

PREDICTING LIVE WEIGHT FROM BODY MEASUREMENTS USING REGRESSION MODELS IN ADULT FEMALE ARBIA GOATS OF ALGERIA

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ABSTRACT

The aim of the present study was to determine the current variation in live weight and body measurements in the main indigenous population Arbia goats reared in two different locations (Batna and Biskra) in the eastern and South-eastern regions of Algeria and to investigate the predictability of live weight from body measurements using the stepwise regression model. The animal material studied consisted of 239 Arbia breed goats from Batna (n=93) and Biskra (n=146). The least squares mean obtained for chest circumference, abdominal circumference, body length, height at withers, back height, chest depth, neck circumference and live weight were 79.44 cm, 90.45 cm, 66.45 cm, 70.11 cm, 72.02 cm, 35.66 cm, 31.96 cm and 37.17 kg, respectively. Among the regression models developed for the breeding locations, the highest coefficient of determination was obtained from the regression model incorporating chest depth, abdominal circumference, head length-1, head width, chest circumference, forearm circumference, neck circumference and ear width in the Batna location. The results showed that live weights can be estimated with high coefficients of determination using regression models constructed from body measurements specific to the breeding sites.

Key words: Algerian goat population, body weight, estimation, stepwise regression

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INTRODUCTION

Algerian national production of goat meat remains marginal compared to other types of red meat from ruminants, which primarily meet national demand (Djouza and Chehma, 2019), though it is less popular than other types of protein. However, its dietary value and low cholesterol levels are two attractive factors for its consumption (Mouhous *et al.*, 2021). Goat meat is a popular source of protein worldwide. Goat meat production involves the breeding, feeding, and management of goats. They are raised on both large commercial farms and small family farms. This production is a significant source of income for many farmers, and its increasing popularity has led to the development of new markets and opportunities for producers (Ngomane *et al.*, 2022).

Live weight is one of the traits used in the morphological characterization of animal genetic resources (Djouza, 2019; Tölü and Savaş, 2021) and is an essential factor in livestock breeding programs and plays a crucial role in the success of livestock farming (Yilmaz *et al.*, 2013; Yilmaz *et al.*, 2014, Berghof *et al.*, 2019). One important aspect of these programs is the selection

of animals based on their live weight. Livestock farmers aim to breed animals with a higher live weight, as this typically correlates with increased meat, milk, or wool production (Yilmaz *et al.*, 2019; Cemal *et al.*, 2019; Cemal *et al.*, 2021).

Estimating the live weight of farm animals is an important aspect of livestock management. It can help farmers monitor animal growth, adjust feeding programs, and determine market readiness. While digital scales are the most accurate method for determining live weight, they can be expensive and impractical for small-scale farmers. An alternative method is to estimate live weight using body measurements, such as chest girth, body length, and hip width (Yilmaz *et al.*, 2013, Habib *et al.*, 2019). This method is particularly useful for animals that are difficult to handle or transport, such as sheep (Iqbal *et al.*, 2014, Khan *et al.*, 2014), cattle and goats.

The use of linear body measurements to estimate live weight has been extensively researched and developed over the years (Yilmaz *et al.*, 2013; Odadi, 2018; Chinchilla-Vargas *et al.*, 2018; Meghelli *et al.*, 2020; Ouchene-Khelifi and Ouchene, 2021). In goats, estimation of live weight using body measurements is also a useful tool for producers. Linear body

measurements such as heart girth, body length, and hip width are commonly used to estimate live weight. The use of regression equations specific to the breed and age of the goat can improve the accuracy of live weight estimates (Yilmaz *et al.*, 2013; Waheed *et al.*, 2020; Singh *et al.*, 2020, Dige *et al.*, 2022).

While linear body measurements provide a useful live weight-estimating tool in farm animals, it is important to note that these estimates are approximations of the animal's actual weight (Yilmaz *et al.*, 2013; Habib *et al.*, 2019, Ambel and Bayou, 2022). Although digital scales are the most accurate, using linear body measurements is a practical and cost-effective alternative. Breed- and age-specific regression equations can improve accuracy of live weight estimates. Factors such as body condition, age, breed, and sex can all influence estimation accuracy (Yilmaz *et al.*, 2013; Altay, 2022). Therefore, regular monitoring and adjustment of feeding programs based on actual weight measurements are important to ensure proper nutrition and growth. In Algeria, limited research has been conducted on live weight estimation from body measurements in goats; the current study aims

to predict it from body measurements using regression models in female adult goats.

