

Technical Options for Body Weight Estimation: Prediction of Body Weights of Indigenous Sheep Populations from their Linear Body Measurements

Abstract

The field data collection was conducted before the war (before October 2020) in Tigray Regional State, Ethiopia. The objective of the study was to determine relationships between the linear body traits (LBTs) and body weight of the indigenous sheep, and to develop regression equations for predicting live body weights of each population. Begait (173), Rutanna (151) and Arado (164) sheep of sample animals were randomly involved in the field data collection. Dentition was used to determine the age of the animals and were from one permanent incisor up to four permanent incisors. The data were analyzed by Statistical Package for Social Sciences software. The indigenous sheep populations were kept under low input extensive production system. The overall direct field weighed live body weights of Begait, Rutanna and Arado sheep were 40.4 ± 0.49 Kg, 48.3 ± 0.94 Kg and 28.3 ± 0.29 Kg, respectively. Hence, Rutanna sheep could be primarily used for mutton production due to their large live body weight. The correlations ($P < 0.01$) between LBTs and direct field weighed live body weight of the indigenous sheep revealed that the LBTs could be used as indirect selection traits and could be used to predict the live body weights of the indigenous sheep in remote rural areas where weighing scale is not available using regression equations. Except in male Rutanna, chest girth or chest circumference could be solely used to predict the live body weights of the indigenous sheep breeds. Genetic characterization of the indigenous sheep populations should be conducted for the identification of economically important candidate genes.

Key words: Body weight prediction, correlation, indigenous sheep, linear body traits, regression equation

INTRODUCTION

Human societies selected sheep for their meat, milk, and wool [1]. Morphological characterization of livestock breeds is very important for developing a breeding strategy in a particular production system [2]. All livestock production management practices are dependent on the knowledge of livestock weight assessment [3]. There is a balanced relationship between

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body linear traits and live weight in animals. Moreover, estimating the live weight using linear body traits is practical, faster, easier, and cheaper in the rural areas where the weighing scales are lacked by the breeder [4,5]. Linear body traits that influence positively the body weight of animals are evaluated as indirect selection criteria in sheep breeding strategy [6]. Body weight prediction is important both for commercial purposes and veterinary dosages of medicines which usually depend on the estimated live body weight of the animals [7].

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Physical characteristics and body conformation of livestock species can be determined by morphometric characterization and body trait correlations [8]. The knowledge of weight and age of sheep is very useful information to make appropriate management decisions. Linear dimensions of animals can be used to estimate body weight in most farms which lacked accurate scales [9]. In the remote rural areas, it is impossible to obtain any accurate measurement of body weight for the genetic improvement program. Moreover, there is difficulty in price setting of sheep marketing, and usually marketing is based on subjective practices of physical appraisal, visual judgment and loin-eye-area palpation [10] and scientifically inaccurate [3]. Linear body traits were used to predict live body weight by several authors in many breeds of sheep when there is no access to weighing scale [11,12,13]. The study of correlations between different body traits allows for a comprehensive understanding of the relationships between different physical traits [14]. Linear body traits can be used as indirect selection criteria to improve live body weight if there exist strong correlation of linear body traits with body weight [15,16] or could be used to predict live body weight of animals [17,18] and/or monitoring growth and choosing replacement males and females [19]. Linear body traits are important traits in reflecting the breed standards [20] and are important in describing about the morphostructure of the animals.

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Knowledge of livestock live body weight is essential in livestock breeding and production. The output of this study will be paramount important for breeders, veterinarians, nutritionists, development agents (DAs) and marketing. This is because the regression equations will be used for selection by the breeders and DAs, administrating treatment doses by the veterinarians, and to determine the feed ration of an individual or group of sheep by the nutritionists. Moreover, the regression equations will be essential in marketing of the indigenous sheep particularly in farms involved in mutton production. Regression equations for the prediction of live body weight from the linear body traits of the indigenous sheep (Begait, Rutanna and Arado) are not yet developed

and practiced. Therefore, the objective of the study was to determine quantitative relationships between the linear body traits (explanatory variables) and body weight (response variable), and to develop regression equations for predicting live body weights of each indigenous sheep population.

