

Predição do peso corporal de suínos “tipo banha” por meio de medidas morfométricas

Predicting body weight in fat-type pigs using morphometric measurements

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Highlights

Morphometric traits are highly correlated with body weight in fat-type pigs.
Carcass length and thoracic circumference are sufficient to predict body weight.
Body weight and morphometric measurements is similar in males and females.
Multiple linear regression models predict pig body weight with high accuracy.

Abstract

This study aimed to develop predictive equations for body weight (BW) in fat-type (lard-type) pigs raised under extensive or semi-extensive systems, and to determine the most significant morphometric predictors. Data were collected from 240 pigs (122 males and 118 females) on smallholder farms, with BW ranging from 4.7 to 68.0 kg. The following traits were recorded: body weight (BW), carcass length (CL), thoracic circumference (TC), hip circumference (HC), withers height (WH), and hip height (HH). Descriptive statistics (means, standard deviations, coefficients of variation, and maximum values) were calculated separately for each sex. Pearson's correlation coefficients indicated that all morphometric measurements were strongly correlated with BW ($r \geq 0.90$) in both sexes. Data were tested for normality (Cramer–von Mises), and male and female datasets were analyzed separately using stepwise multiple linear regression. The resulting sex-specific equations were compared using an F test, with no differences detected between males and females ($P = 0.376$). Therefore, a single pooled equation was considered sufficient to explain BW variation in both sexes: $BW = -35.51 + 0.80 \times TC + 0.11 \times CL$ ($R^2 = 0.93$; $P < 0.0001$). To assess practical applicability, the general equation was validated using CL and TC data from an independent set of 53 pigs ($BW = 6.5\text{--}42.8$ kg) not included in model development. Predicted

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and observed values were highly correlated ($r = 0.96$), indicating strong predictive performance. These findings demonstrate that CL and TC are sufficient to accurately predict BW in fat-type pigs, providing a practical tool for small-scale producers who lack access to weighing scales.

Key words: Morphometry. Multiple linear regression. Pig production.

Resumo

Objetivou-se elaborar equações de predição do peso corporal de suíno tipo banha criados de modo extensivo ou semi-extensivo, visando identificar as medidas morfométricas mais relevantes para a sua predição. Foram coletados dados de peso corporal (PC), comprimento de carcaça (CC), circunferência torácica (CT) e de quadril (CQ), altura de cernelha (AC) e de quadril (AG) de 240 animais, sendo 122 machos e 118 fêmeas, com PC entre 4,7 e 68,0 kg, criados em pequenos estabelecimentos rurais com perfil familiar. Para a análises descritivas das variáveis foram calculadas as médias, desvios padrão, coeficientes de variação e valores máximos para cada sexo. Também foram calculados os coeficientes de correlação de Pearson (r), onde todas as medidas morfométricas apresentaram fortes correlações ($r \geq 0,90$) com o PC em ambos os sexos. Em seguida os dados foram submetidos ao teste de normalidade (Cramer-von Mises) e os dados de machos e fêmeas foram submetidos separadamente à análise de regressão linear múltipla pelo método Stepwise. Posteriormente as equações geradas de machos e fêmeas foram comparadas pelo teste F, não havendo diferença entre os sexos ($P = 0,376$). Esse resultado evidenciou que uma equação é suficiente para explicar a variação do peso corporal de machos e fêmeas, sendo: PC: $-35,51 + 0,80 \times CT + 0,11 \times CC$ ($R^2 = 0,93$; $P < 0,0001$). Para avaliar a aplicabilidade prática da equação, foram usados para estimar o PC, dados de CC e CT de 53 suínos com pesos entre 6,5 e 42,8 kg que não participaram da parametrização da equação. Observou-se uma alta correlação entre valores preditos e observados ($r = 0,96$), sugerindo boa capacidade preditiva da equação. O resultado evidencia que CC e CT são medidas morfométricas suficientes para prever o PC de suínos tipo banha de maneira precisa, favorecendo pequenos produtores que não dispõem de balanças em suas propriedades.

Palavras-chave: Morfometria. Regressão linear múltipla. Suinocultura.

Introduction

Pork is the most widely consumed animal protein worldwide, with global demand largely met by intensive production systems based on meat-type pig breeds. These animals deposit little fat and are characterized by greater body volume in regions associated with high-value cuts such as the loin and ham. They also show high productive and reproductive performance,

reflecting substantial advances in genetic improvement over recent decades (Silva et al., 2024).