MATERIALS AND METHODS

Description of study locations: The research took place in two areas in the eastern and southeastern parts of Algeria – Batna and Biskra. While Batna is situated between 4°-7° east longitude and 35°-36° north latitude and experiences a semi-arid climate; however, mountain and forest areas above 1200 m are classified as quasi-humid (Meridja *et al.*, 2020). Similarly, Biskra, located in the southeastern part of Algeria at the entrance of the Sahara, has coordinates of 5.44° E longitude and 34.48° N latitude at an elevation of 124 m. The northern part of the region is adjacent to Batna, while the southern regions are governed by Ouargla, Djelfa, and El Oued provinces (Figure 1). In these areas, goat breeding is a widespread practice with herds typically consisting of a limited number of animals. For instance, in Batna, rural communities practice this farming method by allowing goats to graze on post-harvest fields and providing free fodder (Bengouga *et al.*, 2019).

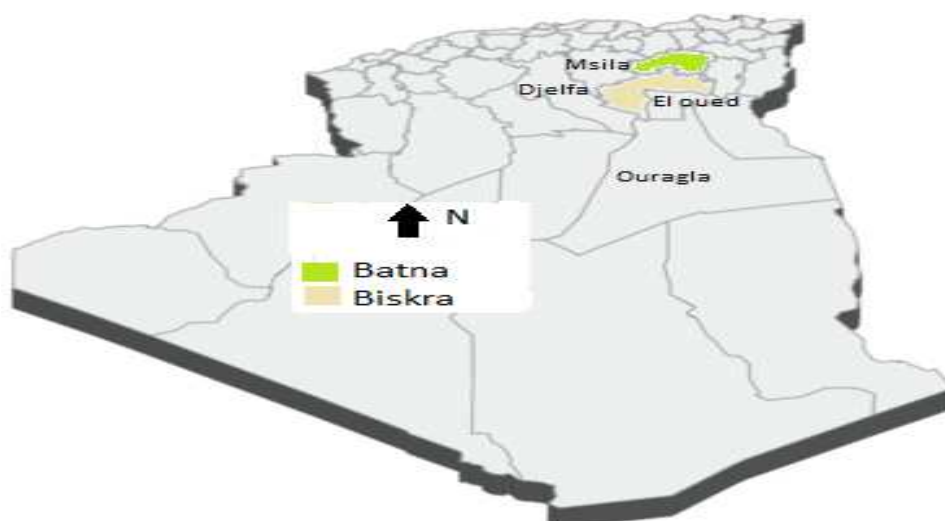


Fig.1 Geographical locations of the study areas (Batna and Biskra) in Algeria

Animal material: Goats were selected based on herd size, prioritizing breeders with large herds. This yielded a total sample size of 239 adult female Arbia goats, each approximately 2 years old (age determined by teeth examination) from two different locations in Algeria (Batna and Biskra). A total of 93 goats from Batna and 146 from Biskra were randomly selected within the participating farms.

Body measurements and live weight: Body measurements were taken following the FAO (2013) guidelines, including chest circumference, abdominal circumference, body length, height at the withers, back height, chest depth, neck circumference, thigh

circumference, ear length, horn length, head length 1, head length 2, cannon length, distance between ears, head width, forearm circumference, pastern circumference, distance between eyes, ear width and cannon circumference (Figure 2). Precautions were implemented to prevent any inaccuracies resulting from the animal's posture and movements during measurement. A single trained person performed all measurements, when animals were calm and standing squarely on a flat, horizontal surface with heads in normal position. Body measurements were recorded using tailor tape. Live weights were measured using a digital scale (50 g precision) after goats immobilization.

