)	0.994	0.931	0.268	0.935	0.991	0.857

¹Models [1], [2], and [3] = models in the current study using heart girth (HG), withers height (WH), and hip height (HH); H1 = model proposed by Heinrichs et al. (1992) using heart girth; H2 = model proposed by Heinrichs et al. (1992) using withers height; Reis = model proposed by Reis et al. (2008) using heart girth.

²MSEP = mean squared error of prediction; CCC = concordance correlation coefficient; ρ = correlation coefficient estimate; and C_b = bias correction factor.

tistical analyses were performed using a mixed model as described by Littell et al. (2006), utilizing PROC NLMIXED of SAS (2000; SAS Institute Inc., Cary, NC) and considering the herd as a random effect and body measurements as fixed effects:

$$Y_{ij} = a \times BM^b + u_{i1} + e_{ij},$$

where Y_{ij} = BW of the i th heifer in the j th herd, in which i ranges from 1 to 150 and j ranges from 1 to 5; BM = fixed effect of biometric measurements (HG, WH, or HH); a and b = fixed effects parameters of the potential model; u_{i1} = random effects parameters, assuming $N(0, \sigma_e^2)$; and e_{ij} = random error associated with each observation, assuming $N(0, \sigma_e^2)$. Data points were removed if the studentized residual was outside the range of -2.5 to 2.5 (Neter et al., 1996). The critical level of probability for type I error was set at 0.05.

To evaluate the adequacy of the models, an independent data set composed of 38 measurements of BW (obtained after overnight feed withdrawal) and biometric measurements (HG, WH, and HH) from 4 experiments performed with crossbred Holstein-Zebu and Holstein dairy heifers was used to assess the adequacy of the proposed models (Miranda et al., 1999; Guimarães, 2009; Vidaurre, 2009; Santos et al., 2010). The BW values obtained from these animals were converted to full BW by dividing the fasted BW by 0.96, as recommended by NRC (2001).

The proposed equations were compared with those suggested by Heinrichs et al. (1992) for Holstein dairy heifers:

$$\begin{aligned} \text{BW (kg)} &= 102.71 - 2.876 (\text{HG, cm}) \\ &+ 0.02655 (\text{HG, cm}^2), [\text{H1}] \end{aligned}$$

$$\begin{aligned} \text{BW (kg)} &= 623.13 - 16.837 (\text{WH, cm}) \\ &+ 0.11989 (\text{WH, cm}^2), [\text{H2}] \end{aligned}$$

and by Reis et al. (2008) for crossbred Holstein-Zebu dairy heifers:

$$\begin{aligned} \text{BW (kg)} &= 1,717 - 35.167 (\text{HG, cm}) + 0.238978 \\ &(\text{HG, cm}^2) - 0.00046260 (\text{HG, cm}^3). \end{aligned}$$

The evaluation of these models was based on the analysis of the linear regression between observed (Y -axis) and predicted values (X -axis), under the following hypotheses: null hypothesis (H_0): $\beta_0 = 0$, alternative hypothesis (H_A): $\beta_0 \neq 0$; H_0 : $\beta_1 = 1$, H_A : $\beta_1 \neq 1$. Only in the case that both hypotheses are accepted can the

Figure 1. Relationships between BW and heart girth (HG), withers height (WH), or hip height (HH) for crossbred Holstein-Zebu dairy heifers. The data were obtained from 150 heifers in 5 commercial herds. The nonlinear equations were adjusted for the random effect of herd using a mixed model.

Figure 2. Relationships between observed and predicted BW using proposed models [1] (heart girth), [2] (withers height), and [3] (hip height), and models proposed by Heinrichs et al. (1992) using heart girth and withers height, and the model proposed by Reis et al. (2008) using heart girth.

model be considered a proper predictor of the observed values. The analysis of linear regression was achieved using PROC MIXED methodology (SAS Institute Inc.), with the experiment as a random effect (St-Pierre, 2001). Thus, 0.05 was adopted as the level of probability for type I error.