By contrast, fat-type (lard-type) pigs show a more balanced conformation between the thoracic and pelvic regions and typically present skin wrinkling, a feature associated with high fat deposition. These animals are also valued for the organoleptic qualities of their meat (Araújo et al., 2020).

In developing regions where subsistence pig production remains common, lard-type pigs are particularly attractive to smallholders. They are generally raised under extensive or semi-extensive systems, which require low initial investment and allow the use of locally available natural resources for both feeding and shelter construction, enabling animals to express natural behaviors (Anis et al., 2020). This management approach is feasible due to the animals' hardiness, tolerance to climatic stress, adaptability, and resistance to diseases and ectoparasites (P. L. C. Carvalho & Viana, 2011; Araújo et al., 2020).

Regular body weight assessment is essential in any pig production system. It is a key parameter for appropriate nutritional and reproductive management, supports growth rate monitoring, and facilitates the selection of higher-performing animals to remain in the herd, thereby improving overall farm decision-making.

Although weighing scales provide the most accurate measurements, their use may be limited by high purchase costs and the labor required to handle and restrain animals. The procedure can also be highly stressful for pigs because they must be moved to a designated weighing area (Gusmão et al., 2009; Zaragoza, 2010; Panda et al., 2021). As an alternative, body weight can be estimated from morphometric measurements such as carcass length, thoracic and hip circumference, and withers and rump heights. These measurements have been widely used to develop prediction equations for pigs of different breeds, categories, and ages (Kumari et al., 2020; Panda et al., 2021; Baruzzi et al., 2023; Franchi et al., 2023) and

several studies have reported accurate and precise estimates (Mutua et al., 2011; Walugembe et al., 2014; Sungirai et al., 2014; Palhares et al., 2018; Holanda et al., 2020; Panda et al., 2021).

Despite the substantial body of research on predicting pig body weight, there is still a gap in the literature regarding equations developed specifically for fat-type pigs raised under extensive and semi-extensive conditions. Differences in animal traits and production systems, among other factors, may directly influence the precision and accuracy of weight estimates.

In this context, the present study aimed to develop equations to predict body weight in fat-type pigs raised under extensive or semi-extensive systems, and to determine which morphometric measurements are most relevant for prediction.

Material and Methods

All animal care procedures were approved by the Ethics Committee of the Federal University of Maranhão (Approval No. 23115.0322201/2021-17).

Data were collected from 19 family-based farms located in the rural area of Chapadinha, Maranhão state (MA), Brazil, and neighboring municipalities, where pigs are raised as part of diversified small-scale agricultural systems. The study included non-defined breed pigs raised under extensive or semi-extensive systems.

A total of 240 pigs were evaluated (122 males, both intact and castrated, and 118 females), with body weights ranging from 4.7 to 68.0 kg (Figure 1). Body weight

(BW) and the following morphometric traits were recorded: carcass length (CL; straight-line distance from the base of the ear to the base of the tail), thoracic circumference (TC; measured immediately behind the forelimbs and anterior to the first mammary glands), hip circumference (HC; circumference around the abdomen just anterior to the

hind limbs), withers height (WH; distance from the ground to the dorsal region of the scapula with the animal standing on a flat surface), and rump height (RH; distance from the highest point of the caudal region to the ground, with the animal standing on a flat surface). All measurements were taken by a single evaluator.