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The objective of the study was to determine relationships between the linear body traits (LBTs) and body weight of the indigenous sheep, and to develop regression equations for predicting live body weights of each population

MATERIALS AND METHODS

Description of the Study Areas

The field data collection was carried out in Kafta Humera, Tsegede and Welkait districts. Kafta Humera district is the lowland part of Western Zone of Tigray Region, Ethiopia whereas Welkait and Tsegede districts are the highland areas of Western Zone of Tigray Regional State, Ethiopia. The Western Zone of Tigray is located at 570 and 991 kilometers (km) far from Mekelle and Addis Ababa, respectively [21]. The Zone also lies at 13°42' to 14°28' North latitudes and 36°23' to 37°31' East longitudes [22].

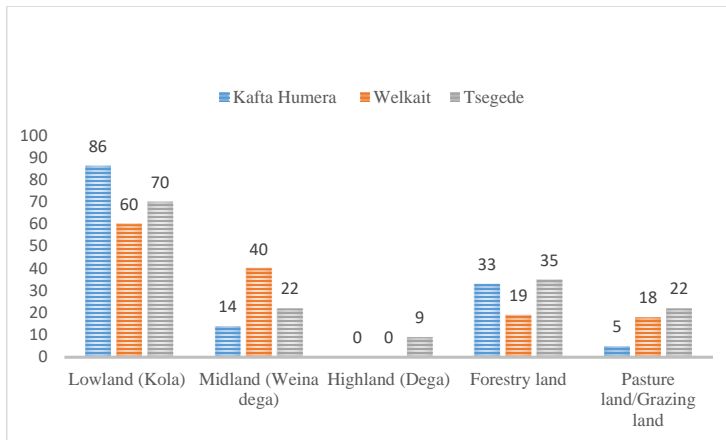
The altitude, rainfall and temperature of Kafta Humera, Welkait and Tsegede districts are presented hereunder (Table 1). Agro-ecology, forestland and grazing land of Kafta Humera, Welkait and Tsegede districts are also presented below (Figure 1) [23].

Table 1 Altitude, rainfall and temperature of Kafta Humera, Welkait and Tsegede districts

District	Altitude (MASL)		Rainfall (mm)		Temperature (°C)	
	Min-Max	Average	Min-Max	Average	Min-Max	Average
Kafta Humera	500-1849	1174.5	650-750	700	25-48	36.5
Welkait	700-2354	1527	700-1800	1250	18-25	21.5
Tsegede	680-3008	1844	1200-2500	1850	12-35	23.5

Meter Above Sea Level (MASL), millimeter (mm), Minimum-Maximum (Min-Max)

Source: [23]



Source: [23]

Figure 1 Agro-ecology, forestland and pastureland of each district (%)

Data collection and statistical analysis

Begait (173), Rutanna (151) and Arado (164) adult sheep which totaled 488 sample animals kept at on-farm management system were randomly involved in the field data collection. Dentition was used to determine the age of the animals and were from one permanent incisor (1PPI) up to four permanent incisors (4PPI).

The quantitative and qualitative data were collected according to the standard breed descriptor list for the sheep breeds developed by FAO [24] guideline and precautions developed by ESGPIP [9]. The linear body traits were measured using flexible measuring tape while body weight (BW) was measured using suspended spring balance having 100kg capacity with 0.2 kg precision. There were eighteen (18) linear body traits measured (in centimeter) which comprised of Body length (BL), Chest girth (ChG), Chest depth (ChD), Height at withers (HW), Rump height (RuH), Rump length (RuL), Rump width (RuW), Hair/wool length (HWL), Scrotal girth (ScG), Scrotal depth (ScD), Teat length (TtL), Head length (HdL), Head width (HdW), Ear length (EL), Horn length (HL), Shin circumference (ShC), Tail length (TL) and Tail width (TW). A correlation and regression analyses between linear body measurements as predictor variables and body weight as a response variable were conducted. Mean comparison of sex and age class of the animals was made, and correlation analysis of linear body measurements and body weights of

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the indigenous sheep was performed. Stepwise Multiple Regression Analysis (SMRA) procedure of Statistical Package for Social Sciences [25] was the statistical method used to determine the best fitted regression equation for the prediction of live body weights of the three indigenous sheep.

