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Practical procedures to body weight estimation and correction factors applied to Campolina horses

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ABSTRACT - The objective of this study was to evaluate the accuracy of the following six body weight (BW) estimation methods in Campolina (CAM) horses: A - weight tape placed at three different positions on the animal's thorax; B - Crevat and Quetelet's formula; C - Hall's formula; D - Hintz and Griffiths's table; E - Santos's table; and F - Cintra's formula. A total of 380 CAM horses were separated according to sex, age class, and gestational stage and evaluated. To determine their accuracy, weights measured on a scale and weight estimates of the six methods were compared by paired t-test, mean prediction error (MPE), and coefficient of determination (R^2), using R software. The predictive capacity of method F was lower in the 6-12 months age class, so this formula is not indicated. The BW was overestimated compared with the actual weight by methods A (with weight tape placed in position 3) and B and underestimated by method C. Methods D and E accurately estimated BW of CAM horses. Correction factors are required to accurately estimate BW in this breed using methods B and C. Method A with the weight tape placed in position 2 is the most accurate for predicting BW, including pregnant female horses, and can, therefore, be considered the most suitable method for estimating BW of CAM horses.

Keywords: breed, equine, foal, nutrition

1. Introduction

The Campolina breed (CAM) stands out in the national equine market in functional sports and service activities, such as exhibitions, endurance, and daily activities of rural properties. These animals are valued for being docile and resistant, with strong and vigorous body constitution, and for having a comfortable gait for the rider called "marcha", making it attractive for leisure (Lucena et al., 2016).

Nutritional status assessment is used in horse breeding to manage the herd. Body condition score and body weight (BW) are used to assess the nutritional status of animals. Body weight is one of the main parameters used in several daily management activities, including diet formulation, assessment of nutritional programs, optimization of training, and determination of drug dosages (Lewis, 2000). It is estimated that horses acquire 65% of adult BW in the first year of life (NRC, 2007). According to Garcia et al. (2011), horses have 10% of their adult weight at birth, and reach 45% at six months of age and 65% at 12 months. These values show the sigmoidal nature of horse growth curves, as reported in the Mangalarga Marchador breed by Souza et al. (2017a), Ribeiro et al. (2018), and Souza et al. (2019).

There are several methods to estimate BW in horses. Using a weighing scale is the most accurate method to determine BW; however, the high implementation costs became impractical in the reality of rural properties. Alternative methods such as weight tapes, tables, and mathematical formulas are more practical, cheaper, and more accurate for a qualitative overview of the animal (Ellis and Holands, 2002; Wagner et al., 2009; Hoffmann et al., 2013).

The theoretical principle of these alternative methods for assessing BW consists of estimating the volume of the animal, using formulas that correlate body measurements that are highly correlated with BW (Milner and Helwitt, 1969). In this way, weighing tapes are built based on mathematical equations that consider these body measurements, mainly chest circumference and body length (Carroll and Huntington, 1988; Ellis and Hollands, 2002).

However, it is worth mentioning that, generally, weighing tapes used in horses are most often developed by private companies, and information about the details of their manufacture, how they were designed, and for which breeds and age groups of the animals they were developed are not available in the scientific literature, as already verified in other studies that tested commercial tapes (Ellis and Holand, 1998; Ellis and Holand, 2002; Wagner and Tyler, 2011; Souza et al., 2017b). In addition, many breeders and professionals have doubts about the best position for the tape and if it interferes with the reliability of this method. According to Hintz (2002) and García Neder et al. (2009), the efficiency of BW estimation methods is also affected by animal characteristics (sex, age, gestational stage, and breed) and external variables (feed availability, health status, and environmental conditions).

Several studies, such as that of Souza et al. (2017b), were conducted to determine the accuracy of these methods, which showed that the weight tape positioned behind the withers and behind the elbow was the most efficient method to estimate the real BW of Brazilian Mangalarga Marchador horses in different age classes and gestational stages. The authors also observed that mathematical formulas should only be used to estimate BW when adjusted with specific correction factors according to sex and gestational stage. Therefore, studies are needed to determine the accuracy of estimation methods described in the literature at various ages and in different environmental conditions.

The present study aimed to evaluate and compare the accuracy of six methods to estimate BW in young (male and female) and adult (males, non-pregnant females, pregnant females) Campolina horses.

2. Material and Methods

Data used in this study were collected in the second half of 2012 during the National Campolina Horse Show (Belo Horizonte, MG, Brazil), after the approval of the Research Ethics Committee, under protocol 039/12. We evaluated a sample of 380 horses divided by sex (males, non-pregnant females, and pregnant females), age class (6 to 12 months, 12 to 24 months, 24 to 36 months, 36 to 60 months, and more than 60 months of age), and gestational stage (up to five months of gestation, 6-8 months, and 9-11 months) (Table 1).

