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Assessment of the relationship between body weight and body measurements among Morkaraman, Tushin and Awassi sheeps with different ages

Uğur ÖZENTÜRK[1,a*], Ömer ELTAS[2,b], Okan DEMİR[3,c], Ali Alparslan SAYIM[4,d]

[1] Atatürk University Faculty of Veterinary Medicine, Department of Animal Science Yakutiye, Erzurum, Türkiye
[2] Atatürk University Faculty of Veterinary Medicine, Department of Biometrics, Yakutiye, Erzurum, Türkiye
[3] Atatürk University Faculty of Agricultere, Department of Agricultural Economics, Yakutiye, Erzurum, Türkiye
[4] Ankara University Graduate School of Health Sciences, Department of Biostatistics, Ankara, Türkiye

0000-0002-2037-9340 [a]; 0000-0002-7415-3371 [b]; 0000-0002-3581-5061 [c]; 0009-0009-4299-3315 [d]

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ABSTRACT

This study aimed to identify morphological predictors of body weight in Morkaraman, Tushin, and Awassi sheep across different age groups, providing valuable insights for effective livestock management and breeding programs. Data were collected from 260 Morkaraman, 109 Tushin, and 96 Awassi sheep, with body measurements including body length (BL), wither height (WH), chest girth (CG), chest width (CW), chest depth (CD), rump width (RW), rump height (RH), ear length (EL), head length (HL), forehead width (FW), cannon forelimb circumference (CFC), and cannon hindlimb circumference (CHC). Pearson correlation analysis was conducted to assess relationships between body weight and these morphological traits. A multiple linear regression model was developed using the backward stepwise elimination method to estimate body weight based on the collected measurements. The results revealed that the Morkaraman breed and the 3-year-old age group had the highest average body weights. Among the morphological traits, CG (r = 0.702), RH (r = 0.694), BL (r = 0.678), and WH (r = 0.677) exhibited the strongest correlations with body weight. The final regression model identified CG, RW, RH, and HL as the most significant predictors, collectively explaining approximately 78.3% of the variation in body weight. These findings underscore the importance of selecting specific morphological traits for accurate body weight estimation in sheep. The results of this study have significant implications for sheep farming, particularly in enhancing breeding, management, and selection strategies. By focusing on key morphological predictors, livestock producers can improve decision-making processes, optimize resource allocation, and promote the overall productivity and sustainability of sheep farming operations.

Farklı yaşlardaki Morkaraman, Tuj ve İvesi koyunlarında vücut ağırlığı ile vücut ölçüleri arasındaki ilişkinin değerlendirilmesi

ÖZET

Araştırmada, farklı yaş gruplarındaki Morkaraman, Tuj ve İvesi koyunlarında vücut ağırlığı ve vücut ölçümleri arasındaki ilişkilerin belirlenmesi amaçlandı. Bu ilişkiler korelasyon ve regresyon analizleri yoluyla incelenerek, etkili hayvancılık yönetimi ve yetiştirme programları için önemli olan vücut ağırlığının tahmininde en iyi açıklayıcılığa sahip morfolojik özellikler belirlendi. Toplam 260 adet Morkaraman, 109 adet Tuj ve 96 adet İvesi ırkı koyunun vücut ağırlıkları değerlendirildi. Her bir koyun için alınan vücut ölçümleri, vücut uzunluğu (VU), cidago yüksekliği (CY), göğüs çevresi (GÇ), göğüs genişliği (GG), göğüs derinliği (GD), sağrı genişliği (SG), sağrı yüksekliği (SY), kulak uzunluğu (KU), baş uzunluğu (BU), alın genişliği (AG), ön incik çevresi (ÖİC) ve arka incik çevresi (AİC)'dir. Vücut ağırlığı ile bu morfolojik özellikler arasındaki ilişkileri değerlendirmek için Pearson korelasyon analizi yapılmıştır. Toplanan ölçümler temel alınarak vücut ağırlığını tahmin etmek amacıyla geriye dönük adım adım eleme yöntemi kullanılarak bir çoklu doğrusal regresyon modeli geliştirilmiştir. Sonuçlar, Morkaraman ırkı ve 3 yaş grubu koyunların en yüksek ortalama vücut ağırlıklarına sahip olduğunu ortaya koymuştur. Morfolojik özellikler arasında, GÇ (r = 0,702), SY (r = 0,694), VU (r = 0,678) ve CY (r = 0,677) vücut ağırlığı ile en güçlü korelasyonları göstermiştir. Nihai regresyon modeli, GÇ, SG, SY ve BU'yu en önemli yordayıcılar olarak belirlemiş ve bu değişkenlerin vücut ağırlığındaki varyasyonun yaklaşık %78,3'ünü açıkladığı tespit edilmiştir. Bu bulgular, koyunlarda doğru vücut ağırlığı tahmini için belirli morfolojik özelliklerin seçilmesinin önemini vurgulamaktadır. Çalışmanın sonuçları, koyunculukta, özellikle yetiştiricilik, yönetim ve seleksiyon stratejilerinin iyileştirilmesi açısından önemli etkiler taşımaktadır. Temel morfolojik tahmin edicilere odaklanarak, hayvancılık üreticileri karar alma süreçlerini iyileştirebilir, kaynak kullanımını optimize edebilir ve koyunculuk faaliyetlerinin genel verimliliği ile sürdürülebilirliğini artırabilir.