Multiple linear regression model for female Rutanna sheep

$$Y_j = \alpha + \beta_1(X_1) + \beta_2(X_2) + \beta_3(X_3) + \beta_4(X_4) + e_j \dots \dots \dots (1)$$

Y_j -the response variable (BW), α (Regression intercept), β_1 , β_2 , β_3 , β_4 (Regression coefficients of the predictor variables), X_1 , X_2 , X_3 , X_4 are the predictor variables (ChG, BL, RuW and ShC), respectively, and e_j is the residual random error

Multiple linear regression model for male Rutanna sheep:

$$Y_j = \alpha + \beta_1(X_1) + \beta_2(X_2) + \beta_3(X_3) + \beta_4(X_4) + \beta_5(X_5) + e_j \dots \dots \dots (2)$$

Y_j -the response variable (BW), α (Regression intercept), β_1 , β_2 , β_3 , β_4 , and β_5 (Regression coefficients of the predictor variables), X_1 , X_2 , X_3 , X_4 and X_5 are the predictor variables (ChD, ScD, ChG, TL and HdL), respectively, and e_j is the residual random error

RESULTS

Live body weights, and Correlations between Linear Body Measurements and Body Weights of the indigenous sheep

The indigenous sheep populations were kept under low input extensive production system. The sample photos of the indigenous sheep are presented hereunder (Figures 2, 3 and 4). The overall direct field weighed live body weights of Begat, Rutanna and Arado sheep were 40.4 ± 0.49 kilograms (Kg), 48.3 ± 0.94 Kg and 28.3 ± 0.29 Kg, respectively. The direct field weighed live body weights of the indigenous sheep increased with the advancement of age class of the animals (Table 2). The body weight of Begait sheep revealed highest positive significant ($P < 0.01$) correlations with BL ($r = 0.684$), ChG ($r = 0.880$), ChD ($r = 0.817$), HW ($r = 0.629$) and RuH ($r = 0.618$) whilst little or no ($P > 0.05$) correlations were exhibited with ScG ($r = 0.443$), ScD ($r = 0.252$) and EL ($r = 0.039$). The body weight of Rutanna sheep revealed highest positive significant ($P < 0.01$) correlations with BL ($r = 0.777$), ChG ($r = 0.913$), ChD ($r = 0.874$), HW ($r = 0.742$) and RuH ($r = 0.697$) whilst little or no ($P > 0.05$) correlations were exhibited with HaL ($r = 0.039$).

= -0.079), ScD ($r = 0.350$), TtL ($r = 0.167$) and EL ($r = 0.031$) (Table 3). The body weight of Arado sheep revealed highest positive significant ($P < 0.01$) correlations with ChG ($r = 0.788$), ChD ($r = 0.705$) and HL ($r = 0.645$) whilst little or no ($P > 0.05$) correlations were exhibited with ScG ($r = 0.481$), ScD ($r = 0.156$), EL ($r = 0.005$) and TL ($r = 0.104$) (Table 4).

