Indian Journal of Animal Sciences **92** (6): 770–775, June 2022/Article
https://doi.org/10.56093/ijans.v92i6.108921

Comparison of regression methods and Shaeffer's formula for predicting the live body weights of Ganjam goats

DILLIP KUMAR KARNA[1]✉, ADITYA PRASAD ACHARYA[1], BHABESH CHANDRA DAS[1], GANGADHAR NAYAK[1] and M R DIBYADARSHINI[1]

Odisha University of Agriculture and Technology, Bhubaneswar, Odisha 751 003 India

Received: 26 December 2020; Accepted: 21 March 2022

ABSTRACT

Linear regression and polynomial regression of order two and three were utilized to predict the live weight of Ganjam goats across five age groups using chest girth as predictor and their accuracies were compared with the prediction of weight made by Shaeffer's formula. Live body weight of Ganjam goat recorded by electronic weighing balance was used as standard for calculating the error of prediction. The body weights of 1014 Ganjam goats (329 males and 685 females) were estimated by each technique during 2015 to 2017. Compared with electronic weighing scale, the body weight estimates in Ganjam goat exceeded in all age groups for Shaeffer's formula whereas predicted body weight estimates by linear regression and second order polynomial regression were close to the live body weights. The estimates of linear regression and second order polynomial regression were significantly different from the electronic weighing scale for all age groups. The study concluded that polynomial regression of order two had better predictive value for live body weight of Ganjam goat, followed by third order polynomial regression, linear regression and Shaeffer's formula, in order.

Keywords: Live weight, Polynomial regression, Shaeffer's formula

Livestock body weight is the most significant and essential economic factor for selection and production performance. Estimation of live body weight of small ruminants is important for a number of reasons, such as breeding, appropriate feeding and treatment of diseases (Slippers *et al*. 2000). It is also used for determining prices while selling animals. However, visual appreciation method is often used in rural and inaccessible areas to estimate body weight and monitor the performance of small ruminants where weighing scales are not easily available (Vanvanhossou 2018) and it would be difficult to know the correct weight of small ruminants (Mahmud *et al*. 2014).

Researchers use parameters such as body length, width of pelvis, height at withers and chest girths along with live weight of meat animals for the evaluation of live animals (Atta *et al*. 2004). Since the body weight and morphometry of the animals are highly correlated, it would be helpful in determining the extent of variation in body weight caused by biometry of the animal and thus helpful in formulation of a suitable selection criterion on the basis of body conformation of animals (Khan *et al*. 2003). In this study, four different techniques of live weight prediction were compared with electronic weighing scale as the benchmark. The main objective was to evaluate the methods and to arrive at the accurate estimates of live body weight in Ganjam goats.

Present address: [1]College of Veterinary Science and Animal Husbandry, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha. ✉Corresponding author email: dkarna@gmail.com

MATERIALS AND METHODS

Study location: The study area included four field centers (Chhatrapur, Rambha, Khallikote and Jirabadi located at 19.35-19.92^{0}N and 84.98^0-85.12^{0}E) of All India Coordinated Research Project on Goat Improvement in the Ganjam District of Odisha. Ganjam district is the home tract of the Ganjam breed of goat, which is the most important recognised goat breed of Odisha.

Goat breed, measurement techniques and study design: Ganjam breed native to Ganjam district was selected since this breed is popular and mostly reared in range system by poor and marginal farmers. The flock size of Ganjam goats ranged from 40 to 500. The farmers move along with their flocks in search of browsing material in most part of the years. Data on body weight (kg), body length (cm), wither and chest girth (cm) were recorded on 1014 Ganjam goats (329 males and 685 females) during 2015 to 2017. The measurement techniques employed were electronic weighing scale, Schaeffer's formula and calculator method. The body weights (BW) of goats were recorded in kg by using an electronic weighing scale with precision up to 100 g. Therefore, electronic weighing scale was used as a reference point for other four techniques. The body weight of each goat was estimated separately by four measurement techniques and was compared with the weight obtained by electronic weighing scale.

