rccp Revista Colombiana de Ciencias Pecuarias

Relationship between body and testicular measurements in young buffalo bulls in Cuba¤

Relación entre las mediciones corporales y testiculares en búfalos jóvenes en Cuba

Relação entre medidas corporais e testiculares em búfalos jovens em Cuba

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(Received: May 06, 2015; accepted: January 23, 2017)

doi: 10.17533/udea.rccp.v30n2a05

Abstract

Background: appropriate selection of sires holds great importance in plans to genetically improve and raise buffalos. **Objective:** to obtain a statistical model that provides accurate associations between body and testicular measurements intended for selection of Bufalypso breed sires. **Methods:** measurements of body weight (BW), thoracic perimeter (TP), and scrotal circumference (SC) from 649 buffalos aged 2 to 36 months, were used to obtain the models corresponding to the associations between these traits. The statistical significance of the model and the model's parameters were evaluated using a one-way analysis of variance. The best-fit model was established by calculating determination coefficients (R^2) and mean squared error (SE). **Results:** the most adequate regression model between thoracic perimeter and body weight was $TP = 19.89*BW^{0.37}$, with 99% and 0.03 for R^2 and, SE, respectively. The best association between scrotal circumference and body weight was obtained with the model $SC = 1.13*BW^{0.51}$, with values of 89% for R^2 and of 0.1 for SE. The model that best expressed the relationship between scrotal circumference and thoracic perimeter was $SC = 0.02*TP^{0.89}$, with $R^2 = 89\%$ and SE = 0.01. **Conclusion:** nonlinear models described better the association between body and testicular measurements than the linear ones. These results suggest that nonlinear models are effective for selecting buffalo sires.

Keywords: *body weight, modeling, nonlinear regression, scrotal circumference, thoracic perimeter.*

¤ To cite this article: Almaguer Y, Font H, Cabrera S, Arias Y. Relationship between body and testicular measurements in young buffalo bulls in Cuba. Rev Colomb Cienc Pecu 2017; 30:138-146.

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Resumen

Antecedentes: la selección de sementales tiene gran importancia en los planes de mejora genética y cría de búfalos. **Objetivo**: obtener los modelos estadísticos que mejor relacionan las mediciones corporales y testiculares en machos jóvenes de raza Bufalypso para su uso en la selección de futuros sementales. **Métodos:** se midió el peso corporal (BW), el perímetro torácico (TP) y la circunferencia escrotal (SC) a 649 búfalos, entre 2 y 36 meses de edad, obteniéndose los modelos correspondientes a las relaciones entre estas características. La significación estadística de los modelos y parámetros se evaluó mediante análisis de varianza de una vía. El mejor modelo de ajuste se determinó a partir de cálculos de los coeficientes de determinación (R^2) y el error cuadrático medio (SE). **Resultados:** el modelo más adecuado entre el perímetro torácico y el peso corporal fue $TP = 19{,}89*BW^{0.37}$, con valores de R^2 de 99% y de 0,03 para SE. La mejor relación entre la circunferencia escrotal y el peso corporal se obtuvo con el modelo $SC = 1{,}13*BW^{0.51}$, con un R^2 igual al 89% y un SE de 0,1. El modelo que mejor expresó la relación entre la circunferencia escrotal y el perímetro torácico fue $SC = 0{,}02*TP^{0.89}$, con valores de 89% para R^2 de y de 0,01 para SE. **Conclusión:** los modelos no lineales describieron mejor la relación entre las mediciones corporales y testiculares que los modelos lineales. Los resultados sugieren que la selección de los sementales sería más efectiva utilizando modelos no lineales.

Palabras clave: *circunferencia escrotal, modelación, perímetro torácico, peso corporal, regresión no lineal.*