Table 2 Direct field weighed live body weights (Kg) of indigenous sheep across breed, sex and age class

Classes	Breed		
	Begait sheep	Rutanna sheep	Arado sheep
Sex			
Male	52.7±1.25	70.5±1.92	36.6±2.25
Female	39.5±0.44	45.3±0.70	28.0±0.28
Overall	40.4±0.49	48.3±0.94	28.3±0.29
<i>P</i> value	0.000	0.000	0.000
Age Class			
1PPI	33.9±0.81	40.8±1.2	24.7±0.48
2PPI	40.9±0.84	47.9±1.7	28.6±0.88
3PPI	41.4±0.94	50.2±3.1	29.1±0.74
4PPI	43.2±0.78	53.2±1.4	29.4±0.33
Overall	40.4±0.49	48.3±0.94	28.3±0.29
<i>P</i> value	0.000	0.000	0.000

Permanent Pair of Incisors (PPI)

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Figure 2 Sample Photo of Ram of Begait sheep (Adebay, Kafta Humera district)



Figure 3 Sample Photo of Ram of Rutanna sheep (May Kadra, Kafta Humera district)



Figure 4 Sample Photo of Arado sheep (Chegar Kudo, Tsegede district)

UNDER PEER REVIEW

Table 3 Pearson's Correlation Coefficients of Linear Body Measurements and Body Weight of Indigenous Begait (above diagonal) and Rutanna (below diagonal) Sheep Populations

	BL	ChG	ChD	HW	RuH	RuL	RuW	HaL	ScG	ScD	TtL	HdL	HdW	EL	ShC	TL	TW	BW
BL		0.653* *	0.753* *	0.675* *	0.621* *	0.300* *	0.455* *	- 0.269* *	0.532	0.493	0.069	0.619* *	0.386* *	- 0.03 9	0.393* *	0.542* *	0.422* *	0.684* *
ChG	0.710* *		0.868* *	0.641* *	0.607* *	0.369* *	0.572* *	- 0.290* *	0.347	0.180	0.328* *	0.621* *	0.452* *	0.04 8	0.386* *	0.482* *	0.412* *	0.880* *
ChD	0.726* *	0.830* *		0.714* *	0.671* *	0.357* *	0.534* *	- 0.274* *	0.051	-0.144	0.171* *	0.665* *	0.462* *	0.04 3	0.488* *	0.562* *	0.502* *	0.817* *
HW	0.706* *	0.735* *	0.775* *		0.839* *	0.368* *	0.457* *	-0.127 *	0.695* *	0.329	0.093	0.652* *	0.482* *	0.05 5	0.423* *	0.555* *	0.426* *	0.629* *
RuH	0.639* *	0.671* *	0.735* *	0.870* *		0.339* *	0.397* *	-0.045 *	0.618* *	0.701* *	0.150	0.657* *	0.575* *	0.04 9	0.417* *	0.557* *	0.359* *	0.618* *
RuL	0.334* *	0.345* *	0.415* *	0.373* *	0.425* *		0.301* *	0.009 *	0.092	0.066	0.207* *	0.273* *	0.247* *	0.09 2	0.159* *	0.109 *	0.224* *	0.285* *
RuW	0.340* *	0.276* *	0.417* *	0.280* *	0.299* *	0.385* *		-0.174* *	0.074	-0.060	0.230* *	0.393* *	0.151* *	- 0.08 4	0.184* *	0.291* *	0.271* *	0.522* *
HaL	-0.014	-0.063	-0.078	-0.035	-0.056	0.066	-0.109		-0.435	-0.298	-0.038	-0.047	0.054	0.06 0	-0.130	-0.017	-0.050	- 0.279* *
ScG	0.343	0.357	0.790* *	0.346	0.408	-0.075	0.444	0.016		0.790* *	a	0.460	0.169	0.38 7	0.248	0.545	-0.142	0.443
ScD	0.145	0.065	-0.138	0.088	0.010	-0.236	-0.219	0.348	-0.194		a	0.521	0.443	0.16 4	0.309	0.273	-0.124	0.252
TtL	0.212* *	0.220* *	0.277* *	0.263* *	0.227* *	-0.055 *	0.247* *	-0.129	a	a		0.098	0.208* *	- 0.07	-0.021	-0.013	-0.160* *	0.243* *

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Did your data met the following conditions?
The Pearson correlation can only be used when:

1. when you have two quantitative variables that are normally distributed
2. exhibit a linear relationship, are independent
3. homoscedastic, and free from outliers.

If any of these conditions are not met, alternative methods such as Spearman's rank correlation may be more appropriate.