Procedure of recording morphometry: Goats were weighed during early morning before the animals were left loose for browsing. The linear body measurements were recorded using a measuring tape with graduation in centimetre. The body length (BL) was measured from the point of pin bone to point of shoulder (Scapula). The wither height (WH) was measured as the distance from the ground level to the level of wither of the animal in standing position. The chest girth (CG) was measured by taking the measurement of circumference of the chest just behind the front leg.

Electronic weighing scale: It is a standard weighing balance and therefore, in this study, it was used as reference point for evaluation of body weights using other techniques. Animals' weights were recorded by subtracting the weight of the enumerator from the weight of the enumerator and animal together.

Shaeffer's formula: The original equation used for calculating live weight was:

$$W = (BL \times CG^2)/300$$

where W, body weight in lbs; BL, length of the animal from point of shoulder to pin bone in inches; and CG, chest girth of the animal in inches (Sastry *et al*. 1983, Khan *et al*. 2003). The formula was reformatted to measure the body weight in kg as mentioned in Table 1.

Data analysis: The linear and polynomial regression models were used for predicting the live weight (kg) from the measurements of chest girth (cm) (Table 1).

Table 1. Formula for different models used for body weight estimation

Prediction methods	Model/ Formula
Linear regression	BW = b0 + b1 * (CG)
Polynomial regression (order-2)	BW = b0+ b1 * (CG) + b2 * $(CG)^2$
Polynomial regression (order-3)	BW = b0+ b1 * (CG) + b2 * $(CG)^2$ + b3*$(CG)^3$
Shaeffer's formula	BW = BL * $(CG)^2$/ 10815.42

The whole data on body weight and measurements were divided into five age group classes, viz. Age group 1 to Age group 5. Age group 1 included goats of 0-2 months age, Age group 2 for goats of 3 months, Age group 3, 4 and 5 included goats of 6 months, 9 months and one year age, respectively. The descriptive statistics and regression analysis were carried out using R software (version 4.0.3).

The linear and polynomial regression analysis was done with chest girth (CG) as predictor variable. The dataset was split into training dataset with 70% of data and testing dataset with 30% of data using using the 'rsample' package in R (Kuhn and Wickham 2019) for each of the age groups. The linear and polynomial regression of order one and two were carried out to predict the live weight from the chest girth. The Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) were estimated for the best fitted regression equation for each age groups as described by Topal and Boulkbasi (2008). The prediction bias (D) was estimated by taking the average of Di of the test sample where

$$Di = (Wi - \hat{Wi}) \text{ for } (i = 1 \text{ to } n)$$

'Wi' being the i^{th} observed body weight of test sample and '$\hat{Wi}$' as predicted weight as described by Mayaka *et al.* (1995)

RESULTS AND DISCUSSION

Live body weight: The mean body weight of Ganjam goats in the five age groups (Age group 1,2, 3, 4 and 5) was observed as 4.57±1.86 kg, 8.77±2.27 kg, 10.20±2.00 kg, 14.25±3.01 kg, 18.75±3.38 kg, respectively (Table 2). The body length (BL), chest girth (CG) and wither height (WH) in the respective age groups is given in Table 2. Increase in the live weight and linear body measurements with increase in age indicated that the studied population were in good health conditions. This observation corroborated with the observations made by Dereje and Aynalem (2013) and Sam *et al.* (2016) who also found that rate of increase in live body weight of goat increased as age increased till the first set of incisors and decreased gradually on attaining maturity.

Prediction of body weight using regression analysis with chest girth as predictor variable: The details of the regression analysis with chest girth as predictor of live weight are presented using linear regression (Table 3), second order polynomial regression (Table 4) and third order polynomial regression (Table 4). The R^2 value for all age groups ranged from 46.3 to 88.1% in linear regression, 46.2 to 89.4% in second order polynomial regression, 46.3 to 89.3% in third order polynomial regression. The use of chest girth alone as a predictor of body weight is a simple and rapid method of estimating the body weight of Ganjam goats in the field. Chest girth measurement has been used to estimate the body weight of small ruminants. Afolayannn *et al*. (2006), Moaeen-ud-Din *et al.* (2018), Chinchilla-Vargas *et al*. (2018), Hopker *et al.* (2019) and Karna *et al*. (2020) found chest girth to be the most important predictor of body weight for Yankasa sheep, Pakistani Beetal goats,