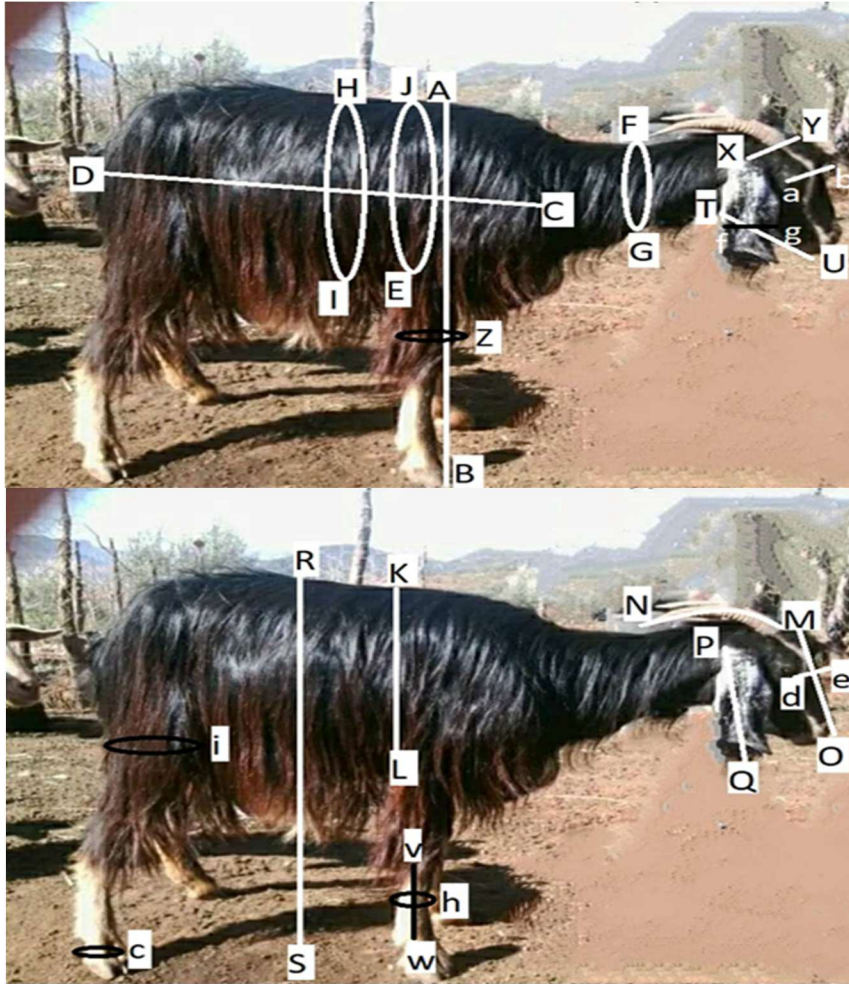


Fig. 2 Body measurements illustration on Arbia goat (E-J chest circumference; I-H abdominal circumference; C-D body length; A-B height at the withers; R-S back height; K-L chest depth; F-G neck circumference; i thigh circumference; P-Q ear length; M-N horn length; M-O head length 1; T-U head length 2; V-W cannon length; X-Y distance between ears; a-b head width; Z forearm circumference; c pastern circumference; d-e distance between eyes; f-g ear width; h cannon circumference)

Statistical analysis: Statistical analyses were performed using SAS (1999). Data normality was assessed through UNIVARIATE and MULTIVARIATE procedures. All variables were normally distributed ($p > 0.05$). Homogeneity of variances among multiple groups was evaluated using Levene's test, showing homogeneous variances across groups ($p > 0.05$). Variance analyses and least squares means were then computed using the GLM procedure of the SAS (1999) software. In addition, phenotypic correlations between variables were obtained using the PROC CORR procedures in SAS (1999). The following are the mathematical models that are employed in the analysis of variance.

Model used for live weight

$$Y_{ij} = \mu + a_i + e_{ij}$$

Model used for body measurement

$$Y_{ij} = \mu + a_i + \beta_1(X_i - \bar{X}) + e_{ij}$$

Where;

Y_{ij} = Observations for live weight and body measurement

μ = Overall mean of the trait

a_i = Fixed effect of region (i= Batna and Biskra)

β_1 = Coefficient of regression of live weight

\bar{X} = Mean weight

X_i = Weight

e_{ij} = Random errors with the assumption of $N(0, \sigma^2)$

Estimation formulas for live weights were derived through a SAS (1999) procedure for stepwise multiple regression, utilizing different body measurements by region. The linear regression model presented below was utilized for deriving the formulas.

$$\hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i$$

$\hat{\beta}_0$ = Constant

$\hat{\beta}_1$ = Regression coefficient

x_i = Body measurements

x₁ = chest depth (CD),
 x₂ = abdominal circumference (AC),
 x₃ = head length-1 (HdL1),
 x₄ = head width (HdW)
 x₅ = chest circumference (CC)
 x₆ = forearm circumference (FC)
 x₇ = neck circumference (NC)
 x₈ = ears width (EW)
 x₉ = body length (BL)

x₁₀ = distance between ears (DE)
 x₁₁ = height at the withers (HW)

RESULTS AND DISCUSSION

Descriptive statistics of body measurements and live weight in the Arbia goat population are shown in Table 1.