Resumo

Antecedentes: a seleção de reprodutores é muito importante nos programas de melhoramento e criação de búfalos. **Objetivo:** obter modelos estatísticos que melhor relacionem as medidas corporais e testiculares em machos jovens da raça Bufalypso, para serem usados na seleção de futuros reprodutores**. Métodos:** foi medido o peso corporal (BW), o perímetro torácico (TP) e a circunferência escrotal (SC) de uma amostra de 649 búfalos, com idades entre 2 e 36 meses. A significância estatística dos modelos e dos parâmetros foi avaliada pela análise de variância. O melhor modelo de ajuste foi determinado a partir do cálculo dos coeficientes de determinação (R^2) e o quadrado médio do erro (SE)**. Resultados:** o modelo mais adequado para o perímetro torácico e o peso corporal foi $PT = 19{,}89*BW^{0,37}$ com R^2 de 99% e SE de 0,03. A melhor relação entre circunferência escrotal e o peso corporal foi obtida com o modelo $SC = 1{,}13*BW^{0,51}$ com R^2 de 89% e SE de 0,1. O modelo que melhor representou a relação entre a circunferência escrotal e o perímetro torácico foi $SC = 0{,}02*TP^{0,89}$ com valores de R^2 de 89% e SE 0,01**. Conclusão:** os modelos não lineares descreveram melhor a relação entre as mensurações corporais e as testiculares do que os modelos lineares. Esses resultados sugerem que a seleção dos reprodutores seria mais eficaz utilizando os modelos não lineares.

Palavras chave: *circunferência escrotal, modelagem, perímetro torácico, peso corporal, regressão não-linear.*

Introduction

From the time when buffaloes were first introduced into Cuba, buffalo rearing has evolved through several stages, such as adaptation, spread, and productive management. The initial river species (*Bubalis bubalis*) and swamp species (*Bubalis carabanensis*) were crossbred to obtain the current Bufalypso breed.

Cuba's buffalo herd has increased remarkably in recent years. Approximately 3000 heads were introduced into the country between 1983 and 1986 according to data published by ONEI (2013). More than 61,000 heads, of which 46,000 were milking buffalo cows, produced more than 4.3 million L of milk during 2012. Moreover, there were 9,900 births and 10,700 slaughters in the same year, producing more than 4,000 tons of buffalo meat. These developments result from a growing number of studies in animal sciences, genetic improvements, reproduction and health.

Proper strategies for selecting future buffalo sires are very important in breeding programs (Crudeli *et al.,* 1997; Yanez *et al.,* 1997). Selection demands systematic assessment of buffalo calves from an early age, and sires are commonly selected for their body and testicular measurements. Physiology has adapted to environmental challenges, influencing these measurements. Knowledge and control of animal growth enable specialists and breeders to design selection programs suitable for a given species and is therefore of immense interest (Olegario *et al*., 2012).

Studying buffalo bulls in Cuba, Montes *et al.* (2007) proposed a set of linear correlations between body and testicular measurements of buffalo calves. Nevertheless, after analyzing the dispersion graphics of those traits, we suggest that the accuracy of buffalo sire selection could be improved with the adoption of nonlinear models. The objective of this study was to obtain statistical models that best relate body and testicular measurements in young males in order to use them for the selection of future Bufalypso sires.

Materials and methods

Statistical analysis

The analysis was conducted on a sample of Bufalypso buffalos between 2 and 36 months of age. The sample, representative of the total population, consisted of 649 buffalo calves/bulls from 12 herds spread across the country. Sampling was stratified with proportional allotment at 95% confidence level, as follows: 2-12 months of age (84 calves), 13-24 months of age (97 young bulls), and 25-36 months of age (468 adult bulls).

The animals were reared in tropical conditions (from 22 to 38 °C), and fed on natural pastures, without concentrate. Body weight (BW), thoracic perimeter (TP), and scrotal circumference (SC) were measured in each animal. Body weight (BW) was measured using an analog scale (Fairbanks Scales, Kansas City, MO, USA). Thoracic perimeter (TP) and scrotal circumference (SC) were measured with a metric tape.

Relevant traits were analyzed by simple regression using the classical regression method (Ortiz, 2000); namely, the statistical significance of the model and the model parameters were evaluated by a one-way analysis of variance, and the parameter values were estimated. The best-fit model was determined from R^2 coefficients and mean squared error.

Prior to the regression analysis, the variables and their interrelationships were subjected to descriptive analysis to determine their natural trends and to select a candidate set of nonlinear models. The selected models are presented in Table 1.

Table 1. Regression models to describe the relationship between body weight (BW) and testicular measurements in Bufalypso buffalos.

Models	Mathematical equation
Linear	$y = \beta_0 + \beta_1 * x$
Logarithmic	$y = \beta_0 + \beta_1 * \ln(x)$
Quadratic	$y = \beta_0 + \beta_1 * x + \beta_2 * x^2$
Cubic	$y = \beta_0 + \beta_1 * x + \beta_2 * x^2 + \beta_3 * x^3$
Power	$y = \beta_0 * x^{\beta 1}$
Growth	$y = \exp^{(\beta 0 + (\beta 1 * x))}$
Compound	$y = \beta_0 * (\beta_1^x)$

β_0, β_1, β_2, β_3 = model parameters. Ln = natural logarithm. exp = exponent.