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HdL	0.676*	0.735*	0.761*	0.730*	0.695*	0.245*	0.295*	-0.105	0.333	-0.107	0.237*		0.588*	0.11	0.410*	0.441*	0.452*	0.624*	
	*	*	*	*	*	*	*				*		*	5	*	*	*	*	
Hd	0.559*	0.587*	0.684*	0.559*	0.494*	0.387*	0.418*	-0.015	0.410	-0.297	0.093	0.675*		0.05	0.259*	0.325*	0.263*	0.439*	
W	*	*	*	*	*	*	*				*	*		6	*	*	*	*	
EL	0.104	-0.006	0.059	0.152	0.182*	0.069	-0.033	-0.011	0.113	-0.347	0.147	0.174*	0.068	0.015	0.017	-0.005	0.039		
ShC	0.570*	0.607*	0.614*	0.524*	0.556*	0.188*	0.252*	-0.078	0.581*	-0.325	0.026	0.599*	0.527*	0.05	0.300*	0.462*	0.424*		
	*	*	*	*	*	*	*				*	*	*	3	*	*	*		
TL	0.546*	0.553*	0.531*	0.546*	0.628*	0.218*	0.287*	-0.006	0.496*	-0.304	0.110	0.569*	0.392*	0.02	0.526*		0.363*	0.493*	
	*	*	*	*	*	*	*				*	*	*	0	*	*	*	*	
TW	0.398*	0.492*	0.527*	0.444*	0.454*	0.432*	0.172*	0.078	0.414	0.074	-	0.349*	0.363*	-	0.413*	0.355*		0.479*	
	*	*	*	*	*	*	*				0.288*	*	*	0.06	*	*	*	*	
											*	*	*	0					
BW	0.777*	0.913*	0.874*	0.742*	0.697*	0.352*	0.346*	-0.079	0.704*	0.350	0.167	0.773*	0.642*	0.03	0.671*	0.582*	0.540*		
	*	*	*	*	*	*	*		*	*	*	*	*	1	*	*	*	*	

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed), ^aCannot be computed because at least one of the variables is constant, Body length (BL), Chest girth (ChG), Chest depth (ChD), Height at withers (HW), Rump height (RuH), Rump length (RuL), Rump width (RuW), Hair length (HaL), Scrotal girth (ScG), Scrotal depth (ScD), Teat length (TtL), Head length (HdL), Head width (HdW), Ear length (EL), Shin circumference (ShC), Tail length (TL), Tail width (TW), Body weight (BW)

Table 4 Pearson's Correlation Coefficients of Linear Body Measurements and Body Weight of Indigenous Arado Sheep Population

	BL	ChG	ChD	HW	RuH	RuL	RuW	WL	ScG	ScD	TiL	HdL	HdW	EL	HL	ShC	TL	TW	B W	
BL	1																			
ChG	0.620* *	1																		
ChD	0.623* *	0.777* *	1																	
HW	0.504* *	0.641* *	0.668* *	1																
RuH	0.489* *	0.552* *	0.621* *	0.837* *	1															
RuL	0.354* *	0.356* *	0.315* *	0.333* *	0.277* *	1														
RuW	0.514* *	0.469* *	0.469* *	0.323* *	0.275* *	0.193* *	1													
WL	- 0.218* *	- 0.230* *	- 0.188* *	-0.151	- 0.163* *	- 0.195* *	- 0.181* *	1												
ScG	0.565	0.648	0.509	0.797	0.858* *	0.034	0.301	0.226	1											
ScD	0.113	-0.091	-0.070	0.433	0.420	-0.653	0.581	0.000	0.42 0	1										
TiL	0.184* *	0.187* *	0.245* *	0.088	0.071	0.119	0.317* *	- 0.194* *	a	a	1									
HdL	0.536* *	0.652* *	0.600* *	0.575* *	0.477* *	0.450* *	0.405* *	-0.150	0.62 5	- 0.42 0	0.254* *	1								
HdW	0.507* *	0.507* *	0.537* *	0.537* *	0.457* *	0.216* *	0.367* *	0.117	0.75 2	0.38 7	0.137	0.523* *	1							
EL	0.043	0.044	-0.007	0.049	0.079	0.024	-0.021	-0.034	0.16 2	0.65 8	-0.089	-0.057	-0.001	1						