The precision and accuracy of the models were assessed by the estimate of the concordance correlation coefficient (CCC) as described by Lin (1989). The CCC was divided into correlation coefficient (ρ), as the precision indicator, and bias correction factor (C_b), as the accuracy indicator, where higher values indicate a more precise or accurate model, respectively (Lin, 1989; King and Chinchilli, 2001; Liao, 2003).

Furthermore, the efficiency of the prediction models was evaluated using the estimate values of the mean

square error of prediction (MSEP), root MSEP (RMSEP), and MSEP components such as the squared bias, the systematic error, and the random error. The squared bias represents the central tendency of the error (mean of the deviations). The systematic error represents the error associated with the slope of the regression, and the random error represents the error that was not explained by the model (Bibby and Toutenburg, 1977). The CCC, MSEP, and RMSEP were estimated using the Model Evaluation System (College Station, TX; <http://nutritionmodels.tamu.edu/mes.html>) as described by Tedeschi (2006).

The proposed prediction model using HG (model [1]) presented a higher correlation coefficient for BW (0.96), followed by WH (0.90) and HH (0.89). Moreover, model [1], which used HG as the single estimator for

BW prediction, presented the lowest Akaike information criterion (Akaike, 1974) and the lowest Bayesian information criterion. Therefore, HG appeared to be the best predictor, superior to both WH and HH (Table 2; Figure 1).

Only model [1], in which HG was the independent variable, predicted values that fit the observed data well ($\beta_0 = 0$, $P = 0.91$; $\beta_1 = 1$, $P = 0.76$; Table 3, Figure 2). The model presented a mean bias of 4.84 kg, which represents an underestimation of 1.9% of the observed BW. Model [1] accounted for 93.6% of the variation in BW and presented the lowest value for RMSEP (5.41% of observed BW). The major part of the prediction error was associated randomly (87% of MSE), indicating that only 13% of the error was associated with the model. Model [1] presented the highest proximity of observed BW with the identity line ($Y = X$; Figure 2). In addition, model [1] had the highest values of CCC, ρ , and C_b , indicating greater precision and accuracy. Therefore, the proposed model using HG (model [1]) was considered the only appropriate model for the prediction of BW for dairy heifers.

The model proposed using WH (model [2]) had lower mean bias than model [1] but higher RMSEP due to overestimation of the BW <272 kg and underestimates of BW >272 kg (Table 3; Figure 2). The proposed model using HH (model [3]) had the highest mean bias (72.02 kg of BW) and RMSEP (30.83% of observed BW), with the highest contribution of error due to squared bias among all the models (Table 3). The bias of model [3] increased with increasing BW in heifers (Figure 2).

The model proposed by Heinrichs et al. (1992) using HG ([H1]) produced a significant global bias constant ($\beta_0 = 22.84$ kg of BW; $P = 0.04$), its major limitation. The underestimation was expected because the model was developed for Holstein dairy heifers in the United States (Heinrichs et al., 1992), which appear to have a higher ratio of biometric measurements to BW than crossbred Holstein-Zebu dairy heifers. Although the model proposed by Heinrichs et al. (1992) using WH ([H2]) had the second highest CCC, it overestimated the BW of heifers >200 kg (Table 3, Figure 2), demonstrating the inadequacy of BW prediction for crossbred Holstein-Zebu dairy heifers.

The model proposed by Reis et al. (2008) had similar limitations as the HG model of Heinrichs et al. (1992) regarding the global bias constant ($\beta_0 = 27.81$ kg of BW; $P = 0.017$). Although the model proposed by Reis et al. (2008) was developed based on measurements of crossbred Holstein-Zebu dairy heifers, its empirical nature represents the main reason for its inadequacy, because it is population dependent. Furthermore, Reis et al. (2008) did not evaluate their model against an

independent data set, which remains a limitation for its adoption.

The models to predict BW from measurements of HG or WH proposed by Heinrichs et al. (1992) and the model proposed by Reis et al. (2008) from HG are not suitable for crossbred Holstein-Zebu. The proposed nonlinear allometric model using HG is recommended for predicting the BW of crossbred Holstein-Zebu heifers.

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