Table 1. Descriptive statistics of body measurements and live weight in Arbia goat population

Variable	Region	N	Mean±SD	CV (%)	Minimum	Maximum	General
CC	Batna	93	79.40±7.205	9.07	34	94	79.55±6.132
	Biskra	146	79.64±5.457	6.85	64	92	
AC	Batna	93	94.04±8.225	8.75	64	111	89.53±8.469
	Biskra	146	87.01±7.517	8.64	64	111	
BL	Batna	93	66.55±5.611	8.43	54	85	66.68±5.642
	Biskra	146	66.75±5.673	8.50	52	90	
HW	Batna	93	67.76±4.462	6.58	57	80	70.86±4.95
	Biskra	146	72.59±4.333	5.97	60	84	
BH	Batna	93	69.84±4.666	6.68	57	86	72.66±4.86
	Biskra	146	74.25±4.212	5.67	61	86	
CD	Batna	93	35.56±2.500	7.03	30	42	35.96±2.752
	Biskra	146	36.18±2.866	7.92	27	49	
NC	Batna	93	33.02±3.304	10.01	25	41	31.52±3.307
	Biskra	146	30.68±3.006	9.80	20	40	
TC	Batna	93	30.05±3.878	12.90	14	39	27.4±3.849
	Biskra	146	25.91±2.926	11.29	19	35	
EL	Batna	93	23.16±3.164	13.66	17	34	23.9±3.514
	Biskra	146	24.31±3.639	14.97	10	30	
HL	Batna	93	22.62±5.601	24.76	11	40	22.55±5.78
	Biskra	146	22.51±5.910	26.26	7	41	
HdL1	Batna	93	20.29±1.486	7.32	17	24	22.43±2.469
	Biskra	146	23.63±2.066	8.74	20	30	
HdL2	Batna	93	20.58±1.747	8.49	17	26	20.64±2.474
	Biskra	146	20.68±2.804	13.56	11	28	
CL	Batna	93	14.61±1.391	9.52	7	19	14.75±1.572
	Biskra	146	14.82±1.664	11.23	8	19	
DE	Batna	93	13.73±1.057	7.70	12	17	14.67±1.852
	Biskra	146	15.19±1.992	13.11	9	20	
HdW	Batna	93	13.27±0.823	6.20	11	15	13.78±1.191
	Biskra	146	14.06±1.271	9.04	11	20	
FC	Batna	93	13.37±1.235	9.24	9	16	13.99±2.024
	Biskra	146	14.34±2.283	15.92	8.5	20	
PC	Batna	93	9.91±0.819	8.26	8	12	10.65±1.256
	Biskra	146	11.07±1.267	11.44	8	15	
DEY	Batna	93	11.47±0.899	7.84	9	14	11.14±1.1
	Biskra	146	10.95±1.159	10.58	9	16	
EW	Batna	93	8.71±0.980	11.25	7	12	8.95±1.164
	Biskra	146	9.09±1.237	13.62	5	14	
CnC	Batna	93	9.12±1.064	11.67	7	14	8.66±1.1895
	Biskra	146	8.40±1.181	14.05	6	17	
LW	Batna	93	36.80±7.284	19.79	22	58	37.28±7.607
	Biskra	146	37.55±7.787	20.74	20	65	

CC: chest circumference, **AC:** abdominal circumference, **BL:** body length, **HW:** height at the withers, **BH:** back height, **CD:** chest depth, **NC:** neck circumference, **TC:** thigh circumference, **EL:** ear length, **HL:** horn length, **HdL1:** head length 1, **HdL2:** head length 2, **CL:** cannon length, **DE:** distance between ears, **HdW:** head width, **FC:** forearm circumference, **PC:** pastern circumference, **DEY:** distance between eyes, **EW:** ear width, **CnC:** cannon circumference, **LW:** live weight

Upon examining the descriptive statistics, it is evident that goats display a higher coefficient of variation for the horn length and live weight. Although individuals from the same breed were used in the study, this can be considered a natural reflection of the fact that sampling was conducted in two different geographical regions.