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* *Sorumlu Yazar e-posta adresi / Corresponding Author e-mail address:* ugur.ozenturk@atauni.edu.tr

1. Introduction

Sheep farming plays a crucial role in sustainable agriculture and economic development worldwide. In Türkiye, it is a vital resource for addressing the animal protein deficit, contributing to food security, supporting the textile industry, and sustaining rural livelihoods. A significant portion of Türkiye's sheep population consists of indigenous breeds, with family-type enterprises often managing flocks through traditional methods and natural grazing practices (1,2)**.** The Morkaraman, Awassi, and Tushin sheep are among the most important breeds in the Eastern Anatolia sheep population, sharing adaptations to the region's challenging environmental conditions. The Morkaraman, which accounts for 21.5% of Turkiye's sheep population and is predominantly found in the Eastern Anatolia region (3,4). The Awassi breed, commonly raised in the Southeastern Anatolia region, is known for its fat-tailed morphology, adaptability to harsh environments, and high milk yield among domestic breeds, representing about 4% of the sheep population in Turkiye (3-6). The Tushin breed, commonly raised in and around Kars province in Eastern Anatolia, is known for its fatty thighs and is primarily bred for meat production (3,4,7).

Body weight is a key characteristic monitored throughout an animal's life. Accurate knowledge of body weight is essential for managing animal health, devising appropriate feeding strategies, determining optimal slaughter times, planning breeding programs, and selecting suitable breeding animals (8,9)**.** Moreover, body weight serves as a crucial criterion in type determination, feed utilization, drug dosing, growth assessment, and evaluating fattening results (7,9-11). In rural areas, where extensive farming practices are common and weighing devices are often unavailable, estimating body weight can be challenging. In these situations, farmers often rely on visual estimates, which can result in inaccuracies in decision-making and livestock management (1,9).

As animals grow and develop, they undergo changes in body structure and shape along with weight gain (12,13). These morphological changes are key indicators of their overall growth and development (6,11). Because of this, body measurements can be a useful tool for estimating an animal's body weight (8-10,14,15). Understanding the relationship between body weight and these measurements are important for evaluating fattening performance, selecting breeding animals, and making management decisions (14). Additionally, regularly measuring body weight and body dimensions in sheep is essential for monitoring growth and making effective management decisions (6).

Despite the recognized significance of body weight estimation in livestock management, there remains a need for further research on the specific relationships between body weight and morphological traits in indigenous sheep breeds, particularly within the context of Türkiye. The Morkaraman, Awassi, and Tushin breeds, as important representatives of the Eastern Anatolia sheep population, hold considerable importance in the Turkish sheep population. However, there is a limited number of studies that have specifically addressed these breeds across various age groups and environmental conditions. This research aims to fill this gap by exploring these relationships, ultimately providing targeted management strategies for farmers.

This study aims to determine the relationships between body weight and body measurements in Morkaraman, Tushin, and Awassi sheep across different age groups. Through correlation and regression analyses, we sought to identify morphological predictors of body weight, which are important for effective livestock management and breeding programs. It is hypothesized that body measurements, specifically chest girth, and body length, are significant predictors of body weight across different age groups of Morkaraman, Tushin, and Awassi sheep.

2. Material and Methods

This research was conducted at the Sheep Husbandry Unit of the Atatürk University Food and Livestock Research Centre. The study was ethically approved by the Local Ethics Committee of Atatürk University Animal Experiments. A total of 260 Morkaraman, 109 Tushin, and 96 Awassi ewes were used in the study.