The regression analyzes were performed using SPSS (version 15, 2006, IBM, Chicago, IL, USA). The expected values were obtained and converted into graphic format using Microsoft Office Excel (Microsoft, Redmond, WA, USA).

Results

Body weight, thoracic perimeter, and scrotal circumference

The BW ranged from 52 to 603 Kg, TP from 80 to 215 cm, and SC from 7 to 31 cm. As expected, these traits were normally distributed. The statistical characteristics of these traits, sorted by animal age, are presented in Table 2.

Regression between thoracic perimeter and body weight

All models were statistically significant. Their associations and variability estimators are presented in Table 3. The R^2 value was higher in the nonlinear models than in the linear model, exceeding 96% in all instances, presenting the lowest variability. The cubic and power law models presented the best fits. According to the estimators for the selection of the best-fit model, the power law model exhibited the

Table 2. Statistical parameters of body and testicular measurements according to age in Bufalypso buffalos.

Variables	Mean	SD	S	K
From 2 to 12 months of age				
BW	104.98	42.97	0.61	-0.95
TP	108.3	17.73	0.39	-1.03
SC	11.89	2.89	0.23	-0.55
From 13 to 24 months of age				
BW	331.45	60.48	0.4	-0.48
TP	167.96	11.74	0.41	-0.46
SC	22.29	2.8	0.02	-0.38
From 25 to 36 months of age				
BW	408.89	61.97	0.06	-0.14
TP	180.68	11.11	-0.07	-0.1
SC	24.17	2.47	-0.41	0.43

SD = standard deviation. S = skew. K = kurtosis. BW = body weight. TP = thoracic perimeter. SC = scrotal circumference.

highest correlation and determination coefficients (99 and 98%, respectively) and the lowest standard error (0.03; Table 3).

The mean square error (MSE) in the first four models gradually decreased from 43.33 to 19.51, whereas the MSE of the power law model never surpassed 0.03.

Table 3. Estimators of the models relating thoracic perimeter (TP) to body weight (BW) in Bufalypso buffalos.

Models	Association		Variability		Sig
	R	R^2	SE	MSE	
Linear	0.97	0.94	6.58	43.33	***
Logarithmic	0.98	0.96	5.08	25.88	***
Quadratic	0.98	0.97	4.69	22.08	***
Cubic	0.99	0.97	4.41	19.51	***
Power	0.99	0.98	0.03	0.03	***

R = correlation coefficient. R^2 = coefficient of determination. SE = standard error. MSE = mean squared error. Sig = statistical significance (*: p<0.05; **: p<0.01; ***: p<0.001).

Table 4 lists the calculated values of the best-fit estimators for the models. All of the fitted models yielded significant coefficients.

Based on these results, we can state that the power law model, $TP = 19.89 * BW^{0.37}$ provides the best fit between TP and BW (Figure 1).

Regression between scrotal circumference and body weight

The statistical significance of the models relating SC to BW is presented in Table 5, and the parameter values are listed in Table 6. All models were significant, although the β_3 parameter of the cubic model was non-significant, suggesting that SC does not vary as the cube of BW.

If SC is assumed as a linear function of BW, scrotal circumferences are underestimated at weights below 100 Kg. In this weight bracket, growth of the structures is accelerated in relation to the increase in BW.

The linear model yielded the lowest coefficient of determination (approximately 80%), followed by the logarithmic and the quadratic models, whose values were very similar. The highest coefficient of determination (89%) was, once again, obtained by the power law model. The estimators of variability showed a similar pattern, being lower than 0.1 for both parameters in the power law model.

The power law fit to the test variables is plotted in Figure 2. The SC is related to BW as $SC = 1.13*BW^{0.51}$.

Regression between scrotal circumference and thoracic perimeter

Finally, we related SC to TP. The statistical outcomes of the hypothesis testing of the models and the model parameters are listed in Tables 7 and 8, respectively. All models and parameters were significant, except the estimated value of β_2 in the cubic model. The coefficients of determination (Table 7) were similar in all linear, logarithmic, and quadratic models. The growth and compound models also displayed very similar, but slightly higher, estimator values. The highest coefficient of determination

Table 4. Parameters and estimators in regression of thoracic perimeter (TP) vs. body weight (BW) in Bufalypso buffalos.