Table 2. Mean of growth traits with standard deviations in parenthesis

Age	N	Body Weight (BW)	Body Length (BL)	Wither Height (WH)	Chest Girth (CG)
1	175	4.57 (1.86)	36.98 (5.77)	41.11 (6.66)	38.94 (5.94)
2	231	8.77 (2.27)	46.30 (4.43)	47.89 (5.77)	48.69 (5.17)
3	277	10.20 (2.00)	52.25 (4.13)	55.49 (4.16)	54.87 (3.59)
4	349	14.25 (3.01)	53.79 (5.87)	58.31 (5.93)	57.80 (4.78)
5	217	18.75 (3.38)	59.75 (5.81)	62.78 (6.00)	63.61 (5.32)

N, number of observations.

Table 3. Age group-wise linear regression statistics with chest girth as predictor variable

Age	N	Terms	Coefficients	Standard error	p-value	Adjusted R^2 (%)	AIC
1	175	Intercept	-6.733	0.36	<0.001	88.1	266.7190
		CG	0.289	0.01	<0.001		
2	231	Intercept	-9.848	0.75	<0.001	77.9	534.7052
		CG	0.382	0.01	<0.001		
3	277	Intercept	-11.070	1.46	<0.001	50.8	726.9269
		CG	0.385	0.03	<0.001		
4	349	Intercept	-13.508	1.45	<0.001	58.3	1091.1624
		CG	0.480	0.02	<0.001		
5	217	Intercept	-9.662	2.41	<0.001	46.3	750.8154
		CG	0.445	0.04	<0.001		

N, number of observations.

Table 4. Age group-wise polynomial regression statistics with chest girth as predictor variable

Age	N	Terms	Coefficients	Standard Error	p-value	Adjusted R^2 (%)	AIC
				Order 2			
1	175	Intercept	4.589	0.05	<0.001	89.4	251.8631
		CG 1	20.195	0.60	<0.001		
		CG 2	2.530	0.60	<0.001		
2	231	Intercept	8.814	0.08	<0.001	77.8	536.3895
		CG 1	27.358	1.10	<0.001		
		CG 2	-0.615	1.10	0.578		
3	277	Intercept	10.117	0.09	<0.001	54.8	710.1870
		CG 1	20.537	1.35	<0.001		
		CG 2	5.942	1.35	<0.001		
4	349	Intercept	14.132	0.12	<0.001	58.6	1090.2718
		CG 1	37.077	1.93	<0.001		
		CG 2	3.280	1.93	0.091		
5	217	Intercept	18.717	0.19	<0.001	46.2	752.2402
		CG 1	29.018	2.46	<0.001		
		CG 2	-1.853	2.46	0.453		
				Order 3			
1	175	Intercept	4.589	0.05	<0.001	89.3	253.6952
		CG 1	20.195	0.60	<0.001		
		CG 2	2.530	0.60	<0.001		
		CG 3	-0.244	0.60	0.687		
2	231	Intercept	8.814	0.08	<0.001	77.8	537.5965
		CG 1	27.358	1.10	<0.001		
		CG 2	-0.615	1.10	0.578		
		CG 3	-0.974	1.10	0.379		
3	277	Intercept	10.117	0.09	<0.001	57.4	699.2031
		CG 1	20.537	1.31	<0.001		
		CG 2	5.942	1.31	<0.001		
		CG 3	-4.758	1.31	<0.001		
4	349	Intercept	14.132	0.12	<0.001	59.2	1087.2010
		CG 1	37.077	1.92	<0.001		
		CG 2	3.280	1.92	0.088		
		CG 3	4.311	1.92	0.025		
5	217	Intercept	18.717	0.19	<0.001	46.3	752.6754
		CG 1	29.018	2.46	<0.001		
		CG 2	-1.853	2.46	0.452		
		CG 3	3.046	2.46	0.217		

N, number of observations.