Animal care and feeding

The sheep were held under semi-extensive conditions. The routine annual maintenance and feeding practices were as follows: Reproduction followed a once-a-year mating system, with the breeding season beginning in October, resulting in lambing between March and April. Most lambs born in March, leading to a maximum age difference of one month among lambs born in the same year. During pregnancy, the sheep were provided with 2 kg/day (± 0.2 kg) of roughage and 300 g/day (± 50 g) of a concentrated feed mixture. Lambs stayed with their mothers for two months before being weaned. Starting in May, both sheep and lambs grazed for 10 hours a day on pasture, kept in separate herds. The grazing period, determined by regional climatic conditions, ended in September at the close of the vegetation season. All animals were managed under a standardized feeding regimen, and management practices was equally applied across the flock.

Body weight determination

The body weight of each sheep was measured using a scale with an accuracy of 100 grams. Each animal was weighed once during the study. All measurements of the 1-,2-, and 3-year old sheep were taken on a single day and only once.

Body measurements

Various body measurements were taken for each sheep, including body length, wither height, rump height, chest depth, rump width, chest width, ear length, head length, forehead width, chest girth, cannon forelimb circumference, and cannon hindlimb circumference (2,12). Each measurement was taken once per animal.

The specific measurement points used in the study are detailed below:

Body length (BL): The distance from the shoulder tip to the seat tuber (between the articulatio humeri and tuber ischii), measured in centimeters using a measuring tape.

Wither height (WH): The vertical length from the highest point of the withers (processus spinosus of the 4th thoracic vertebra) to the ground.

Rump height (RH): The height from the highest point of the rump (most dorsal point of the sacrum at the level of the tuber coxae) to the ground.

Chest depth (CD): The depth from the highest point of the caudal vertebra (processus spinosus of the 4th thoracic vertebra) to the sternum.

Rump width (RW): The width between the right and left hip processes (two tuber coxae).

Chest width (CW): The width of the chest between the front legs.

Ear length (EL): The distance from the base of the ear to its tip, measured in centimeters using a measuring tape.

Head length (HL): The distance from the highest point of the head to the tip of the upper lip, measured in centimeters with a measuring tape.

Forehead width (FW): The width measured from the highest point of the forehead projection to the line connecting the inner angles of the eyes (between the two eye sockets).

Chest girth (CG): The circumference passing through the withers and sternum, completely encircling the chest, measured in centimeters using a measuring tape.

Cannon forelimb circumference (CFC): The circumference of the thinnest part of the Cannon forelimb bones (metacarpus), measured in centimeters using a measuring tape.

Cannon hindlimb circumference (CHC): The circumference of the thinnest part of the Cannon hindlimb bones (metatarsus), measured in centimeters with a measuring tape.

Statistical analysis

Descriptive statistics of the data were calculated and given as "Mean ± Standard Deviation" (Table 2). Prior to hypothesis testing, data were examined with Shapiro- Wilk test for normality and Levene test for homogeneity of variances, as parametric test assumptions. The effect of age and breed on collected body measurements was evaluated using a two-way ANOVA model. The model included main effects of age and breed, and their two-way interaction term. Pearson correlation analysis was used to evaluate the relationship between body measurements and body weight. A multiple linear regression model was constructed using the backward stepwise elimination method to estimate body weight based on body measurement data. In this model, categorical variables were included as dummy variables, with one category designated as the reference group. Statistical significance was defined as a probability value of less than 0.05, unless otherwise specified. All analyses were performed using the SPSS 30.0 software package.

3. Results

The study determined the body weight averages of different sheep breeds. According to the findings, the breed with the highest body weight average was Morkaraman (50.08 ± 11.86 kg), followed by Tuj (45.30 ± 9.98 kg), while the breed with the lowest body weight average was Awassi (43.49 ± 10.50 kg). The body weight averages based on age were 36.66 ± 6.07 kg for 1-year-old sheep, 50.26 ± 8.02 kg for 2-year-old sheep, and 54.03 ± 10.34 kg for 3-year-old sheep. The study concluded that the sheep with the highest body weight were 3-year-old Morkaraman sheep, with an average body weight of 57.12 ± 10.50 kg.