Models	Parameters											
	β_o			β_1			β_2			β_3		
	Value	SE	Sig	Value	SE	Sig	Value	SE	Sig	Value	SE	Sig
Linear	90.11	0.82	***	0.22	0.002	***						
Logarithmic	-126.58	2.25	***	51.15	0.39	***						
Quadratic	71.25	0.96	***	0.38	0.007	***	-0.0002	1.1 x 10^5				
Cubic	59.22	1.58	***	0.57	0.021	***	-0.0009	7.8 x 10^5	***	7.8 x 10^8	8.5 x 10^8	***
Power	19.89	0.25	***	0.37	0.002	***						

β_0, β_1, β_2, β_3 = model parameters. SE = standard error. MSE = mean squared error. Sig = statistical significance (* = p<0.05; ** = p<0.01; *** = p<0.001).

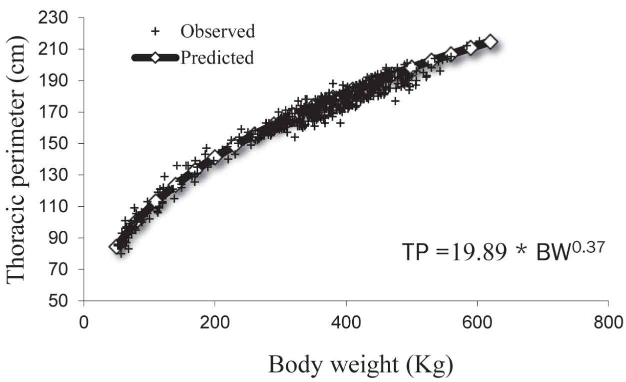

Figure 1. Relationship between thoracic perimeter (TP) and body weight (BW) in Bufalypso buffalos.

Table 5. Estimators for selecting the relationship between scrotal circumference (SC) and body weight (BW) in Bufalypso buffalos.

Models	Association		Variability		Sig
	R	R^2	SE	MSE	
Linear	0.89	0.80	2.16	4.68	***
Logarithmic	0.92	0.84	1.94	3.77	***
Quadratic	0.92	0.84	1.92	3.69	***
Cubic	0.92	0.84	1.91	3.68	***
Power	0.94	0.89	0.09	0.01	***

R = correlation coefficient; R^2 = coefficient of determination; SE = standard error; MSE = mean squared error; Sig = Statistical significance (* = p<0.05; ** = p<0.01; *** = p<0.001).

Table 6. Parameters and estimators for regression of scrotal circumference (SC) vs. body weight (BW) in Bufalypso buffalos.

Models	Parameters											
	β_o			β_1			β_2			β_3		
	Value	SE	Sig	Value	SE	Sig	Value	SE	Sig	Value	SE	Sig
Linear	9.22	0.27	***	0.04	0.0007	***						
Logarithmic	-27.10	0.86	***	8.54	0.150	***						
Quadratic	5.14	0.39	***	0.07	0.003	***	-6 x 10^5	4.4 x 10^6	***			
Cubic	4.26	0.67	***	0.09	0.009	***	-0.0001	3.3 x 10^5	**	1 x 10^7	3.7 x 10^8	NS
Power	1.13	0.04	***	0.51	0.007	***						

β_0, β_1, β_2, β_3 = model parameters. SE = standard error. Sig = statistical significance (NS = non-significant; * = p<0.05; ** = p<0.01; *** = p<0.001).

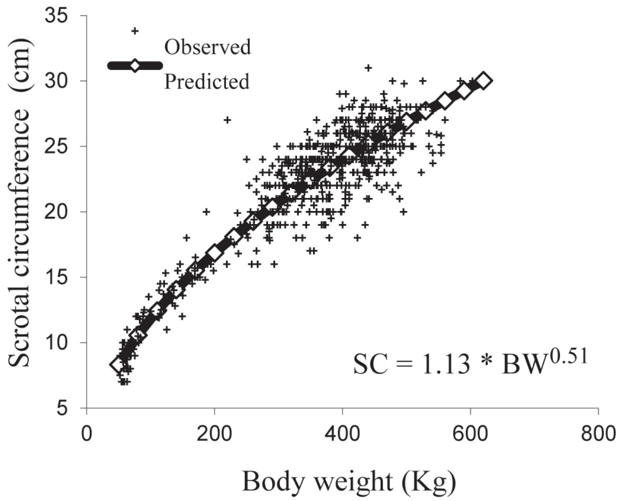

Figure 2. Relationship between scrotal circumference (SC) and body weight (BW) in Bufalypso buffalos.

