Int. J. Morphol.,
31(4):1376-1382, 2013.

Evaluation of Three Mathematical Functions to Describe the Relationship Between Body Weight, Body Condition and Testicular Dimensions in Yankasa Sheep

Evaluación de Tres Funciones Matemáticas para Describir la Relación entre Peso Corporal, Condición Corporal y Dimensión Testicular en Carneros Yankasa

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YAKUBU A. & MUSA-AZARA, I. S. Evaluation of three mathematical functions to describe the relationship between body weight, body condition and testicular dimensions in Yankasa sheep. ***Int. J. Morphol., 31(4)***:1376-1382, 2013.

SUMMARY: Body size and testicular measurements have been found to be important parameters utilized in breeding soundness evaluation. The present study therefore, aimed at determining the relationship between body weight (BW), body condition score (BCS), testicular length (TL), testicular diameter (TD) and scrotal circumference (SC) in 120 extensively reared Yankasa rams (approximately 30 months old) using linear, quadratic and cubic predictive models. Coefficient of determination (R^2), Adjusted R^2, the estimate of Mallows' Cp, RMSE (Root mean squares error) and the parsimony principle (p=number of parameters) were used to compare the efficiency of the different models. Strong Pearson's correlation coefficients (r = 0.83-0.94; P<0.01) were found between BW, TL, TD and SC. Spearman correlations between BCS and other variables were also highly significant (r = 0.78-0.85; P<0.01). SC was the sole variable of utmost importance in estimating BW, which was best predicted using the cubic model. However, the optimal model for BW prediction comprised TD, SC and BCS with p, R^2, Adjusted R^2, RMSE and Cp values of 4, 0.948, 0.946, 1.673 and 4.85, respectively. The present findings could be exploited in husbandry and selection of breeding stock for sustainable sheep production especially within the resource-poor farming system under tropical and subtropical conditions.

KEY WORDS: Body size; Body condition; Testicular measurements; Rams; Regression models.

INTRODUCTION

Country reports on farm animal genetic resources (FAO, 2011; Yakubu, 2010) illustrate that importance of farm animal genetic resources are very diverse, particularly for the poor under smallholder production systems in the developing world. Sheep is an important source of meat (Fadare *et al*., 2012), and plays other socio-economic roles especially in the lives of rural dwellers. The productivity of livestock (including sheep) in Nigeria is however low, amongst others, due to a low fertility rate in the breeding herds. Thus to keep up with the increasing demand of animal protein production and the productivity of sheep, there is a need for sustainable improvement strategies. Improvement of sheep productivity requires effective actions on its various components, with prolificacy being one of the most important. Considering the morphological and physiological breed characteristics in sheep breeding operations, determination of breeding value of candidate breeder rams at a good age is very important. This is advantageous for improvement of both economic gain of operations and effectiveness of selection (Elmaz *et al*., 2008).

Generally, body size and testicular measurements are important parameters utilized in breeding soundness evaluation. Knowing the body weight of an animal is important for a number of reasons such as breeding, correct feeding, health matters, growth as well as classification. Live body weight and testicular size have been found to generally indicate the production of viable spermatozoa by the male (Agga *et al*., 2011). The biometrical analysis of testicular development is of great importance since it is significantly correlated with reproductive activity (Emsen, 2005). Sperm competition is a common phenomenon across the animal kingdom and is recognized as a major factor in the sexual selection of males. Because the testes produce sperm and reflect investment in ejaculates, one of the predicted consequences of sperm competition is that the testes should

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be relatively large when the likelihood of sperm competition is high (Schulte-Hostedde *et al*., 2005; Bernardi *et al*., 2010). In the male for instance, there is the need to establish measurable criteria for judging breeding soundness and guiding selection of males for breeding. Since farmers may not be in a position to test ejaculate qualities of males before using them for breeding, a procedure that would utilize external testicular measurements may provide a good guide to breeding soundness especially where males are reputed to have exceptionally high libido (Ugwu *et al*., 2009; Boligon *et al*., 2010; Shoyombo *et al*., 2012). All else being equal, scrotal circumference as a highly heritable trait, could be used as an effective selection criterion in order to increase flock fertility and reduce the number of breeding rams required (Abbasi & Ghafouri-Kesbi, 2011). The body scoring is based on a subjective assessment of the fat level and muscle thickness on the backbone behind the last rib. Body condition score and its use are important in terms of achieving the desired performance in certain physiological periods in sheep breeding where extensive conditions are dominant (Sezenler *et al*., 2011).