First, animals were weighed on a scale (Filizola®, Model 3000 kg, precision of 1,000 g) that was previously calibrated and installed in the premises of the exhibition area. Then, BW of the animals was estimated using the following alternative methods described in the literature:

A - Commercial measuring tape for weighing horses (Sertão Agroveterinária®), composed of resistant plastic canvas, approximately 2.3 m long, placed in three different positions on the thorax of the animal, as described by Souza et al. (2017b). Position 1: tape positioned immediately after the elbow and over the withers; position 2: tape positioned immediately after the elbow and after the withers; position 3: tape positioned behind the withers at the perpendicular height of the ninth rib.

B - Crevat and Quetelet's mathematical formula (Cintra, 2013):

BW (kg) = $TP^3 \times 80$, in which TP^3 = thoracic perimeter in cubic meters.

The measuring tape was placed on the thorax behind the withers at the perpendicular height of the ninth rib after respiratory expiration.

Table 1 - General characterization of the Campolina sample studied

Sex	Age (months)	n	BCS	WH (cm)	BL (cm)	TP (cm)	CP (cm)	DTI	BI
Males	6 to 12	19	3.0±0.0	134.4±5.7	129.7±5.6	152.3±6.1	17.1±1.0	11.2±0.4	85.2±2.6
	>12 to 24	24	3.0±0.2	149.2±8.3	147.4±7.0	172.9±7.6	19.0±0.8	11.0±0.4	85.2±3.1
	>24 to 36	9	3.3±0.5	156.1±2.9	156.1±3.3	185.0±6.1	19.8±0.5	10.7±0.4	84.4±2.7
	>36 to 60	28	3.1±0.3	159.7±3.1	157.6±5.2	186.3±5.8	19.9±0.8	10.7±0.3	84.6±2.9
	>60	34	3.2±0.4	158.9±5.1	160.8±5.8	189.6±5.4	20.2±0.8	10.6±0.3	84.8±2.9
Non-pregnant females	6 to 12	33	2.9±0.1	135.8±5.3	130.4±7.2	154.0±6.7	16.9±1.0	11.0±0.5	84.7±3.6
	>12 to 24	63	3.2±0.4	148.8±4.9	148.5±7.0	175.8±8.2	18.4±0.8	10.5±0.4	84.4±2.7
	>24 to 36	34	3.5±0.5	153.2±4.5	154.9±6.1	186.9±8.1	19.1±0.7	10.2±0.4	82.9±2.8
	>36 to 60	42	3.6±0.5	158.6±4.3	160.3±6.7	193.6±7.4	19.4±0.7	10.0±0.4	82.8±3.1
	>60	58	3.5±0.6	159.1±4.5	161.6±6.1	196.3±7.8	19.8±0.8	10.1±0.5	82.4±3.3
	Gestation stage								
Pregnant females	>5 months	4	3.5±0.4	161.0±2.5	161.0±4.5	201.5±13.4	19.5±0.6	9.7±0.6	80.1±5.2
	6 to 8 months	20	3.4±0.4	157.1±5.1	161.1±4.5	199.9±5.4	19.4±0.7	9.7±0.3	80.6±1.8
	9 to 11 months	12	3.3±0.6	158.0±3.6	161.3±6.4	202.8±6.6	19.1±0.6	9.4±0.4	79.5±3.1

n - number of animals; BCS - body condition score, scale from 0 to 5 (Carrol and Huntington, 1988); WH - withers height; BL - body length; TP - thoracic perimeter; CP - cannon perimeter; DTI - dactylo-thoracic index; BI - body index.

C - Mathematical formula proposed by Hall (1971) and modified by Carrol and Huntington (1988):

BW (kg) = $[(TP^2 \times BL)/11900]$, in which TP^2 = thoracic perimeter in square centimeters, with the measuring tape positioned on the thorax immediately after the elbow and over the withers after respiratory expiration; and BL = body length in centimeters measured with a measuring stick positioned at the tip of the shoulder and at the tip of the buttock.

D - Table proposed by Hintz and Griffiths (1984). This is the only method that considers a correction factor for pregnant female horses. If the animal is a pregnant female, the weight obtained in this table is multiplied by 1.02 (eight months pregnant), 1.06 (nine months pregnant), 1.11 (10 months pregnant), or 1.17 (11 months pregnant).

E - Table proposed by Santos et al. (2008) that was developed for Brazilian Pantaneira horses.

F - Mathematical formula proposed by Cintra (2013) that is specific for weaned foals up to 12 months of age:

BW (kg) = $(TP - 25)/0.7$, in which TP = thoracic perimeter in centimeters with the measuring tape positioned on the thorax immediately after the elbow and over the withers after respiratory expiration.