(89.0%) was, once again, obtained by the power law model. The values for standard error and of mean squared error for the power, growth and compound error models were lower and more similar between themselves. Consequently, the relationship between the SC and TP is given as SC = 0.02*TP$^{0.89}$, and it is plotted in Figure 3.

Table 7. Estimators for determining the relationship between thoracic perimeter (TP) and scrotal circumference (SC) in Bufalypso buffalos.

Models	Association		Variability		Sig
	R	R^2	SE	MSE	
Linear	0.91	0.83	1.96	3.85	***
Logarithmic	0.91	0.83	1.97	3.87	***
Quadratic	0.92	0.84	1.95	3.79	***
Cubic	0.92	0.84	1.94	3.78	***
Power	0.94	0.89	0.09	0.01	***
Growth	0.93	0.86	0.1	0.01	***
Compound	0.93	0.86	0.1	0.01	***

R = correlation coefficient. R^2 = coefficient of determination. SE = standard error. MSE = mean squared error. Sig = statistical significance (* = p<0.05; ** = p<0.01; *** = p<0.001).

Table 8. Parameters and estimators for regression of scrotal circumference (SC) vs. thoracic perimeter (TP) in Bufalypso buffalos.

Models	β_o			β_1			β_2			β_3		
	Value	SE	Sig	Value	SE	Sig	Value	SE	Sig	Value	SE	Sig
Linear	-5.40	0.49	***	0.16	0.003	***						
Logarithmic	-94.98	2.07	***	22.92	0.40	***						
Quadratic	-11.51	1.82	***	0.25	0.02	***	-0.0003	8.6 x 10^5	***			
Cubic	-9.76	1.28	***	0.21	0.13	***	6.776	0.1246	NS	-7.1 x 10^7	1.9 x 10^7	***
Power	0.02	0.002	***	1.37	0.019	***						
Growth	1.44	0.025	***	0.0096	0.00015	***						
Compound	4.23	0.11	***	1.0097	0.0001	***						

β_0, β_1, β_2, β_3 = model parameters; SE = standard error; Sig = statistical significance (^{NS} = non-significant; * = p<0.05; ** = p<0.01; *** = p<0.001).

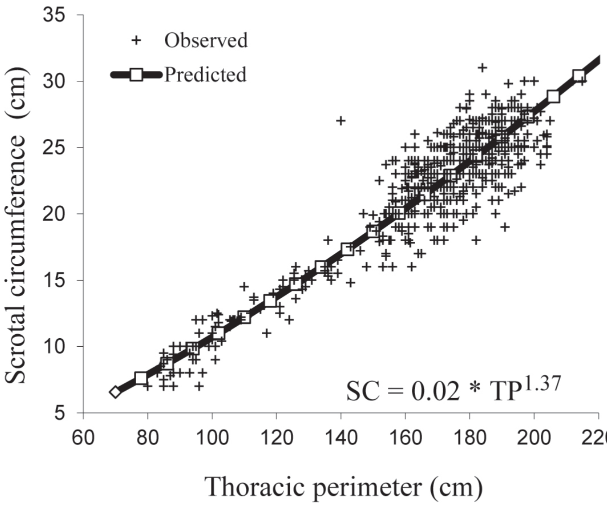

Figure 3. Relationship between scrotal circumference (SC) and thoracic perimeter (TP) in Bufalypso buffalos.

Discussion

Body weight mean increases more rapidly between 0 and 36 than between 37 and 100 months of age (Ahmad *et al*., 2011) and there is a close relationship with testicular development (Cardoso da Luz *et al*., 2013). During this period sperm cell division begins at approximately 12 months of age and spermatogenesis starts at 15 months of age (Arrighi *et al*., 2010).

The average values observed for scrotal circumference in our study coincide with those by Henry *et al.* (2013) for Jaffarabadi calves (11.57 cm), but are lower than results reported for Murrah (14 cm) and Mediterranean breeds (16.2 cm) for animals aged up to 12 months. At 18 months old, average SC (22.29 cm) coincides with values reported for specimens of the Mediterranean breed (23.2 cm) and are lower for Jaffarabadi and Murrah breeds (19 cm).

Cardoso da Luz *et al*. (2013) obtained 25.30 cm average SC at 24 months with a sample of three specimens. The sample analyzed for this study included 54 specimens of this age, and the resulting SC average value was 23.70 cm, which is slightly lower.