Various regression analyses involving linear, quadratic and cubic models have been used widely to describe quantitative association between dependent and independent variables in animal studies including those involving body size, body condition and testicular measurements (Elmaz *et al*.; Cankaya, 2009; Yan *et al*., 2009; Erat, 2011; Sebolai *et al*., 2012; Yakubu, 2012).

There is dearth of information on the association between body size, its condition and testicular measurements in Nigerian sheep. Therefore, the present study was designed to predict body weight of Yankasa sheep (the most numerous of all Nigerian breeds of sheep) from testicular length, testicular diameter, scrotal circumference and body condition score and to choose the most appropriate regression equations using linear, quadratic and cubic models. This may aid management decisions on the husbandry and selection of rams for breeding purposes especially in their breeding tracts under the resource-poor livestock farming systems in tropical and subtropical environments.

MATERIAL AND METHOD

Management of experimental animals and data collection.

Data were obtained from 120 rams of the indigenous Yankasa sheep in their breeding tracts. The randomly selected animals which were approximately 30 (thirty) months old, were extensively managed in Nasarawa State, north central Nigeria. Age was determined from the available records on rams provided by the livestock keepers; and where information was missing, the age of each ram was estimated using dentition. They were subjected to the traditional grazing methods, while their feeding was supplemented with kitchen wastes. Records were taken on body weight (BW), body condition score (BCS), testicular length (TL) ((largest dorso-ventral distance), testicular diameter (TD) (widest anterior-posterior position) and scrotal circumference (SC) (widest part of the testes, after the testes had been firmly pushed into the scrotum) early in the morning before the animals were released for grazing. BW was measured in kilograms (kg), using a hanging spring balance and a sack. The TL and TD were measured with the aid of a vernier caliper and recorded in centimetres (cm). The SC in centimetres (cm) was measured with the aid of a flexible tape. The BCS was determined based on a 5-point scale (ranging from 1 to 5 representing emaciated, poor, acceptable, fat or obese animals, respectively) (Agga *et al*.).

Statistical analysis. Descriptive statistics were computed for BW, TL, TD, SC and BCS, respectively. The Pearson's correlation coefficients were used to assess the association between the BW, TL, TD and SC. The Spearman correlation coefficients were estimated to quantify the relationship between BCS and BW, TL, TD and SC. In order to predict BW from TL, TD, SC and BCS, the linear, quadratic and cubic approaches were fitted. The regression equations employed were:

$Y = b_0 + b_1X + e$ 1 (linear model)
$Y = b_0 + b_1 X + b_2 X^2 + e$ 2 (quadratic model)
$Y = b_0 + b_1 X + b_2 X^2 + b_3 X^3 + e$ 3 (cubic model)

Y = body weight
b_0 = the intercept
X = independent variables, either the TL, TD, SC or BC
b_1, b_2 and b_3 = regression coefficients
e = random error.

The full regression model of the measurements that were objectively and subjectively measured (all the three testicular measurements and BC inclusive) was defined as:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5$$

where,

Y = dependent or endogenous variable (body weight)
a = intercept
b 's = regression coefficients
X's = independent or exogenous variables (TL, TD, SC and BC)

In order to obtain the optimal model for BW prediction, Coefficient of determination (R^2) (to quantify the proportion of variability explained by a model), Adjusted $R^2 = (1 – [(n-1) / (n-p)] (1-R^2)$, RMSE (Root mean squares error) and the Parsimony principle (which states that a model with fewer variables (p) is preferred to one with many variables) were used to compare the efficiency of the different models. The estimate of Mallows' Cp (Conceptual predictive) (MacNeil *et al*., 1983) was also considered in the evaluation of the models since Mallows' Cp is a more reliable statistic than R^2 when the number of observations (n) is small. An equation was considered to be reliable when the R^2 was high and Cp was low.