Body condition score (BCS) was evaluated on a scale from 0 (cachectic) to 5 (very obese) according to the methodology proposed by Carrol and Huntington (1988). To characterize the conformation of the studied animals, the height at the withers, body length, cannon perimeter, and TP were measured according to the methodology cited by Cabral et al. (2004a). With these measures, body (BI) and dactylo-thoracic (DTI) indices were determined to classify the animals according to their functional fitness (Cabral et al., 2004b) (Table 1).

All the statistical analyses were performed using the statistical software R (version 3.4.3; R Core Team, 2017). Sex and age factors were considered as fixed effects. Normality of the data was tested by Shapiro-Wilk test in each age class, sex, and gestational stage at 5% significance level.

The mean BW estimated by the different alternative methods were compared with the real BW (determined using the weighing scale) using the paired t-test parametric method, which is applied to determine if two dependent samples were selected from populations that have the same distribution. The null hypothesis is that the means (real and estimated) are equal. If the null hypothesis is rejected, this test shows that the samples differ from each other, assuming a significance level of 5%, in other words, that there are significant differences between the real and the estimated BW. The test statistic is given by equation 1:

$$T = \frac{D - \mu_d}{Sd/\sqrt{n}} \quad (1)$$

in which D represents mean difference of pairs for sample, μ_d is the mean difference of pairs for population, and Sd is standard deviation of difference of pairs for sample, following a Student's t-distribution with n – 1 degrees of freedom. By hypothesis (samples from the same population), the mean population difference of deviations (μ_d) is zero. The difference between the value observed on the scale and the value estimated by each method for all animals grouped in each of the five age classes was calculated, in which D is the mean and Sd is the standard deviation of these differences.

The mean prediction error (MPE), equation 2, was also used:

$$MPE = 100\left(\frac{BW_r - BW_e}{BW_r}\right) \quad (2)$$

in which BW_r is the real BW and BW_e the estimated BW (Sallum Neto et al., 2013). The MPE was obtained through the means of the deviations between the actual weight and the weight estimated by the alternative methods, in which negative values indicate overestimation of the actual weight and positive values, its underestimation; the closer to zero, the better is the MPE value of the method.

The coefficient of determination (R^2) was used and calculated as the square of the simple linear correlation coefficient between the estimated and observed values; the closer to 1, the better.

Whenever the null hypothesis was not rejected, the means between the estimating methods and the real weights were similar, according to the paired t test. Then, the MPE and the R^2 were used as a complement to select the most reliable method to estimate BW in each subgroup studied. On the other hand, if the null hypothesis was rejected, then the estimated means were different from those observed, according to the paired t test at 5% significance level, and the method is not considered a good one.

Specific correction factors were also determined for methods B and C in this breed, according to the methodology proposed by Souza et al. (2017b). For method B, the correction factor was calculated by dividing the real BW by the BW estimated by this method and then multiplying by the constant (80) of method B. For method C, the correction factor was calculated by dividing the real BW by the BW estimated by this method and then dividing the constant (11,900) of method C by the obtained value.

3. Results

The BI of males and non-pregnant females (BI<85) classified the animals as small in stature (Table 1). Considering DTI, the animals of both sexes were hypometric, small, and slim (DTI<10.5) as they approached adulthood. Body index values <85 and DTI<10.5 in pregnant female horses decreased as gestation progressed, and animals of this breed were, therefore, classified as small in stature and hypometric.

Normality was verified by the Shapiro-Wilk test for all data (P>0.05). The BW estimated using the weight tape differed from the real weight shown on the scale (P<0.05) when the tape was at position 3 in males and at positions 1 and 3 in females (Table 2 and Figure 1). Within the age classes, the real and estimated BW were similar when the tape was at positions 1 and 2 (P>0.05), except for males aged 36 to 60 months and females over 36 months. The BW estimated with the tape at position 3 differed from the scale weights in all age classes for both sexes (P<0.05). The BW using the tape at position 3 were overestimated (MPE ranging from −0.0845 to −0.2186) (Table 2). In the studied population, the mean differences observed at positions 1 and 2 were 2.15 kg for males and 4.5 kg for females.

The BW estimated by the mathematical formulas differed from the scale weights in the overall population as well as after subgrouping by sex and age class (P<0.05), except for Campolina females aged 24 to 36 months (Method C, Table 3 and Figure 1). The MPE values show that method C underestimated BW, while method B overestimated it (Table 3).