Table 2 presents the least square means and standard errors for body measurements and live weights. Exception for horn length (HL) and head length-2 (HdL2), all traits indicate significant differences ($p < 0.05$) between locations (Batna vs. Biskra), used as fixed effects in the statistical model. Additionally, the statistical model showed that the live weight utilized as a covariate, had a significant impact on all characteristics discussed.

Table 3 displays the correlation coefficients between live weight and body measurements based on the sampling locations. The Batna region showed the strongest correlations coefficients, with high values specifically between live weight and chest circumference (CC), abdominal circumference (AC), body length (BL), height at withers (HW), and back height (BH) for both locations.

Different regression models for live weight estimation were developed for each location; their coefficients of determination (R^2) are given in Table 4. Eight models were developed for Batna and Five for Biskra. All prediction models except model 1 (Table 4), created for the Batna region showed a determination coefficient above 0.75. Conversely, all models retalted to Biskra region had determination coefficient below 0.75.

The study showed that live weights and height at withers (HW) in Arbia goats were comparable to Ouchene-Khelifi and Ouchene (2021)'s findings for the same breed. However, body length (BL) values were lower than those reported by the same authors. The live weights observed were also lower than those reported by Daskiran and Koluman (2014) for Kilis and Honamli goats. Arbia goats raised in Biskra exhibited higher live weight, height at withers, back height, ear length and width, head length, distance between ears, forearm, and pastern circumference compared to those in Batna. This difference may result from factors related to the management of animals, or it may represent tangible evidence of how animals adjust to their specific environment.

While chest circumference (CC) and cannon circumference (CnC) in this study were similar to previous findings of Djaout *et al.*, (2022) on the same genotype, BL values were relatively low. However, HW, CC, EL, and HL exceeded values reported for Mekatia goats in North-central Algeria reported by Fantazi *et al.*,

(2017). These differences in body measurements and live weight can be attributed to regional variations, breed differences, age, management system, and feeding practices. Strong positive phenotypic correlations between live weight and body measurements were observed, aligning with previous studies of Pesmen and Yardimci (2008), Matsebula *et al.*, (2013), Ahmed *et al.*, (2017), Adhianto *et al.*, (2020); Ouchene-Khelifi and Ouchene (2021); Dakhlan *et al.*, (2021) and Ambel and Bayou, (2022). According to Iqbal *et al.*, (2013), the best fitted regression models found for adult goats (13-18 months of age) were body length and height at withers.

All stepwise regression models for Batna included chest depth, while Biskra models included chest circumference. This indicates that both chest circumference and depth are important factors in live weight estimation, as seen in previous studies (Badi *et al.*, 2002, Villiers *et al.*, 2009; Tadesse *et al.*, 2012, Yilmaz *et al.*, 2013; Hussaini *et al.*, 2018; Yakubu *et al.*, 2022).

It is important to note that accuracy generally increases with additional body measurements, but excessive variables reduce practicality. Therefore, researchers should prioritize high-accuracy models requiring fewer measurements, particularly in areas where weighing is difficult. Consequently, Model 5 (Batna) and Model 4 (Biskra) are recommended choices for live weight estimation in Arbia goats.

Conclusion: As results, the study of Arbia goats' live weight and body measurements has provided valuable knowledge for locations where the breed is raised. The discovery of distinct prediction models for each location is significant because it reveals that new models may be needed for different regions where the same breed is grown, beyond breed-specific needs identified in previous studies. These findings show that live weight is an important selection criterion for field breeding, can be predicted from body measurements like chest depth, abdominal circumference, head length-1, head width, chest circumference, forearm circumference, neck circumference and ear width.

Conflict of Interest: The authors have declared no conflict of interest.

Author's contributions: LD: study conception and design, data collection, interpretation of data analysis, searching of articles, and manuscript preparation. OY: data analysis and interpretation, review, editing, and preparation of the final revised manuscript. AC: study design and conception, reviewing the manuscript. ND: data collection, searching of articles. All authors read and approved the manuscript.