HL	0.499*	0.582*	0.756*	0.635*	0.541*	0.034	0.170	0.172	0.640	0.095	0.183	0.591*	0.649*	-0.136	1				
ShC	0.247*	0.346*	0.301*	0.278*	0.353*	0.119	0.154*	-0.046	-0.050	0.000	0.179*	0.271*	0.220*	0.038	0.483*	1			
TL	0.190*	0.102	0.167*	0.199*	0.261*	-0.008	0.030	0.162*	0.165	-0.245	0.000	0.226*	0.110	-0.003	0.421*	0.190*	1		
TW	0.286*	0.344*	0.352*	0.209*	0.188*	0.145	0.279*	0.024	-0.034	-0.131	0.185*	0.269*	0.099	0.035	0.224	0.099	0.233*	1	
BW	0.599*	0.788*	0.705*	0.528*	0.491*	0.184*	0.497*	-0.259*	0.481	0.156	0.249*	0.570*	0.480*	0.005	0.645*	0.266*	0.104	0.367*	1

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed), ^aCannot be computed because at least one of the variables is constant, Body length (BL), Chest girth (ChG), Chest depth (ChD), Height at withers (HW), Rump height (RuH), Rump length (RuL), Rump width (RuW), Wool length (WL), Scrotal girth (ScG), Scrotal depth (ScD), Teat length (TL), Head length (HdL), Head width (HdW), Ear length (EL), Horn length (HL), Shin circumference (ShC), Tail length (TL), Tail width (TW), Body weight (BW)

Developing Regression Equations: Prediction of Live Body Weights of the Indigenous Sheep Populations from their Linear Body Measurements

A stepwise multiple regression analysis was used to predict the live body weights of the male and female indigenous sheep. The numbers of technical options for prediction of the live body weights of the female and male Begait, Rutanna and Arado sheep are different. There are three technical live body weight prediction options for female Begait sheep, and male (2PPI-3PPI) Arado sheep whilst there is only one for female Arado sheep, four for female Rutanna, two for male Begait and five technical live body weight prediction options for male Rutanna sheep (Table 5).

One of the established regression equation (Table 5) of each breed and sex is presented below.

Begait (1PPI-4PPI)

$$Y_j = -65.662 + 1.078(\text{ChG}) + 0.264(\text{BL}) + 0.375(\text{TW}) \dots \dots \dots (\text{Female})$$

$$Y_j = -80.228 + 0.770(\text{ChG}) + 0.844(\text{RuH}) \dots \dots \dots (\text{Male})$$

Rutanna (1PPI-4PPI)

$$Y_j = -85.003 + 1.081(\text{ChG}) + 0.378(\text{BL}) + 0.475(\text{RuW}) + 0.684(\text{ShC}) \dots \dots \dots (\text{Female})$$

$$Y_j = -163.956 + 1.522(\text{ChD}) + 1.461(\text{ScD}) + 0.987(\text{ChG}) + 0.285(\text{TL}) + 0.893(\text{HdL}) \dots \dots (\text{Male})$$

Female Arado (1PPI-4PPI)

$$Y_j = -16.034 + 0.632(\text{ChG})$$

Male Arado (2PPI-3PPI)

$$Y_j = -18.832 + 1.741(\text{ChG}) + -5.360(\text{HdW}) + -0.575(\text{RuL})$$

Table 5 Technical Options for Prediction of Live Body Weights of the Indigenous Sheep from their Linear Body Measurements