Table 2 - Scale and tape-estimated body weights of Campolina equines

Sex	Age (months)	n	Scale weight (kg)	Commercial tape (kg) - Method A								
				Position 1			Position 2			Position 3		
				Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2
Males	6 to 12	19	259.4±32.4	263.0±63.2	−0.0099	0.4192	262.6±62.8	−0.0082	0.4407	296.4±35.1*	−0.1459	0.7667
	>12 to 24	24	376.9±51.8	371.9±52.0	0.0135	0.9464	372.4±50.0	0.0109	0.9169	419.5±50.7*	−0.1172	0.7573
	>24 to 36	9	451.3±23.4	445.7±37.8	0.0126	0.3731	437.5±33.5	0.0304	0.4064	496.8±42.1*	−0.1021	0.0720
	>36 to 60	28	471.8±46.5	486.7±38.0*	−0.0342	0.7388	469.7±34.7	0.0012	0.6913	510.2±40.6*	−0.0848	0.6099
	>60	34	492.0±39.9	499.5±40.5	−0.0169	0.5639	483.1±35.4	0.0155	0.4252	532.4±37.3*	−0.0845	0.5889
Total		114	420.9±93.6	425.9±99.0	−0.0113	0.9081	416.2±91.3	0.0082	0.8939	461.0±93.8*	−0.1031	0.9188
Non-pregnant females	6 to 12	33	256.6±43.7	253.2±32.9	0.0022	0.5751	255.5±31.6	−0.0075	0.5774	307.9±37.5*	−0.2186	0.4208
	>12 to 24	63	384.3±54.6	381.7±50.6	0.0043	0.9012	384.2±48.8	−0.0029	0.9015	437.6±54.0*	−0.1441	0.8042
	>24 to 36	34	437.4±73.6	456.7±52.1	−0.0924	0.3135	450.9±50.7	−0.0795	0.2989	506.3±58.4*	−0.2186	0.0094
	>36 to 60	42	496.0±62.2	509.0±50.6*	−0.0449	0.0641	497.2±67.0	−0.0149	0.5871	541.4±52.4*	−0.1409	0.1616
	>60	58	516.6±65.7	524.7±50.3*	−0.0294	0.0881	517.9±51.8	−0.0122	0.8058	546.2±46.4*	−0.1270	0.2338
Total		230	435.9±108.9	432.9±104.8*	−0.0277	0.6653	429.9±102.2	−0.0194	0.8823	464.5±96.8*	−0.1654	0.0021

n - number of animals; MPE - mean predict error; R^2 - coefficient of determination.
* Significant difference under the paired test (P<0.05).