Table 2. Least squares means and standard errors for body measurements and live weight in the Arbia goat population

Factor	N	CC	AC	BL	HW	BH	CD	NC	TC	EL	HL
Region		P=0.929	P=0.000	P=0.958	P=0.000	P=0.000	P=0.501	P=0.000	P=0.000	P=0.018	P=0.351
Batna	93	79.47±0.487	94.33±0.544	66.43±0.463	67.75±0.359	69.79±0.362	35.55±0.238	33.17±0.258	30.38±0.318	23.27±0.360	22.92±0.505
Biskra	146	79.41±0.388	86.56±0.434	66.46±0.369	72.47±0.286	74.24±0.289	35.76±0.19	30.76±0.206	25.71±0.254	24.36±0.287	22.32±0.402
Reg (Linear)		P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000	P=0.001	P=0.000
LW		0.572±0.040	0.777±0.045	0.427±0.038	0.365±0.030	0.332±0.030	0.173±0.020	0.238±0.021	0.125±0.026	0.106±0.030	0.421±0.042
Overall	239	79.44±0.311	90.45±0.348	66.45±0.296	70.11±0.229	72.02±0.231	35.66±0.152	31.96±0.165	28.05±0.203	23.82±0.230	22.62±0.322

CC: chest circumference, AC: abdominal circumference, BL: body length, HW: height at the withers, BH: back height, CD: chest depth, NC: neck circumference, TC: thigh circumference, EL: ear length, HL: horn length,

Table 2- Continue: Least squares means and standard errors for body measurements and live weight

Factor	N	HdL1	HdL2	CL	DE	FC	PC	DEY	EW	CnC	LW
Region		P=0.000	P=0.989	P=0.660	P=0.000	P=0.000	P=0.000	P=0.000	P=0.011	P=0.000	P=0.000
Batna	93	20.5±0.171	20.54±0.222	14.76±0.149	13.82±0.155	13.25±0.1	13.4±0.188	11.48±0.102	8.72±0.115	9.12±0.104	36.80±0.726
Biskra	146	23.8±0.136	20.54±0.177	14.84±0.119	15.31±0.123	13.98±0.08	14.28±0.15	10.97±0.082	9.09±0.092	8.35±0.083	37.55±0.544
Reg (Linear)		P=0.000	P=0.000	P=0.015	P=0.000	P=0.000	P=0.000	P=0.000	P=0.005	P=0.000	P=0.000
LW		0.115±0.014	0.101±0.018	0.03±0.012	0.107±0.013	0.066±0.008	0.078±0.016	0.073±0.009	0.027±0.01	0.051±0.009	
Overall	239	22.15±0.109	20.54±0.142	14.80±0.095	14.56±0.099	13.61±0.064	13.84±0.120	10.49±0.065	8.91±0.074	8.73±0.067	37.17±0.453

HdL1: head length 1, HdL2: head length 2, CL: cannon length, DE: distance between ears, HdW: head width, FC: forearm circumference, PC: pastern circumference, DEY: distance between the eyes, EW: ears width, CnC: cannon circumference, LW: live weight

Table 3. Phenotypic correlation coefficients between live weight and body measurements by region