Breeds and models	α	β_1	β_2	β_3	β_4	β_5	R^2	Adj. R^2
Female Begait (1PPI-4PPI)								
$\alpha + \beta_1(\text{ChG})$	-55.848	1.245					0.723	0.721
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{BL})$	-67.415	1.108	0.306				0.743	0.739
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{BL}) + \beta_3(\text{TW})$	-65.662	1.078	0.264	0.375			.751	0.746
Female Rutanna (1PPI-4PPI)								
$\alpha + \beta_1(\text{ChG})$	-64.245	1.360					0.774	0.772
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{BL})$	-81.810	1.138	0.484				0.805	0.801
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{BL}) + \beta_3(\text{RuW})$	-85.137	1.128	0.425	0.490			0.813	0.808
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{BL}) + \beta_3(\text{RuW}) + \beta_4(\text{ShC})$	-85.003	1.081	0.378	0.475	0.684		0.819	0.813
Female Arado (1PPI-4PPI)								
$\alpha + \beta_1(\text{ChG})$	-16.034	0.632					0.509	0.495
Male Begait (1PPI-4PPI)								
$\alpha + \beta_1(\text{ChG})$	-20.402	0.869					0.606	0.557
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{RuH})$	-80.228	0.770	0.844				0.784	0.722
Male Rutanna (1PPI-4PPI)								
$\alpha + \beta_1(\text{ChD})$	-41.294	2.362					0.786	0.770
$\alpha + \beta_1(\text{ChD}) + \beta_2(\text{ScD})$	-65.173	2.342	1.256				0.873	0.852
$\alpha + \beta_1(\text{ChD}) + \beta_2(\text{ScD}) + \beta_3(\text{ChG})$	-107.019	2.049	1.142	0.621			0.916	0.893
$\alpha + \beta_1(\text{ChD}) + \beta_2(\text{ScD}) + \beta_3(\text{ChG}) + \beta_4(\text{TL})$	-147.283	1.671	1.568	0.902	0.363		0.951	0.931
$\alpha + \beta_1(\text{ChD}) + \beta_2(\text{ScD}) + \beta_3(\text{ChG}) + \beta_4(\text{TL}) + \beta_5(\text{HdL})$	-163.956	1.522	1.461	0.987	0.285	0.893	0.969	0.952
Male Arado (2PPI-3PPI)								
$\alpha + \beta_1(\text{ChG})$	-67.366	1.364					0.888	0.851
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{HdW})$	-37.114	1.790	-4.900				0.992	0.983
$\alpha + \beta_1(\text{ChG}) + \beta_2(\text{HdW}) + \beta_3(\text{RuL})$	-18.832	1.741	-5.360	-0.575			1.000	1.000

Adjusted R^2 (Adj. R^2), Body length (BL), Chest girth (ChG), Chest depth (ChD), Rump height (RuH), Rump length (RuL), Rump width (RuW), Scrotal depth (ScD), Head length (HdL), Shin circumference (ShC), Tail length (TL), Tail width (TW)

DISCUSSION

The indigenous sheep populations were kept under low input extensive production system. The overall direct field weighed live body weights (BW) of Begait, Rutanna and Arado sheep were 40.4 ± 0.49 Kg, 48.3 ± 0.94 Kg and 28.3 ± 0.29 Kg, respectively. BW (34.7 ± 0.24) of Zulu sheep with two or more permanent incisors [26], BW (22.09 ± 0.19 Kg) of *Holla* sheep types in Ethiopia [27], Ouled Djellal sheep of Algeria (male =95.87 Kg and female =61.27) [28], BW of Awasi (54.12 ± 0.70), Il de France (55.29 ± 0.99), Shkodrane (33.63 ± 0.61) and Lara e Polisit (35.89 ± 0.61 Kg) sheep in Albania [29], BW of Afar (18.9 ± 0.49) and Gumuz (35.9 ± 0.50 Kg) sheep [2], BW (23.5 ± 0.2 Kg) of sheep in Tahtay Maichew district, Northern Ethiopia [30], BW (29.70 Kg) of Bonga and BW (31.66 Kg) of Horro [31], and BW (35.8 Kg) of Pahari or Kashmiri sheep in Pakistan [32] are not similar with the BW of Begait, Rutanna and Arado sheep populations. BW (25.80 ± 0.20 Kg) of ewe Blackhead Somali [33] and BW (22.81 ± 0.8 Kg) of ewe Blackhead Somali [34] are not similar with BW of ewes of Arado sheep. The differences could be due to genotype, age and sex proportions used, environment and the interaction effects of genotype and environment. Different flocks of different sheep genotypes in different agro-climatic conditions do not receive the same management and result in live body weight variations.