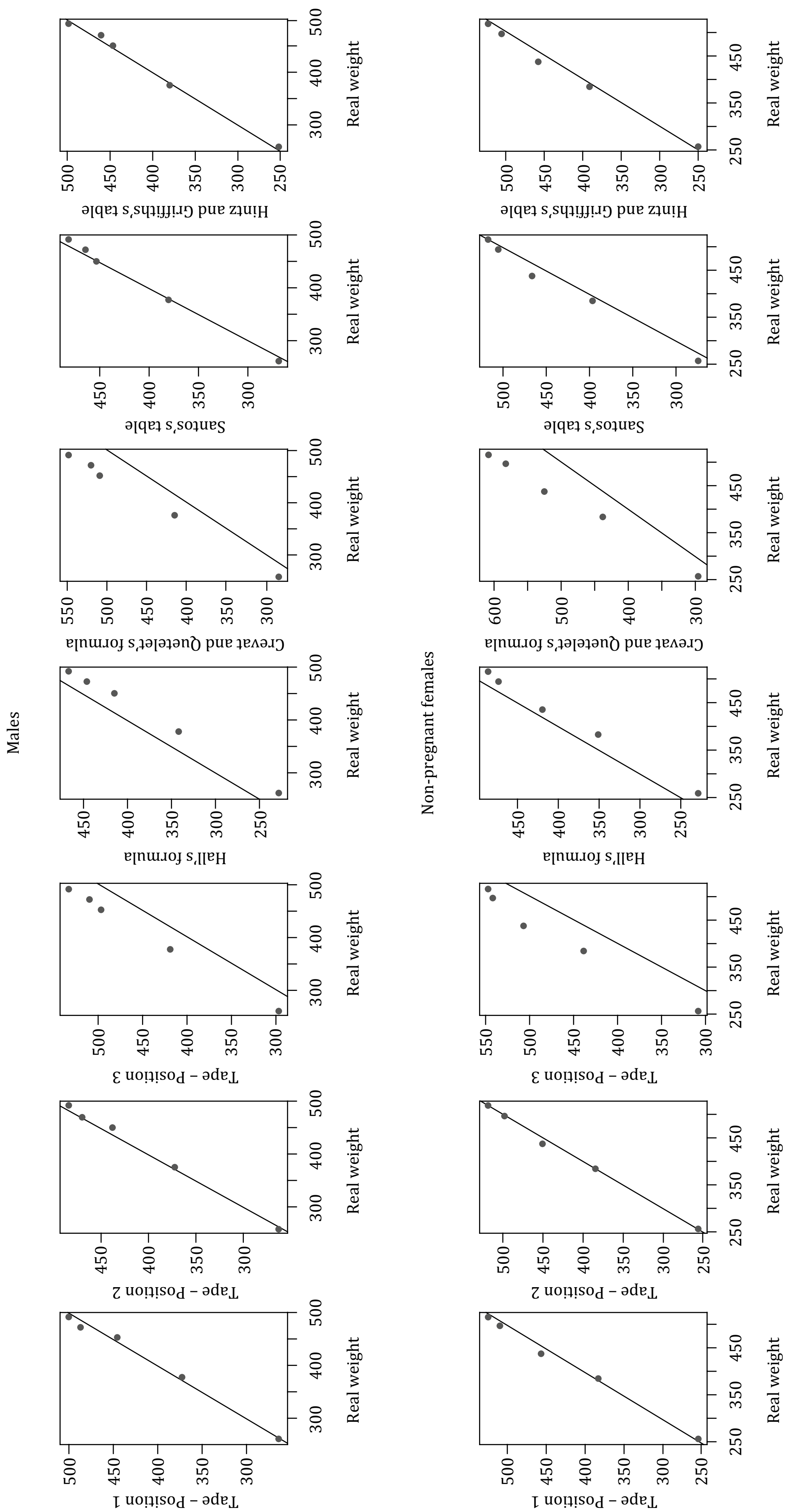

Figure 1 - Graphical representation of consistency of predicted and real body weight observations in males and non-pregnant females.

Table 3 - Scale and formula-estimated body weights of Campolina equines

Sex	Age (months)	n	Scale weight (kg)	Mathematical formulas					
				Hall[1] - Method C			Crevat and Quetelet[2] - Method B		
				Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2
Males	6 to 12	19	259.4±32.4	227.73±29.31*	0.1221	0.9123	284.09±36.11*	−0.0971	0.7986
	>12 to 24	24	376.9±51.8	341.79±51.83*	0.0943	0.9506	415.93±54.81*	−0.1060	0.7847
	>24 to 36	9	451.3±23.4	413.76±33.41*	0.0834	0.4553	508.01±51.13*	−0.1269	0.0600
	>36 to 60	28	471.8±46.5	445.88±37.75*	0.0534	0.8482	519.52±48.91*	−0.1031	0.6638
	>60	34	492.0±39.9	465.65±39.18*	0.0528	0.7097	547.23±47.36*	−0.1137	0.5756
Total		114	420.9±93.6	391.00±94.90*	0.0756	0.9631	465.80±105.70*	−0.1078	0.9188
Non-pregnant females	6 to 12	33	256.6±43.7	228.48±32.63*	0.1019	0.6111	294.18±39.44*	−0.1631	0.4054
	>12 to 24	63	384.3±54.6	350.78±48.64*	0.0860	0.9262	438.17±61.68*	−0.1428	0.8211
	>24 to 36	34	437.4±73.6	418.68±50.90	−0.0039	0.2490	525.78±68.69*	−0.2538	0.3474
	>36 to 60	42	496.0±62.2	473.20±52.63*	0.0332	0.7575	583.17±65.81*	−0.1914	0.7143
	>60	58	516.6±65.7	485.11±47.53*	0.0514	0.7662	608.35±70.51*	−0.1884	0.6531
Total		230	435.9±108.9	399.50±100.00*	0.0566	0.8919	499.90±124.20*	−0.1825	0.8742

n - number of animals; MPE - mean predict error; R^2 - coefficient of determination.
* Significant difference under the paired test ($P<0.05$).
[1] Formula proposed by Hall (Carrol and Huntington, 1988).
[2] Formula proposed by Crevat and Quetelet (Cintra, 2013).

Correction factors were calculated based on the differences between the real weight provided by the scale and weights estimated by methods B and C. Appropriate corrections were made to the constants of these methods, and the new equations are proposed based on the data analyzed in the present study. However, it is noteworthy that these proposed formulas are based on this database, being necessary to verify the applicability and reliability of these new methods on different farms of this breed. The methods were adapted for males, pregnant females, and non-pregnant females as described below:

- For males:

Adapted method B: BW (kg) = $TP^3 \times 72$;

Adapted method C: BW (kg) = $[(TP^2 \times BL)/11{,}000]$.

- For non-pregnant females:

Adapted method B: BW (kg) = $TP^3 \times 68$;

Adapted method C: BW (kg) = $[(TP^2 \times BL)/11{,}226]$.

- For pregnant females:

Adapted method B: BW (kg) = $TP^3 \times 65$;

Adapted method C: BW (kg) = $[(TP^2 \times BL)/10{,}922]$.

The mean BW estimated by method D were similar to the real BW for the general population of males (P<0.05), but not for females (Table 4 and Figure 1). Within each sex and age class, there was a difference between the BW estimated by this method and the real BW in females aged 12 to 24 months and over 36 months (P<0.05). The BW was underestimated in males and overestimated in females using method D.

The BW estimated by method E were different from the real weights shown on the scale for non-pregnant females (P<0.05) (Table 4). Within each sex and age class (Table 4), BW estimated by method E was similar to the scale weight (P<0.05) in all males, except for foals aged 6 to 12 months, which shows that it is also a good BW estimation method.