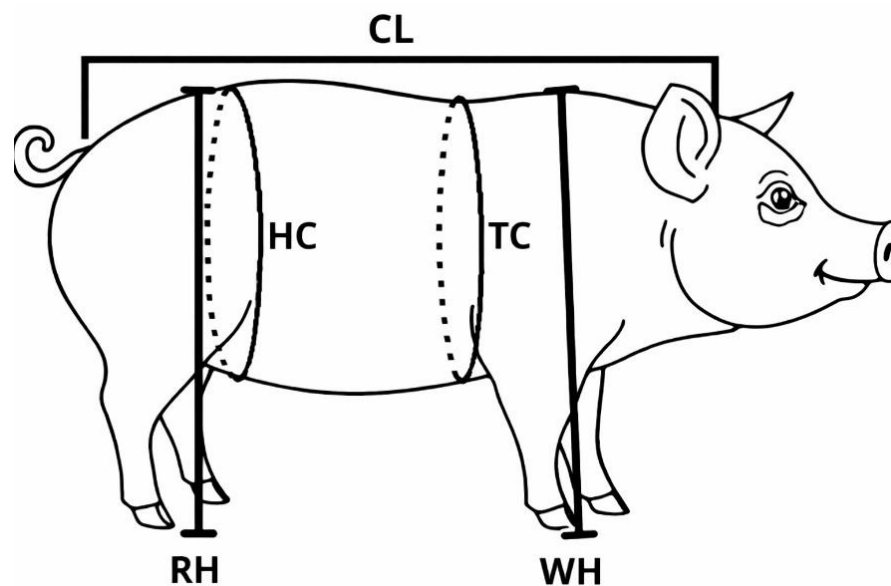


Figure 1. Schematic representation of the morphometric measurements evaluated: carcass length (CL), thoracic circumference (TC), hip circumference (HC), withers height (WH), and rump height (RH).

Animals were weighed using a 120.0 kg-capacity digital scale (TOLEDO®, model 2098) and morphometric traits were obtained with a measuring tape. Data were recorded in Microsoft Excel® and summarized using descriptive statistics (means, standard deviations, coefficients of variation, and minimum and maximum values) calculated separately for each sex. Pearson's correlation coefficients (r) were calculated to assess

associations between BW and morphometric traits within each sex.

Normality was assessed for each trait within each sex using the Cramer–von Mises test. After confirming normality, multiple linear regression models were fitted using stepwise selection, following the model described by Charnet et al. (2008):

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon_i$$

where Y_i represents pig body weight (BW; kg), X_1, X_2, \dots, X_n denote the independent variables corresponding to morphometric traits (CL, TC, HC, WH, RH), $\beta_0, \beta_1, \beta_2, \dots, \beta_n$ are regression coefficients, and ε_i is the random error term. Statistical analyses were performed using SAS 9.0 (Statistical Analysis System for Institute [SAS Institute Inc], 2002), with significance set at 5%.

To obtain sex-specific prediction equations, male and female datasets were analyzed separately using stepwise multiple linear regression. In this procedure, independent variables were added to or removed from the model at each step based on their statistical contribution to predictive performance. After selecting the most relevant traits for BW prediction, multicollinearity among predictors was evaluated using the Variance Inflation Factor (VIF), following Montgomery et al. (1992):

$$VIF = (1 - R^2)^{-1}$$

where R^2 is the coefficient of determination obtained when one predictor is regressed on all other predictors. When only two predictors are included, R^2 corresponds to the square of the Pearson correlation coefficient (r).

To test whether sex affected the regression equations, male and female models were compared using an F test, as described by Motulsky and Ransnas (1987):

$$F = \frac{\frac{(SS_{pool} - SS_{sep})}{(df_{pool} - df_{sep})}}{\frac{SS_{sep}}{df_{sep}}}$$

where SS_{pool} and df_{pool} represent the error sum of squares and degrees of freedom for the model fitted to the pooled dataset (ignoring sex), and SS_{sep} and df_{sep} correspond to the combined error sum of squares and degrees of freedom for the sex-specific models, where $SS_{sep} = SS_{males} + SS_{females}$ and $df_{sep} = df_{males} + df_{females}$.

After confirming that male and female equations were similar ($P > 0.05$), the full dataset ($n = 240$) was reanalyzed using the same stepwise multiple linear regression approach to obtain a general prediction equation. Coefficients in the general equation corresponded to the mean values of coefficients obtained in the sex-specific models. The VIF for the general equation was also calculated.

To assess practical applicability, an independent dataset of 53 additional pigs (BW = 6.50–42.80 kg) not included in model development was used, consisting of 33 males (mean BW = 16.36 kg) and 20 females (mean BW = 19.20 kg). Morphometric measurements from these animals were entered into the general equation to generate predicted BW values, which were plotted against observed values (Figure 2; Reis et al., 2023).