Arado sheep (Tigray highland sheep) has similar BW with Blackhead Somali sheep (27.2 Kg) [35] and Awassi sheep (28.75 ± 0.49 Kg) [36], however, the current live body weight of Arado sheep is not similar with the past live body weight study of the Tigray highland sheep (20.46 ± 2.98) reported by Alemayehu and Tikabo [37]. The deviation could be due to age and sex proportions used for the study, management, agro-climatic and temporal effect. The earlier study of Deribe *et al.* [2] indicated that the BW of Begait (39.7 ± 0.53 Kg) is similar with the present BW of Begait sheep whilst the BW of Rutanna (43.1 ± 0.49) is not similar with the present BW of Rutanna sheep. The differences might be due to environmental, the interaction effects of genotype and environment and temporal effects.

The direct field weighed live body weight of the indigenous sheep increased with the advancement of age class of the animals. The body weights of Begait and Rutanna sheep revealed highest positive significant ($P < 0.01$) correlations with BL ($r = 0.684$, $r = 0.777$), ChG ($r = 0.880$, $r = 0.913$), ChD ($r = 0.817$, $r = 0.874$), HW ($r = 0.629$, $r = 0.742$) and RuH ($r = 0.618$, $r = 0.742$).

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=0.697), respectively whilst the body weight of Arado sheep revealed highest positive significant ($P<0.01$) correlations with ChG ($r=0.788$), ChD ($r=0.705$) and HL ($r=0.645$). The correlations of body weights of the indigenous sheep with these linear body traits indicate that selection practice based on these linear body traits could improve the live body weights of the indigenous sheep. The field live body weight prediction equations of male and female of each indigenous sheep populations are developed by stepwise multiple regression analysis and set regression equations of each breed and sex which will solve the lack of weighing scale at the remote rural areas. Farmers and professionals could use the regression equations to predict the live body weights of the indigenous sheep in the remote rural areas.

CONCLUSION AND RECOMMENDATIONS

~~The indigenous sheep populations were kept under low input extensive production system.~~ The overall direct field weighed live body weights of Begat, Rutanna and Arado sheep were 40.4 ± 0.49 Kg, 48.3 ± 0.94 Kg and 28.3 ± 0.29 Kg, respectively. Male Rutanna (70.5 ± 1.92 Kg) were not comparable with male Begait (52.7 ± 1.25 Kg) and Arado (36.6 ± 2.25 Kg) sheep. The variations in body weight is a function of genotype, feeding, health, sex, age and flock management situations where the populations were kept. Highest positive significant ($P<0.01$) correlations between linear body measurements and direct field weighed live body weight of the indigenous sheep revealed that the linear body measurements could be used as selection traits and used to predict the live body weights of the indigenous sheep. The live body weights of the male and female indigenous sheep at field level (remote rural areas) could be predicted by the regression equations of each breed and sex.

Except in male Rutanna, chest girth or chest circumference could be solely used to predict the live body weights of the indigenous sheep breeds for facilitating management decisions in breeding (selection and genetic improvement), nutrition (ration formulation), health (medicinal doses of veterinary services) and marketing (animal pricing). Genetic characterization of the indigenous sheep populations should be conducted to identify novel and economically important candidate genes.

Ethical Approval:

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There was no ethics approval obtained from an institution because there was no damage on animal body part(s) due to data collection. Therefore, all farmers who owned the indigenous sheep were volunteer for data collection on the exterior body characteristics of the animals.

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