The values for pregnant female horses also differed from the real weight when the tape was at position 3 (Table 5), and the mean difference was 1.60 kg at the three gestational stages at positions 1 and 2. Body weights estimated by methods B and C differed from the real weight shown on the scale (P<0.05) at all gestational stages, except for method C at less than five months of gestation (Table 5). Based on MPE values, only method C underestimated the BW (MPE from 0.0564 to 0.1001), and method B overestimated the real weight at all gestational stages (MPE from −0.2184 to −0.2616). For weaned Campolina foals, the BW estimated by method F differed from the real scale weight (P<0.05), and this parameter was underestimated (Table 6).

4. Discussion

In this study, population of CAM horses, males and non-pregnant females, had BI that classified them as small in stature (BI<85) and matched a conformation closer to traction/load as described by Rezende et al. (2016) (Table 1). Considering DTI, animals of both sexes were hypometric, small, and slim (DTI<10.5) as they approached adulthood. These results disagree with the studies of Lucena et al. (2016), which classified stallions of this breed as medium and eumetric. However, adult females were also classified by the authors as hypometric. These findings demonstrate that the animals are not in the body proportions recommended by the standard of the CAM breed, which classifies them as medium and eumetric (Inglês et al., 2004). A possible explanation for these results, reported by Lucena et al. (2016), would be the subjectivity applied in the selection of the animals used in reproduction, chosen according to results obtained in equestrian competitions. This has also been seen in other scientific study, such as that carried out by Santos et al. (2018), who found that

Table 4 - Scale- and table-estimated body weights of Campolina equines

Sex	Age (months)	n	Scale weight (kg)	Weight tables					
				Santos et al.[1] - Method E			Hintz and Griffiths[2] - Method D		
				Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2
Males	6 to 12	19	259.4±32.4	268.62±29.89*	−0.0397	0.6997	251.32±42.13	0.0339	0.8573
	>12 to 24	24	376.9±51.8	380.17±46.22	−0.0116	0.8385	378.33±57.04	−0.0034	0.1886
	>24 to 36	9	451.3±23.4	453.12±44.49	−0.0050	0.0897	446.11±34.26	0.0108	0.1886
	>36 to 60	28	471.8±46.5	464.91±39.77	0.0118	0.5993	460.86±89.70	0.0185	0.0561
	>60	34	492.0±39.9	480.50±36.01	0.0167	0.0027	497.79±40.88	−0.0151	0.2260
Total		114	420.9±93.6	417.50±85.80	−0.0017	0.6339	418.4±104.30	0.0058	0.7510
Non-pregnant females	6 to 12	33	256.6±43.7	275.26±34.63*	−0.0902	0.3423	249.39±36.74	0.0171	0.4698
	>12 to 24	63	384.3±54.6	396.65±50.88*	−0.0363	0.8200	390.79±53.49*	−0.0196	0.8212
	>24 to 36	34	437.4±73.6	465.26±57.18*	−0.1176	0.0162	458.68±57.49	−0.1029	0.1712
	>36 to 60	42	496.0±62.2	504.34±51.81*	−0.0473	0.0365	505.12±56.90*	−0.0334	0.7091
	>60	58	516.6±65.7	516.26±45.86*	−0.0374	0.0895	522.52±52.16*	−0.0218	0.7325
Total		230	435.9±108.9	433.10±95.90*	−0.0596	0.0546	434.70±105.50*	−0.0297	0.8658

n - number of animals; MPE - mean predict error; R^2 - coefficient of determination.
[1] Table proposed by Santos et al. (2008).
[2] Table proposed by Hintz and Griffiths (1984).
* Significant difference under the paired test ($P<0.05$).

Table 5 - Mean scale, tape-, formula-, and table-estimated weights and standard deviations of pregnant Campolina mares

Pregnancy stage (months)	n	Scale weight (kg)	Commercial tape (kg) - Method A								
			Position 1			Position 2			Position 3		
			Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2
<5	4	520.75±35.79	478.66±59.46	0.0515	0.6782	520.00±51.59	0.0020	0.6926	541.50±40.30*	−0.0855	0.4455
>6 to 8	20	527.42±52.63	524.05±43.69	0.0000	0.0233	528.55±48.52	−0.0042	0.7439	569.11±28.58*	−0.1968	0.7846
>9 to 11	12	537.58±54.29	526.25±48.01	0.0194	0.8309	526.25±48.01	0.0194	0.8447	564.25±9.60*	−0.1531	0.3637
Total	36	530.06±50.73	520.82±46.92	0.0114	0.0186	526.83±47.14	0.0044	0.7532	564.13±26.30*	−0.1703	0.5953