Region	CC	AC	BL	HW	BH	CD	NC	TC	EL	HL	HdL1	HdL2	CL	DE	HdW	FC	PC	DEY	EW	CnC
AC	0.525***																			
Biskra	0.766***																			
Batna	0.479**	0.583***																		
Biskra	0.538***	0.442***																		
Batna	0.542***	0.546***	0.698***																	
Biskra	0.593***	0.469***	0.430***																	
Batna	0.556***	0.572***	0.619***	0.841***																
Biskra	0.609***	0.526***	0.277***	0.736***																
Batna	0.563***	0.678***	0.628***	0.737***	0.765***															
Biskra	0.416***	0.317***	0.262***	0.308***	0.377***															
Batna	0.461***	0.570***	0.622***	0.601***	0.578***	0.689***														
Biskra	0.453***	0.343***	0.415***	0.274***	0.164***	0.098***														
Batna	0.253***	0.358***	0.347***	0.376***	0.441***	0.341***	0.356***													
Biskra	0.322***	0.293***	0.251***	0.240***	0.297***	0.207**	0.110 ^{ns}													
Batna	0.237*	0.248**	0.405***	0.542***	0.633***	0.473***	0.414***	0.441***												
Biskra	0.142*	0.135 ^{ns}	0.060 ^{ns}	0.239**	0.215**	-0.034 ^{ns}	0.180*	0.051 ^{ns}												
Batna	0.408**	0.561***	0.449***	0.449***	0.516***	0.603***	0.534***	0.299**	0.223*											
Biskra	0.639***	0.488***	0.421***	0.358***	0.377***	0.284**	0.365***	0.266**	-0.043 ^{ns}											
Batna	0.443***	0.558***	0.531***	0.614***	0.575***	0.601***	0.586***	0.411***	0.437***	0.473***										
Biskra	0.306***	0.265***	0.178*	0.249**	0.214*	0.109 ^{ns}	0.118 ^{ns}	0.093 ^{ns}	0.186*	0.173*										
Batna	0.298**	0.302**	0.276**	0.318**	0.392**	0.381**	0.233*	0.245**	0.232*	0.489***	0.288**									
Biskra	0.350***	0.279***	0.363***	0.316***	0.239**	0.287***	0.248***	0.308***	0.059 ^{ns}	0.406***	0.061 ^{ns}									
Batna	0.182 ^{ns}	0.223*	0.325*	0.378***	0.383**	0.243*	0.192*	0.254**	0.331***	0.045 ^{ns}	0.414**	0.212*								
Biskra	0.089 ^{ns}	0.139 ^{ns}	0.031 ^{ns}	0.205**	0.306***	0.002 ^{ns}	-0.118 ^{ns}	0.208*	0.178*	0.061 ^{ns}	0.047 ^{ns}	0.028 ^{ns}								
Batna	0.325**	0.344***	0.341***	0.406***	0.452***	0.391***	0.359***	0.294**	0.499***	0.452***	0.518***	0.246*	0.262**							
Biskra	0.358**	0.290**	0.263**	0.293**	0.318**	0.017 ^{ns}	0.365**	0.166*	0.292**	0.351***	0.147*	0.144*	0.090 ^{ns}							
Batna	0.351***	0.454***	0.556***	0.562***	0.552***	0.572***	0.457***	0.328***	0.335***	0.476***	0.460***	0.367***	0.285**	0.392***						
Biskra	0.388**	0.33**	0.286**	0.271**	0.284**	0.117***	0.284**	0.340**	-0.025 ^{ns}	0.349***	0.008 ^{ns}	0.265***	0.183*	0.328**	0.406**					
Batna	0.296**	0.434***	0.401**	0.358**	0.393**	0.355**	0.340**	0.300**	0.237**	0.351**	0.396**	0.182 ^{ns}	0.372**	0.366**	0.406**					
Biskra	0.200**	0.164*	0.025 ^{ns}	0.251***	0.288***	0.260***	-0.025 ^{ns}	0.300**	0.034 ^{ns}	-0.034 ^{ns}	0.446***	-0.033 ^{ns}	-0.040 ^{ns}	0.020 ^{ns}	-0.161*					
Batna	0.414**	0.566***	0.534***	0.509***	0.488**	0.648**	0.587***	0.325**	0.332**	0.543***	0.587***	0.332**	0.412**	0.395**	0.568***	0.442***				
Biskra	0.407***	0.459***	0.228**	0.315**	0.368**	0.392**	0.123 ^{ns}	0.209**	0.133 ^{ns}	0.191*	0.271***	0.181*	0.285**	0.154*	0.211**	0.315***				
Batna	0.407***	0.401**	0.489***	0.662***	0.678***	0.585**	0.531***	0.389***	0.474***	0.602***	0.426***	0.429***	0.208*	0.406***	0.495***	0.283**	0.432***			
Biskra	0.309**	0.221**	0.302**	0.287**	0.094 ^{ns}	0.015 ^{ns}	0.408**	0.261**	0.206**	0.174*	-0.033 ^{ns}	0.214*	-0.065 ^{ns}	0.248**	0.256**	-0.086 ^{ns}	0.041 ^{ns}			
Batna	0.345***	0.257**	0.465***	0.558***	0.589***	0.484**	0.510**	0.443**	0.718***	0.343**	0.345***	0.298**	0.162 ^{ns}	0.401***	0.344***	0.252**	0.344***	0.609***		
Biskra	0.090 ^{ns}	0.125 ^{ns}	-0.014 ^{ns}	0.157**	0.187**	0.060 ^{ns}	0.047 ^{ns}	0.071 ^{ns}	0.655***	-0.085 ^{ns}	0.106 ^{ns}	0.104 ^{ns}	0.222*	0.085 ^{ns}	0.037 ^{ns}	0.156*	0.105 ^{ns}			
Batna	0.359***	0.356***	0.307**	0.356***	0.335**	0.375**	0.328**	0.178**	0.128**	0.353**	0.332**	0.180 ^{ns}	-0.099 ^{ns}	0.216*	0.256**	0.131 ^{ns}	0.423**	0.263**	0.178 ^{ns}	
Biskra	0.241**	0.219**	0.093 ^{ns}	0.205**	0.281***	0.152*	-0.067 ^{ns}	0.053 ^{ns}	0.221**	0.089 ^{ns}	0.248***	0.036 ^{ns}	0.054 ^{ns}	0.158**	0.028 ^{ns}	0.216**	0.210**	-0.045 ^{ns}	0.225**	
Batna	0.631***	0.804***	0.719***	0.729***	0.718**	0.807***	0.693***	0.423**	0.397***	0.661***	0.694***	0.398**	0.395**	0.444**	0.684**	0.546**	0.726**	0.519***	0.378***	0.398***
Biskra	0.746**	0.715**	0.566**	0.595**	0.528**	0.349**	0.473**	0.227**	0.135 ^{ns}	0.489**	0.278**	0.350**	0.081 ^{ns}	0.419**	0.351**	0.176*	0.390***	0.338**	0.070 ^{ns}	0.182*