Mallows suggested the following criterion:

$$C_p = 2p + \frac{SSE_q}{MSE_m} - n$$

where m= SSE_q is the sum squared error for the model with 'q' variable(s) and MSE_m is the mean squared errors for the model with 'm' variables. Suppose that we have a total of 'm' possible candidates for independent variables. We estimate a model using all these variables as independent variables. Then, from these variables we choose 'q' number of variables (where q = 1, 2, 3, …) each time and estimate a model. Also suppose that there are 'p' number of parameters in each of the models that we estimate with 'q' number of independent variables (therefore p = 2, 3, 4, …). n= total number of observations. SPSS (2010) statistical package was employed in the analysis.

RESULTS

Means, standard errors, standard deviations and coefficients of variation for BW, BCS, TL, TD and SC are presented in Table I.

Pearson's bivariate correlations displaying the relationship among BW and testicular measurements of Yankasa rams are shown in Table II. BW was positively and highly correlated with all the testicular measurements. However, the highest correlation was observed between BW and SC, followed by BW and TD and BW and TL (r =0.94, 0.89 and 0.83, respectively; $P<0.01$). Similarly, the Spearman correlation analysis showed that BCS had strong relationship with BW, SC, TD and TL, respectively (r= 0.85, 0.81, 0.78 and 0.82; $P<0.01$) (Table III).

The estimation of BW from TL and TD appeared to be better under the cubic model based on higher R^2 values (Table IV). However, there was no superiority between the cubic and quadratic models in the prediction of BW from BCS. Among the single traits in the linear, quadratic and cubic models, SC was the most important trait in predicting BW, which appeared to be best done under the cubic model (R^2 and Adjusted R^2= 0.890 and 0.887, respectively). However, when single and multiple traits were jointly considered, and using R^2 as a criterion for selection, models 11, 10, 9, 7, 6, 4 and 2 were considered to be candidates for good models (Table V). These models all contained the predictor SC. Model 10 made better prediction and was however chosen as the optimal model (BW = 4.142 + 1.410TD + 0.609SC + 2.962BCS) with p, R^2,

Table I. Descriptive statistics of body weight, body condition and testicular measurements of Yankasa rams.

Traits	Mean	Standard error	Standard deviation	Coefficient of variation (%)
Body weight	35.10	0.66	7.23	20.60
Body condition	2.73	0.07	0.79	28.94
Testicular length	6.53	0.14	1.51	23.12
Testicular diameter	4.85	0.10	1.10	22.68
Scrotal circumference	26.34	0.53	5.81	22.06

Table II. Pearson's correlation coefficients between body weight and testicular measurements of Yankasa rams**.

Traits	BW	TL	TD	SC
BW		0.83	0.89	0.94
TL			0.87	0.80
TD				0.83

BW= body weight, TL=testicular length, TD= testicular diameter SC= scrotal circumference, **Significant at $P<0.01$

Table III. Spearman correlation coefficients of body condition and body weight and testicular measurements of Yankasa rams**

Traits	BCS	BW	TL	TD	SC
BCS		0.85	0.82	0.78	0.81
BW			0.76	0.91	0.94
TL				0.79	0.71
TD					0.85

BCS= body condition score, BW= body weight, TL=testicular length, TD= testicular diameter SC= scrotal circumference. **Significant at $P<0.01$

Adjusted R^2, RMSE and Cp values of 4, 0.948, 0.946, 1.673 and 4.85, respectively.

Table IV. Regression of body weight on various testicular measurements and body condition of Yankasa rams using single traits for the linear, quadratic and cubic models

Model	R^2	Adjusted R^2	Significance
Testicular length			
$BW = 9.008 + 3.997TL$	0.696	0.694	**
$BW = 4.788 + 5.497TL - 0.124TL^2$	0.699	0.694	**
$BW = -2.795 + 9.863TL - 0.894\ TL^2 + 0.043TL^3$	0.700	0.692	**
Testicular diameter			
$BW = 6.700 + 5.855TD$	0.796	0.794	**
$BW = -10.044 + 13.093TD - 0.743TD^2$	0.821	0.818	**
$BW = 27.125 - 12.268TL + 4.729TD^2 - 0.376TD^3$	0.832	0.827	**
Scrotal circumference			
$BW = 4.259 + 1.171SC$	0.886	0.885	**
$BW = 9.590 + 0.704SC + 0.010SC^2$	0.889	0.887	**
$BW = 19.936 - 0.778 + 0.076SC^2 - 0.00SC^3$	0.890	0.887	**
Body condition			
$BW = 12.228 + 8.392BCS$	0.837	0.836	**
$BW = 9.642 + 10.580BCS - 0.420BCS^2$	0.839	0.836	**
$BW = 12.195 + 6.940BCS + 1.113BCS^2 - 0.197BCS^3$	0.839	0.835	**