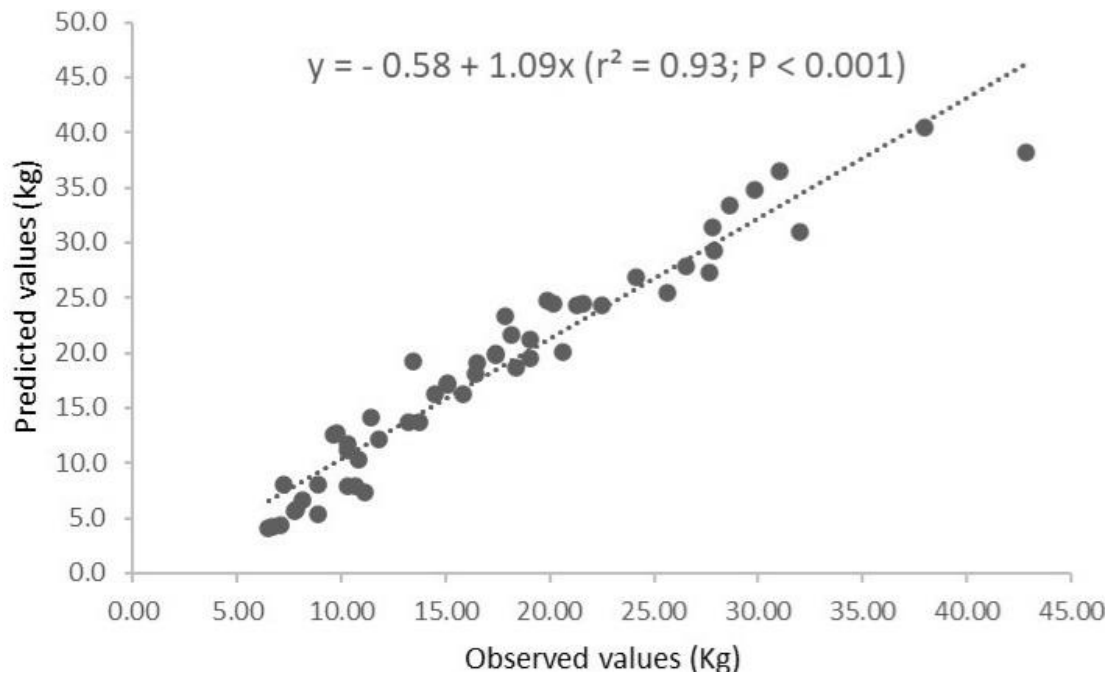


Figure 2. Relationship between predicted and observed body weight values for 53 fat-type pigs.

Results and Discussion

Mean BW was similar between males and females, ranging from 5.00 to 68.00

kg for males (Table 1) and 4.70 to 63.00 kg for females (Table 2). Body weight and all morphometric traits (CL, TC, HC, WH, and RH) followed a normal distribution ($p < 0.05$).

Table 1

Descriptive statistics (mean, standard deviation, minimum, maximum, and coefficient of variation) for body weight and morphometric traits in male fat-type pigs.¹

Variables ²	Mean	SD	Minimum	Maximum	CV (%)
BW (Kg)	20.16	13.85	5.00	68.00	68.69
CL (cm)	68.04	16.11	39.00	108.00	23.68
TC (cm)	60.34	14.49	39.00	102.00	24.02
HC (cm)	60.73	15.71	35.00	102.00	25.87
WH (cm)	46.36	10.17	29.00	76.00	21.94
RH (cm)	49.41	11.24	31.00	82.00	22.75

¹ n = 122.

² BW = body weight; CL = carcass length; TC = thoracic circumference; HC = hip circumference; WH = withers height; RH = rump height.

Table 2

Descriptive statistics (mean, standard deviation, minimum, maximum, and coefficient of variation) for body weight and morphometric traits in female fat-type pigs.¹

Variables ²	Mean	SD	Minimum	Maximum	CV (%)
BW (Kg)	19.15	12.03	4.70	63.00	62.80
CL (cm)	66.72	14.80	40.00	105.00	22.18
TC (cm)	59.25	12.76	39.00	104.00	21.53
HC (cm)	59.26	13.97	36.00	102.00	23.58
WH (cm)	45.74	9.85	29.00	75.00	21.53
RH (cm)	48.97	10.83	31.00	78.00	22.33

¹ n = 118.

² BW = body weight; CL = carcass length; TC = thoracic circumference; HC = hip circumference; WH = withers height; RH = rump height.

To evaluate linear associations between BW and morphometric traits within each sex, Pearson's correlation coefficients (r) were calculated (Tables 3 and 4).