Table 5. Comparison of model fit parameters for different methods

Age	N	Technique	Mean observed/ predicted body weight	Deviation from mean body weight	Mean absolute error	Mean absolute percentage error	Root mean square error
1	40	Original BW	4.497a		-	-	-
		Linear Regression	3.746a	0.75 (1.20)	1.104	0.385	1.399
		Polynomial Regression (order-2)	4.600a	-0.10 (0.52)	0.394	0.123	0.521
		Polynomial Regression (order-3)	4.599a	-0.10 (0.52)	0.393	0.124	0.523
		Shaeffer's formula	5.299b	-0.80 (0.60)	0.838	0.206	0.996
2	56	Original BW	8.646a		-	-	-
		Linear Regression	8.888a	-0.24 (1.24)	0.955	0.121	1.253
		Polynomial Regression (order-2)	8.432a	0.21 (1.17)	0.884	0.110	1.182
		Polynomial Regression (order-3)	8.428a	0.22 (1.17)	0.885	0.110	1.184
		Shaeffer's formula	10.236b	-1.59 (1.34)	1.740	0.207	2.070
3	72	Original BW	10.450a		-	-	-
		Linear Regression	12.008b	-1.56 (1.65)	1.902	0.203	2.262
		Polynomial Regression (order-2)	11.495b	-1.05 (1.70)	1.638	0.171	1.987
		Polynomial Regression (order-3)	11.497b	-1.05 (1.70)	1.639	0.171	1.988
		Shaeffer's formula	14.260c	-3.81 (1.68)	3.847	0.395	4.159
4	88	Original BW	14.618a		-	-	-
		Linear Regression	14.075a	0.54 (1.93)	1.508	0.103	1.997
		Polynomial Regression (order-2)	13.968a	0.65 (2.05)	1.596	0.110	2.136
		Polynomial Regression (order-3)	13.970a	0.65 (2.05)	1.595	0.110	2.135
		Shaeffer's formula	17.417b	-2.80 (2.53)	3.069	0.217	3.763
5	56	Original BW	18.841a		-	-	-
		Linear Regression	16.435b	2.41 (2.53)	2.861	0.151	3.472
		Polynomial Regression (order-2)	17.067a	1.77 (2.86)	2.650	0.144	3.344
		Polynomial Regression (order-3)	17.065a	1.78 (2.86)	2.647	0.144	3.341
		Shaeffer's formula	22.388c	-3.55 (3.93)	4.351	0.235	5.268

Means in the same columns bearing different superscripts differ significantly at P<0.05.

rural African goats, native crossbred Assamese goats and Ganjam goats, respectively.

The strong positive relationships between live weight and linear body measurements such as body length, wither height and chest girth have been utilized by many workers for prediction of the live weight from the body measurements using linear regression and multiple regression technique (Thiruvankadan 2005, Alex *et al*. 2010, Raja *et al*. 2015, Berhe 2017, and Karna *et al*. 2020). There was considerable improvement in the R^2 values and the accuracies of prediction when multiple regression equations were used involving more than one body measurements. However, as the number of predictor variable increases, certain conveniences were sacrificed by the user and it gradually becomes tedious. That is why only chest girth was utilized in the study as a predictor variable for the regression analysis using linear, polynomial (order-2) and polynomial (order-3). Chest girth is fast and easy to measure, and can be measured greater with accuracy by personnel using any measuring tape with a brief guidance about the technique. Body length can also be considered for live body weight estimation however, accurate measurement is more challenging in field condition due to the wiggling nature of goats. Thus, a system requiring chest girth measurement only was helpful in estimation of body weight.