BW= body weight, TL=testicular length, TD= testicular diameter SC= scrotal circumference, BCS= body condition score. R^2= coefficient of determination. ** Significant at P<0.01.

Table V. Coefficients of determination (R^2), Adjusted R^2, root mean squares errors (RMSE) Cp (Conceptual predictive) and number of parameters (p) for selecting the optimal model for the prediction of body weight in Yankasa rams.

Model n	Variables	p	R^2	Adjusted R^2	RMSE	Cp
1	TL, TD	3	0.811	0.808	3.171	309.25
2	TL, SC	3	0.903	0.902	2.266	102.08
3	TL, BCS	3	0.854	0.851	2.788	213.09
4	TD, SC	3	0.923	0.922	2.017	57.28
5	TD, BCS	3	0.892	0.890	2.395	127.46
6	SC, BCS	3	0.936	0.935	1.839	28.32
7	TL, TD, SC	4	0.924	0.922	2.020	58.29
8	TL, TD, BCS	4	0.892	0.889	1.406	129.45
9	TL, SC, BCS	4	0.937	0.935	1.837	28.75
10	TD, SC, BCS	4	0.948	0.946	1.673	4.85
11	TL, TD, SC, BCS	5	0.949	0.947	1.666	4.87
12	TL	2	0.696	0.694	4.002	563.92
13	TD	2	0.796	0.794	3.283	341.37
14	SC	2	0.886	0.885	2.682	139.87
15	BCS	2	0.837	0.836	2.932	248. 93

TL=testicular length, TD= testicular diameter SC= scrotal circumference, BCS= body condition score.

DISCUSSION

The high variability in BW, BCS, TL, TD and SC could be attributed to certain environmental influence such as temperature and nutrition on these parameters, which could serve as a basis for improvement. BW is a very important factor in the selection and production of sheep. Body size and testicular measurements have been found to be important parameters for evaluating breeding soundness (Agga *et al*.). Similarly, Karakus *et al*. (2010) reported that BW significantly influenced TL and TD, respectively. As a result of the beneficial attributes and high heritability estimates (0.4-0.7) of testicular size (Coulter & Foote, 1979), measurements would be useful selection criteria for improvement of flock. Salhab *et al*. (2002), reported that the various testicular measurements were more correlated with body weight of growing lambs than age. Pochron & Wright (2002), showed the significant positive relationship between body size and testicles of animals in non-breeding season. Intraspecific variation in testis size (ejaculate investment) has been implicated as an important factor in male reproductive success because larger testes produce higher quality ejaculates (number of sperm, ejaculate volume and motility) and have higher rates of sperm production (Gomendio *et al*., 1998). Thus males with larger testes are assumed to have higher reproductive success than males with small testes in species with sperm competition (Schulte-Hostedde *et al*.).

It has been shown that testicular diameter and along with scrotal circumference are excellent indicators of spermatogenic function, while body weight either alone or in combination with other variables, have been found to be related to semen volume (Marco-Jimenez *et al*., 2005; Mekasha *et al*., 2008; Elmaz *et al*.). The positive association between SC and BW is an indication that improvement in both traits is possible through selection procedures, considering their high genetic correlations (Duguma *et al*., 2002; Pourlis, 2011). This is an indication that genes that contributed to BW had an influence in the reproductive ability of rams. Scrotal circumference is a simple repeatable method of measurement of testicular size which is highly correlated with testicular weight, semen quality, and with fertility (Waldner *et al*., 2010). The present findings demonstrated that BCS is a good indicator of BW. Sezenler *et al*., reported high correlation coefficients between BCS and BW in some indigenous sheep breeds in Turkey Thus, if BW and the size of the testes/scrotum is condition dependent, livestock breeders may assess the size of the testes and/or scrotum and make reproductive decisions based on this assessment