Table 3

Pearson's correlation coefficients (r) and P-values among body weight and morphometric traits in male fat-type pigs.¹

Variables ²	BW	CL	TC	HC	WH	RH
BW	1.00 -----	-----	-----	-----	-----	-----
CL	0.92 <0.001	1.00 -----	-----	-----	-----	-----
TC	0.96 <0.001	0.88 <0.001	1.00 -----	-----	-----	-----
HC	0.94 <0.001	0.91 <0.001	0.96 <0.001	1.00 -----	-----	-----
WH	0.91 <0.001	0.88 <0.001	0.93 <0.001	0.89 <0.001	1.00 -----	-----
RH	0.94 <0.001	0.91 <0.001	0.95 <0.001	0.91 <0.001	0.96 <0.001	1.00 -----

¹ n = 122.

² BW = body weight; CL = carcass length; TC = thoracic circumference; HC = hip circumference; WH = withers height; RH = rump height.

Table 4

Pearson's correlation coefficients (r) and P-values among body weight and morphometric traits in female fat-type pigs.¹

Variables ²	BW	CL	TC	HC	WH	RH
BW	1.00 -----	-----	-----	-----	-----	-----
CL	0.90 <0.001	1.00 -----	-----	-----	-----	-----
TC	0.96 <0.001	0.89 <0.001	1.00 -----	-----	-----	-----
HC	0.92 <0.001	0.92 <0.001	0.95 <0.001	1.00 -----	-----	-----
WH	0.91 <0.001	0.91 <0.001	0.93 <0.001	0.88 <0.001	1.00 -----	-----
RH	0.90 <0.001	0.91 <0.001	0.93 <0.001	0.89 <0.001	0.97 <0.001	1.00 -----

¹ n = 118.

² BW = body weight; CL = carcass length; TC = thoracic circumference; HC = hip circumference; WH = withers height; RH = rump height.

All traits showed strong correlations with BW according to Vieira's (2008) classification ($r \geq 0.90$) in both sexes. TC exhibited the strongest correlation with BW in both sexes ($r = 0.96$), whereas the weakest correlations were observed for WH in males ($r = 0.91$) and RH and CL in females ($r = 0.90$).

High correlations between BW and morphometric traits have also been widely reported. Using Landrace × Large White crossbred pigs, Sungirai et al. (2014) found strong positive correlations ($r > 0.94$) between BW and morphometric measurements. Similarly, Machebe et al. (2016) evaluated Landrace × Large White crossbred gilts during the growing and finishing phases and reported strong correlations between BW and both CL ($r = 0.95$) and TC ($r = 0.97$).

Similar results were reported by Holanda et al. (2020), who evaluated 20

male and 20 female Duroc × Large White crossbred pigs with BW ranging from 1.518 to 7.010 kg. The authors found strong positive correlations between BW and CL ($r = 0.97$ in males and $r = 0.98$ in females), and between BW and TC ($r = 0.96$ in males and $r = 0.97$ in females), indicating that these traits can be used to estimate BW without weighing scales even in very young animals.

Comparable patterns have been documented in goats, sheep, and cattle, reinforcing the strong association between BW and morphometric traits particularly CL and TC across species (Otte et al., 1992; Stajnko et al., 2008; Mathapo & Tyasi, 2021; Faraz et al., 2021; Kuthu, 2023; Oliveira et al., 2024; Alcântara et al., 2024).

Overall, these findings support the use of CL and TC as reliable predictors of BW in pigs and other species, particularly

in extensive and semi-extensive systems. The strong correlations observed suggest that these variables can be used reliably in prediction models, supporting management practices and feeding planning in production environments with limited access to technological resources.

Sex-specific prediction equations were developed using stepwise multiple linear regression. In this procedure, independent variables were added to or removed from the model at each step based on their statistical contribution to predictive performance.

For males, the best fitting equation was: $BW = -36.10 (\pm 1.46) + 0.78 (\pm 0.06) \times TC + 0.14 (\pm 0.06) \times CL$ ($R^2 = 0.93$; $P < 0.0001$). For females, the equation was: $BW = -34.84 (\pm 1.46) + 0.82 (\pm 0.06) \times TC + 0.09 (\pm 0.05) \times CL$ ($R^2 = 0.93$; $P < 0.0001$), where BW is body weight (kg), CL carcass length (cm), and TC thoracic circumference (cm). These results indicate that CL and TC alone were sufficient to estimate BW in both sexes.

Although all morphometric traits were highly correlated with BW, stepwise selection retained only TC and CL in both sex-specific models, likely due to multicollinearity among the remaining traits.

According to Montgomery et al. (1992), multicollinearity reflects near-linear dependence among regressor variables and can severely compromise the estimation of regression coefficients. It may also overestimate the direct effects of predictors on the response variable, potentially resulting in misleading interpretations (C. G. P. D. Carvalho et al., 1999).