Table 9 presents the comparison between our average SC values with those obtained by Singh *et al*. (2010) for the Murrah buffalo. A high level of coincidence of values in the central age range can be seen, whilst the difference becomes more notable in age ranges under 12 and over 30 months.

Table 9. Scrotal circumference (SC) at different ages.

Age range (months)	SC (cm)	SC* (cm)
0-6	8.9 ± 0.29	14.5 ± 0.50
6-12	13.1 ± 0.31	15.3 ± 0.30
12-15	17.5 ± 0.31	17.4 ± 0.30
15-18	20.3 ± 0.44	18.2 ± 0.40
18-21	20.6 ± 0.50	20.0 ± 060
21-24	23.3 ± 0.27	20.9 ± 0.50
24-27	23.9 ± 0.15	23.9 ± 0.70
27-30	25.0 ± 0.21	24.6 ± 1.00
30-33	25.3 ± 0.90	27.5 ± 0.70
33-36	26.3 ± 0.45	29.4 ± 0.70
36-39	26.8 ± 0.45	28.2 ± 1.50
39-42	28.5 ± 1.50	30.5 ± 0.70

SC = scrotal circumference. SC* = scrotal circumference obtained by Singh *et al.* (2010).

At 30 months of age, average SC (24.17 cm) were lower than those obtained in the aforementioned study for all the breeds (25.8 to 28.2 cm).

As mentioned previously, the best model was selected based on the determination coefficient (R^2) and the mean squared error. In case of relatively close R^2 values, the mean squared error is used to select the model that best expresses the fit of the studied variables since it penalizes larger deviations (Draper and Smith, 1998). It should be noted that several reports used only r or R^2, and significance level for model comparison (Bongso *et al*., 1984; Yanez *et al*., 1997; Cruz *et al*., 2001; Vásquez and Arango, 2002; Sing *et al*., 2010; Ahmad *et al*., 2011; Cardoso da Luz *et al*., 2013; Henry *et al*., 2013).

Regression between thoracic perimeter and bodyweight

The linear relationship between TP and BW, given by TP = 90.11+ 0.22BW, has an R^2 of approximately 94%, similar to 92% obtained by Montes *et al.*

(2007). Fundora *et al.* (2006) estimated body weight of bulls up to 30 months of age (sorted into age groups) and reported R^2 values between 86% and 94% (typically 88%), depending on the progeny. Ramos *et al.,* (2007) stated that body weight is one of the most economically important traits in buffaloes bred for beef, and that previously compiled growth curves allow to select the most precocious animals. Nevertheless, the present study reveals that nonlinear models are the most successful in relating TP to BW. The existent relationship between these variables is particularly well described by the power law. Therefore, we recommend model $TP = 19.89*BW^{0.37}$ for predicting TP from BW.

Regression between scrotal circumference and body weight

Montes *et al.* (2007) reported that body and testicular growth in this buffalo species linearly increases with age, similar to cattle. Therefore, we may reasonably suggest that a nonlinear relationship will emerge over longer test periods. Cruz *et al.* (2001) obtained a linear regression of SC versus BW for 12-month-old buffaloes over a 50-day period and reported an R^2 coefficient of only 28%.

Bongso *et al.* (1984) modeled relationships between SC and BW by a quadratic function and obtained 77% R^2. Yanez *et al.* (1997) obtained 52% R^2 in bulls aged 12 to 14 months. In both studies, the indicator value was inferior to that of the power law models proposed in the present study. In studies by Singh *et al.* (2010) a 0.90 correlation coefficient was obtained for buffalos up to 84 months of age.

The R^2 values of all models investigated in the present study exceeded 83.0%. The R^2 of the linear, quadratic, and power law models were 80, 84, and 89%, respectively. Therefore, we recommend SC be related to BW as $SC = 1.13*BW^{0.51}$.

Regression between scrotal circumference and thoracic perimeter

Our results confirm a relationship exists between corporal and testicular development. Similar relationships have been reported for other buffalo species (Vásquez and Arango, 2002). These relationships can help to identify the biotype of Cuban buffalo bulls (Arias *et al.,* 2009).

We conclude that SC is best related to TP through the power law model $SC = 0.02*TP^{0.89}$ in buffalo bulls between 2 and 36 months of age,

Acknowledgements

The authors acknowledge financial support from AECID (Spain) under Project Nº A2/039476/11, "Institutional strengthening of teaching the subjects of statistics, operations research and reliability and quality, and their scientific application to topics of regional interest."

Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

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