CC: chest circumference. AC: abdominal circumference. BL: body length. HW: height at the withers. BH: back height. CD: chest depth. NC: neck circumference. TC: thigh circumference. EL: ear length. HL: horn length. HdL1: head length 1. HdL2: head length 2. CL: cannon length. DE: distance between ears. HdW: head width. FC: forearm circumference. PC: pastern circumference. DEY: distance between the eyes. EW: ears width. CnC: cannon circumference. LW: live weight. ns: non-significant. *: $p < 0.05$. **: $p < 0.01$. ***: $p < 0.001$

Table 4. Live weight estimation models by region using stepwise regression analysis

Region	Models	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	R ²	P
Batna	1 $\hat{y}_1 = \beta_0 + \beta_1 x_1$	-42.59	2.23								0.65	0.000
	2 $\hat{y}_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2$	-49.08	1.42	0.37							0.76	0.000
	3 $\hat{y}_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$	-56.44	1.06	0.30	1.34						0.80	0.000
	4 $\hat{y}_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4$	-67.09	0.85	0.31	1.09	1.67					0.82	0.000
	5 $\hat{y}_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5$	-69.73	0.74	0.28	0.97	1.72	0.14				0.84	0.000
	6 $\hat{y}_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6$	-72.28	0.72	0.26	0.88	1.57	0.13	0.75			0.85	0.000
	7 $\hat{y}_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7$	-71.12	0.60	0.24	0.74	1.52	0.12	0.79	0.26		0.85	0.000
	8 $\hat{y}_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8$	-69.82	0.68	0.22	0.73	1.54	0.13	0.85	0.33	-0.68	0.86	0.000
Biskra	1 $\hat{y}_1 = \beta_0 + \beta_1 x_5$	-47.80	1.07								0.57	0.000
	2 $\hat{y}_1 = \beta_0 + \beta_1 x_5 + \beta_2 x_2$	-49.11	0.37	0.68							0.62	0.000
	3 $\hat{y}_1 = \beta_0 + \beta_1 x_5 + \beta_2 x_2 + \beta_3 x_9$	-55.62	0.37	0.54	0.27						0.65	0.000
	4 $\hat{y}_1 = \beta_0 + \beta_1 x_5 + \beta_2 x_2 + \beta_3 x_9 + \beta_4 x_{10}$	-57.25	0.37	0.44	0.26	0.68					0.67	0.000
	5 $\hat{y}_1 = \beta_0 + \beta_1 x_5 + \beta_2 x_2 + \beta_3 x_9 + \beta_4 x_{10} + \beta_5 x_{11}$	-66.38	0.38	0.31	0.23	0.62	0.29				0.68	0.000

x_1 = chest depth (CD). x_2 = abdominal circumference (AC). x_3 = head length-I (HdLI). x_4 : head width (HdW). x_5 : chest circumference (CC). x_6 : forearm circumference (FC). x_7 : neck circumference (NC). x_8 : ears width (EW). x_9 : body length (BL). x_{10} =distance between ears (DE). x_{11} =height at the withers (HW). β_0 =Constant. β_1 =Regression coefficient. R^2 =Adjusted estimation power

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