Coimbra et al. (2005) noted that stepwise procedures can help identify

variables that contribute most to collinearity, while selecting predictors that maximize the correlation coefficient with minimal multicollinearity interference. However, Montgomery et al. (1992) recommend additional diagnostic tools, such as the Variance Inflation Factor (VIF), which quantifies the extent to which collinearity inflates the variance of a regression coefficient. According to these authors, a VIF value of 1 indicates no multicollinearity, values greater than 5 high multicollinearity with strong effects on coefficient estimation, and values below 5 moderate multicollinearity with typically minor effects. In the present study, the VIF values for CL and TC were below 5 for both males ($VIF = (1 - 0.882)^{-1} = 4.43$) and females ($VIF = (1 - 0.892)^{-1} = 4.81$), indicating only a small impact on coefficient estimation.

Following the approach proposed by Motulsky and Ransnas (1987), the results indicated no significant difference between

$$\text{sexes } (F = \frac{(2864.76 - 2855.92)}{\frac{(287 - 284)}{2855.92}} = 0.241; P = 0.376).$$

This finding demonstrates that a single general equation is sufficient to explain BW variation in both sexes. Coefficients in the general equation corresponded to the mean values of coefficients obtained in the sex-specific models: $BW: -35.51 (\pm 1.03) + 0.80 (\pm 0.04) \times TC + 0.11 (\pm 0.04) \times CL$ ($R^2=0.93$; $P<0.0001$). Coefficient estimates in the general model were not strongly affected by multicollinearity, since VIF was below five ($VIF = (1 - 0.8852)^{-1} = 4.61$). The evidence that a single equation adequately predicts BW for both males and females suggests that the relationship between BW and body morphology is consistent between sexes.

To assess practical applicability, the general equation was applied to an independent dataset of 53 pigs not used during model development. CL and TC were used to estimate BW, and the predicted values were regressed against observed values (Figure 2).

A strong correlation was observed between predicted and observed BW values ($r = 0.96$), indicating high predictive accuracy. Moreover, the fitted line's intercept was close to zero (0.58), and the slope close to one (1.09), demonstrating good prediction precision relative to actual BW values and supporting the practical applicability of the equation.

These findings align with previous studies showing that CL and TC are effective predictors of BW, regardless of production system, breed, or live weight range. Walugembe et al. (2014) reported that these measurements explained 89% of BW variation. Although the most accurate model in their study also included WH, yielding $R^2 = 0.95$, the authors emphasized that CL and TC alone provided strong predictive capacity. Our results corroborate this conclusion, reinforcing that a model including CL and TC effectively estimates BW in pigs, even when other morphometric traits are correlated with BW.

Likewise, Al Ard Khanji et al. (2018) evaluated regression models using TC and CL across different physiological states of crossbred sows (Landrace \times Large White) and also reported excellent predictive performance. Kumari et al. (2020) and Panda et al. (2021) also reported that CL and TC were the most informative predictors in crossbred

pigs. In both studies, equations based on these two measurements explained 83% of total BW variation. Together, these results reinforce the practical value of CL and TC as reliable BW predictors.

More recently, Divyalakshmi and Pandian (2022) analyzed Large White pigs and suggested that CL and TC may also serve as selection criteria, streamlining routine management. Because weighing animals is more time-consuming than estimating BW using morphometric measurements obtained with a measuring tape, BW estimation via CL and TC offers a practical alternative to removing animals from their pens. Similarly, Baruzzi et al. (2023) emphasized that morphometric measurements directly reflect an animal's physiological status, providing valuable information for decision-making in extensive or semi-extensive systems, where efficient herd management depends on practical and accessible tools.

Overall, applying equations based on CL and TC to estimate BW in pigs raised under extensive or semi-extensive systems can provide clear benefits to producers. These measurements can be collected quickly by a single person in the field, reduce handling time, minimize animal stress, and eliminate the need for specialized equipment.

Finally, implementing a single predictive model for BW regardless of sex further supports the robustness of these predictors in pigs. This approach offers practical advantages for small-scale producers by reducing the logistical challenges associated with weighing animals using scales.

Conclusion

Carcass length and thoracic circumference are key predictors and are sufficient to accurately estimate body weight in fat-type pigs raised under extensive or semi-extensive production systems.

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