Pregnancy stage (months)	n	Scale weight (kg)	Mathematical formulas					
			Hall[1] - Method C			Crevat and Quetelet[2] - Method B		
			Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2
<5	4	520.75±35.79	491.25±32.93*	0.0564	0.9356	661.17±136.30	−0.2616	0.8858
>6 to 8	20	527.42±52.63	485.94±45.59*	0.0766	0.6879	640.38±51.72*	−0.2184	0.6388
>9 to 11	12	537.58±54.29	483.55±49.19*	0.1001	0.9035	669.55±65.78*	−0.2505	0.3217
Total	36	530.06±50.73	485.73±44.57*	0.0822	0.7545	652.41±67.80*	−0.2339	0.4335

Pregnancy stage (months)	n	Scale weight (kg)	Weight tables					
			Santos et al.[3]- Method E			Hintz and Griffiths[4] - Method D		
			Estimated weight (kg)	MPE	R^2	Estimated weight (kg)	MPE	R^2
<5	4	520.75±35.79	522.13±36.40	−0.0111	0.5056	527.50±67.01	−0.0300	0.6955
>6 to 8	20	527.42±52.63	528.06±26.23*	−0.0241	0.3746	539.74±58.17	−0.0621	0.7195
>9 to 11	12	537.58±54.29	529.04±16.63*	−0.0907	0.5170	585.93±59.06*	−0.0791	0.8516
Total	36	530.06±50.73	527.42±24.52*	−0.0615	0.4415	553.78±62.16*	−0.0449	0.7025

n - number of animals; MPE - mean predict error; R^2 - coefficient of determination.
[1] Formula proposed by Hall (Carrol and Huntington, 1988).
[2] Formula proposed by Crevat and Quetelet (Cintra, 2013).
[3] Table proposed by Santos et al. (2008).
[4] Table proposed by Hintz and Griffiths (1984).
* Significant difference under the paired test (P<0.05).

Table 6 - Mean (standard deviations) scale and Cintra's formula (2013) estimated live body weights of weaned Campolina foals and fillies

Sex	n	Scale weight (kg)	Estimated weight (kg)		
			Mathematical formula		
			Cintra[1] - Method F	MPE	R^2
Males	19	259.4±32.4	170.22±9.42*	0.3382	0.9130
Females	33	256.6±43.7	169.87±10.44*	0.3247	0.5466

n - number of animals; MPE - mean predict error; R^2 - coefficient of determination.
[1] Formula proposed by Cintra (2013).
* Significant differences under the paired test (P<0.05).

the judgment methodology adopted to select Campolina animals does not correlate, in subsequent generations, with the morphology recommended by the standard of this breed. Thus, the evolution of the conformation of the horses over the years may be different from those that served as a basis for the elaboration of the CAM breed pattern, changing its classification in terms of body proportions, as verified in the present study. Body index values <85 and DTI<10.5 in pregnant females decreased as the pregnancy progressed and animals were classified as small in height and hypometric.

The accuracy of method A varied as a function of the position of the tape on the animal's thorax, both in the general population and in each age group. In the general population of this study, the mean differences obtained for BW estimated with the tape at positions 1 and 2 were 2.15 kg for males and 4.5 kg for females. Wagner and Tyler (2011) also studied the impact of the position of the tape on the horses and observed a difference of 65.81 kg between the BW estimated by the tape at position 1 and the scale weight in 110 adult horses of more than 20 breeds (Quarter horse, Paso Fino, Mustangs, among others). According to these authors, verification of the reliability of this method is necessary, as there are numerous types of tapes available for purchase on the market, which vary from the material they are manufactured to the indication for breeds to be used. Thus, these differences found between the actual weight and the estimated weight can provide practical information for professionals and breeders about the effectiveness of the tape in kilograms in the animals of the CAM breed, facilitating adjustments in the formulations of diet and application of medications that are based on BW of animals, but additional studies are necessary to verify the efficiency of various types of weighing tapes in the same breed.

Body measurements at a location other than that recommended by the weight estimation method is a factor that reduces its accuracy. The BW of animals using the tape at position 3 were overestimated (Table 2; MPE ranging from −0.0845 to −0.2186), which indicates that placing the tape behind the withers at the perpendicular height of the ninth rib is not the correct approach if applying this method. The measuring tape estimated the BW with good quality (Table 2) when placed at positions 1 or 2 (mainly at position 2, with MPE ranging from −0.0795 to 0.0304) in the different age and sex classes, and it can be used in breeding facilities if there is no scale available. Hoffmann et al. (2013) and Ellis and Hollands (2002) described similar findings, as these studies confirmed the accuracy of commercial weight tapes to estimate BW when placed at position 2.