Comparison of four methods of prediction: The comparison of the live body weight and predicted body weight from linear regression, second order and third order polynomial regression and Shaeffer's formula are presented in Table 5. The prediction bias, Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) are the comparison

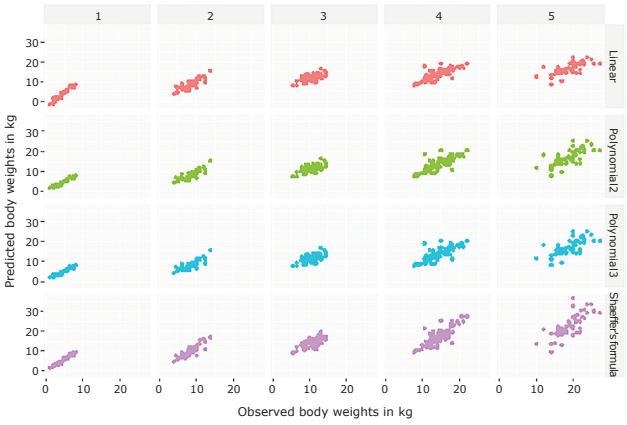

Fig.1. Scatter plot of the original and predicted body weights of the test sample across the five age groups using four different methods of prediction.NB: Age groups from 1 to 5 indicated as column head.

parameters utilized for the evaluation of the accuracies of prediction.

The Shaeffer's formula is one of the most widely used technique for predicting the live body weight especially in large animals like cattle in India (Khan *et al.* 2003, Suranagi *et al.* 2005, Wangchuk *et al.* 2017, Jagdale *et al*. 2018, Wagh *et al*. 2019). The prediction made by the Shaeffer's formula was compared with predictions made by the other regression techniques. Among the four different techniques used, Shaeffer's formula over-estimated body live weights in all age groups. Linear regression under-estimated the body weights for age group 1, 4 and 5 and over-estimated body weights for age group 2 and 3; second order polynomial regression and third order polynomial regression under-estimated the body weights of Ganjam goat for age group 2, 4 and 5 and over-estimated body weights for age group 1 and 3. The body weight estimates predicted using Shaeffer's formula were greater than the predicted body weight using linear regression, second order polynomial regression and third order polynomial regression in all age groups. Compared to electronic weighing scale, the body weight estimates predicted using second order polynomial regression, third order polynomial regression and Shaeffer's formula exceeded by about 0.10, 0.10 and 0.80 kg, respectively for age group 1. In age group 2, the estimates exceeded by about 0.24 and 1.59 kg for predicted body weight by linear regression and Shaeffer's formula, respectively whereas predicted body weight by both second order polynomial regression and third order polynomial regression were lesser than live body weight by 0.17 kg. In age group 3, the body weight estimates of all four techniques exceeded live body weight while in age group 4 and 5, only predicted body weight by Shaeffer's formula exceeded live body weight by 2.80 kg and 3.55 kg, respectively.

In a multiple comparison of the original observed body weights in the test sample with the predicted body weights with four methods, it was observed that the mean observed body weight did not differ significantly from the predicted weight from polynomial regression of order two in all the age groups except the age group of 6 months. However the predicted weight using Shaeffer's formula differed significantly ($P<0.01$) from mean observed weight of sample dataset in almost all the age groups. A closer scrutiny of the comparison metrics revealed that the predicted weight using the polynomial regression was the closest to the observed body weights of the test dataset in almost all the parameters used whereas Shaeffer's formula produced error of greater magnitude comparatively. The fact was elucidated in the scatterplot of observed and predicted weights (Fig. 1) where higher degree of dispersion is clearly visible for weights predicted by Shaeffer's formula. The body weight estimates using polynomial of order 2 in Ganjam goats were within ±15% of live body weight, which is acceptable for dosing with veterinary drugs (Wangchuk *et al.* 2017). The present study suggested the prediction using polynomial regression of order two taking chest girth as predictor over the Shaeffer's formula in Ganjam goats. However, observations made by Suranagi *et al*. (2005) in Bidri goats and Wangchuk *et al.* (2017) in Bhutanese cattle differed with the present observation where they reported better utility of Shaeffer's formula in predicting the body weights.

The body weight predicted using polynomial regression of order two was the better method of predicting the live weight of the Ganjam goats with the prediction error remaining well within 15% in most of the age groups studied. It would be of immense help in the field condition where weighing of goats could be a tedious task. The body weight predicted using the Shaeffer's formula mostly over-predicted the body weight.

ACKNOWLEDGEMENT

Authors are thankful to All India Coordinated Research Project on Goat Improvement (ICAR, New Delhi) for providing financial support to carry out this research.

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