The cubic model appeared to produce better goodness of fit in the present study when traits were considered singly, which is consistent with earlier findings (Yakubu, 2010). In a similar study in bulls, Ahmad *et al*. (2011), submitted that the relationship between BW and SC was curvilinear. Karakus *et al*., reported high R^2 values from the prediction of BW from TL, TD and SC. The choice of model 10 in the present study might not be unconnected with the fact that Cp criterion is more powerful than R^2 and adjusted R^2, because it is a function of the number of observations (n), number of parameters in the subset model and the residual mean squares of the full model (Aziz & Sharaby, 1993). Neter *et al*. (1996) reported that the bias of the regression model was small when subsets of independent variables with small Cp values had a small total mean squared error and Cp value was near p. The best subsets regression analyses can be used for ram evaluation to improve the economic gain and effectiveness of selection under rural settings and at central ram test stations. For the convenience of users who work under field conditions, prediction equations can be constructed involving the SC as a single trait as well its combination with TL and BCS, respectively. Raji *et al*. (2008), reported that testicular measurements described more variation in body weight of goats and with their ease of measurement, provide a simple tool for rural farmers under field conditions to estimate body weight, when used in a simple or multiple regression equation. Since testicular measurements have high correlation with body weight, they may also be used as selection criteria.

CONCLUSION

The study revealed that interrelationships between BW, TL, TD, SC and BCS of Yankasa rams were positive, strong and highly significant. SC was the single trait of utmost importance to predict BW using the cubic model. However, the optimal model for BW prediction included a combination of TL, SC and BCS. These findings, especially of the prediction models developed, could be useful in the management and selection of rams for breeding purposes especially among the rural livestock farmers, which could lead to improved productivity and hence profitability of the sheep enterprise.

ACKNOWLEDGEMENTS

The authors are appreciative of the maximum cooperation accorded them by the livestock farmers in Nasarawa State throughout the period of the research.

YAKUBU A. & MUSA-AZARA, I. S. Evaluación de tres funciones matemáticas para describir la relación entre peso corporal, condición corporal y dimensión testicular en carneros Yankasa. ***Int. J. Morphol., 31(4)***:1376-1382, 2013.

RESUMEN: El tamaño corporal y las mediciones testiculares son importantes parámetros utilizados en la evaluación del buen estado de reproducción. El presente estudio, tuvo como objetivo determinar la relación entre el peso corporal (PC), score de condición corporal (SCC), longitud testicular (LT), diámetro testicular (DT) y la circunferencia escrotal (CE) en 120 carneros Yankasa criados extensivamente (aproximadamente 30 meses de edad), utilizando modelos predictivos lineales, cuadráticos y cúbicos. Se utilizaron el coeficiente de determinación (R^2), R^2 ajustado, estimación Cp de Mallows, ERCM (errores de raíz cuadrada media) y el principio de parsimonia (p = número de parámetros) para comparar la eficiencia de los diferentes modelos. Un fuerte coeficiente de correlación de Pearson (r= 0,83-0,94, p<0,01) se encontró entre PC, LT, DT y CE. Las correlaciones de Spearman entre SCC y otras variables también fueron altamente significativas (r= 0,78-0,85, p<0,01). La CE fue la única variable de suma importancia en la estimación de PC, que fue predicha de mejor manera utilizando el modelo cúbico. Sin embargo, el modelo óptimo para la predicción del PC comprendiendo DT, CE y SCC con valores p, R^2, R^2 ajustado, ERCM y Cp de Mallows de 4; 0,948; 0,946; 1,673 y 4,85, respectivamente. Los presentes hallazgos podrían ser explotados en la cría y selección del ganado de cría para la producción sostenible de ovejas, en especial dentro de sistemas con escasos recursos agrícolas bajo condiciones tropicales y subtropicales.

PALABRAS CLAVE: Centella asiática; Células epiteliales respiratorias; Antiproliferativos.

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Received: 08-02-2013
Accepted: 06-09-2013