Interestingly, the measuring tape at positions 1 and 2 was more accurate in CAM males than in females. This can be related to the existing morphological sex differences, that is, the sexual dimorphism in the species, since males have secondary sexual characteristics that influence the growth of body regions and directly affect BW (Santos et al., 2007; McManus et al., 2010). The differences observed in the accuracy of the tape estimation method according to sex and age class agree with the study of Lewis (2000), which stated that live weight is affected by several factors internal or external to the animal, such as sex, age, gestational stage, BCS, breed, and environmental conditions. This was also confirmed by a study conducted by Souza et al. (2017b) in the Brazilian Mangalarga Marchador breed from the state of Minas Gerais, Brazil, and in the Campolina breed.

For pregnant female horses, there were also differences when the tape was used at position 3 (Table 5), and BW were overestimated, which can be related to the gestational stage, thus showing that using the tape at this position is not recommended in female horses of these genetic groups. Bromerschenkel et al. (2010) also found significant differences (P<0.01) between the estimated BW using the tape at different positions and the real weight shown on the scale in Mangalarga Marchador female horses in the early gestational stage in a study that evaluated the use of the tape placed in two ways: circumference of the thorax passing through the posterior border of the withers (differences of 67.10 kg were found) and circumference of the thorax passing through the maximum height of the withers (error of 13.72 kg). In this study, the mean difference found in the three gestational stages with the tape at positions 1 and 2 was only 1.60 kg.

The BW estimated by the two mathematical formulas differed from the BW on the scale in the general population and in subgroups according to sex and age class (P<0.05), with the exception of CAM females aged 24 to 36 months (Method C, Table 3). A much higher than acceptable variation (above 10% according to Milner and Helwitt (1969)) was observed for the estimated BW of these animals, and it is, therefore, not recommended to use these methods to manage breeding activities in this breed. Milner and Helwitt (1969) found a mean absolute percentage error of 10% in the BW estimated by method B, suggesting that this could be related to the fact that this method uses only TP for the calculation. The differences observed when using the mathematical formulas in our study may be due to these methods having been developed for foreign breeds with different conformations compared with Brazilian breeds; therefore, they are not sufficiently accurate to be used in this genetic group and require the calculation of correction factors, as shown by Souza et al. (2017b).

The BW estimated by methods B and C differed from the scale weight at all gestational stages (P<0.05), except for method C at less than five months of gestation, which shows that these methodologies are not accurate for this breed (Table 5). Method B was more accurate (P<0.05) in the early and mid-gestational stages and can be used in these cases. Method B may show better results in the mid-gestational stage because it has a correction factor for pregnant females from the eighth month. However, for animals at the early gestational stage, there were no differences between the estimated and the scale weight as there is still no effect of fetal growth on the conformation of the animals and, consequently, their BW (NRC, 2007).

Based on MPE values, only method C underestimated BW (MPE from 0.0564 to 0.1001), and method B overestimated the real weight in all gestational stages (MPE from −0.2184 to −0.2616). Bromerschenkel et al. (2010) evaluated the use of Hall's formula to estimate BW in Mangalarga Marchador pregnant female horses in the early gestational stage and found a significant difference (P<0.01) between the BW estimated by this formula and the real weight, which is consistent with the results of our study.

The mean BW estimated by method D were similar to the real BW in the general population of males (P<0.05), but not in females (Table 4). In each sex and age class, there were only significant differences between BW estimated by this method and real BW in females aged 12 to 24 months and over 36 months (P<0.05).

Body weights estimated by method E differed from scale weights in non-pregnant females (P<0.05) (Table 4). However, in each sex and age class (Table 4), BW estimated by this method were similar to the scale weights (P<0.05) in all males, except for foals aged 6 to 12 months, which shows that this is a good BW estimation method.

The MPE values for the BW estimated using the two tables (methods D and E) were similar to those obtained for the tape at positions 1 and 2, which underestimated BW in males and overestimated it in females. However, MPE values for method E were well below the error range reported in the literature, except for CAM females aged >24 to 36 months (−0.1176). These results suggest that the two tables provide good accuracy when applied to Campolina horses. Method E was developed for Pantaneira horses, a breed that originates from crosses of Iberian horses (Luzitano thoroughbred and Spanish thoroughbred, Celtic, Barbo) (McManus et al., 2008), and these are the same animals that originated the Campolina breed. This can explain the efficiency of this method to estimate BW in this breed.

To better evaluate the accuracy of BW estimates in weaned foals, a specific formula for foals up to 12 months of age (method F) was included in the analysis (Table 6). The estimated BW differed from the scale BW ($P<0.05$), and this parameter was underestimated much more than expected for both sexes, which shows that this formula is not accurate in estimating the BW of weaned CAM foals.

5. Conclusions

Weight tape placed at positions 1 and 2 as well as methods D and E can be used to accurately estimate body weight of Campolina females and males. Method A with the tape placed at position 2 is the most accurate in predicting body weight, including pregnant females and weaned foals, and, therefore, can be considered the most appropriate method to estimate body weight of Campolina horses of both sexes and different ages. For methods B and C, correction factors are required to accurately estimate body weight of Campolina horses.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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