Table 1: Pearson correlation analysis results between body measurements and body weight.
Tablo 1: *Vücut ölçüleri ile vücut ağırlığı arasındaki Pearson korelasyon analizi sonuçları.*

	BW			**BW**	
	r	P value		r	P value
BL	0.678	<0.001	**EL**	0.204	<0.001
WH	0.677	<0.001	**HL**	0.564	<0.001
RH	0.694	<0.001	**FW**	0.043	0.358
CD	0.496	<0.001	**CG**	0.702	<0.001
RW	0.366	<0.001	**CFC**	0.44	<0.001
CW	0.457	<0.001	**CHC**	0.492	<0.001

r: Pearson correlation coefficient, BW: Body weight, BL: Body length, WH: Wither height, RH: Rump height, CD: Chest depth, RW: Rump width, CW: Chest width, EL: Ear length, HL: Head length, FW: Forehead width, CG: Chest girth, CFC: Cannon forelimb circumference, CHC: Cannon hindlimb circumference

Table 1 provides information on the direction and strength of the relationships between body weight and the measured body traits. A review of the table reveals positive correlations between body weight and all measured variables. Among these, the relationship between body weight and FW was very weak and not statistically significant ($r = 0.043$, $p = 0.358$). In contrast, the strongest correlations with body weight were observed for CG, RH, BL, and WH, in descending order of strength (Table 1).

Table 2: Age and breed comparison according to body measurements (Mean ± Std. Deviation (SD))
Table 2: *Vücut ölçülerine göre yaş ve ırk karşılaştırması (Aritmetik Ort. ± Std. Sapma)*

		Breed					
		Tuchin	**Morkaraman**	**Awassi**	**P-value(s)**		
Variable	**Age**	*Mean ± SD*	*Mean ± SD*	*Mean ± SD*	Age (A)	Breed (B)	A*B
	1	34.85 ± 3.94 $_{B,b}$	38.97 ± 5.74 $_{C,a}$	31.83 ± 5.42 $_{B,b}$			
BW	2	48.18 ± 6.31 $_{A,b}$	52.73 ± 8.47 $_{B,a}$	46.88 ± 7.16 $_{A,b}$	<0.001	<0.001	<0.001
	3	50.34 ± 9.69 $_{A,b}$	57.12 ± 10.50 $_{A,a}$	49.75 ± 7.60 $_{A,b}$			
	1	67.77 ± 4.48 $_{C,b}$	70.36 ± 5.33 $_{C,a}$	66.6 ± 3.67 $_{C,b}$			
BL	2	74.56 ± 4.09 $_{B,b}$	76.81 ± 4.02 $_{B,a}$	75.68 ± 5.19 $_{B,b}$	<0.001	<0.001	0.317
	3	76.07 ± 4.76 $_{A,b}$	78.62 ± 4.43 $_{A,a}$	77.26 ± 4.32 $_{A,b}$			
	1	65.61 ± 4.06 $_{B,b}$	69.25 ± 4.54 $_{B,a}$	65.07 ± 4.29 $_{B,b}$			
WH	2	72.22 ± 3.46 $_{A,b}$	74.64 ± 4.16 $_{A,a}$	72.8 ± 5.18 $_{A,b}$	<0.001	<0.001	0.342
	3	71.04 ± 3.8 $_{A,b}$	75.41 ± 4.58 $_{A,a}$	71.86 ± 4.32 $_{A,b}$			
	1	66.48 ± 4.32 $_{B,b}$	70.03 ± 4.03 $_{B,a}$	65.4 ± 4.41 $_{B,b}$			
RH	2	72.53 ± 3.23 $_{A,b}$	75.17 ± 4.09 $_{A,a}$	72.61 ± 4.24 $_{A,b}$	<0.001	<0.001	0.227
	3	71.03 ± 3.73 $_{A,b}$	75.63 ± 4.17 $_{A,a}$	72.27 ± 4.2 $_{A,b}$			
	1	31.32 ± 4.06 $_{B}$	32.2 ± 3.85 $_{B}$	31.87 ± 4.54 $_{B}$			
CD	2	35.81 ± 3.98 $_{A}$	34.98 ± 3.69 $_{A}$	36.73 ± 4.04 $_{A}$	<0.001	0.265	0.119
	3	35.07 ± 3.31 $_{A}$	36.65 ± 3.47 $_{A}$	36.15 ± 3.51 $_{A}$			
	1	14.02 ± 2.32 $_{B}$	13.64 ± 2.94 $_{B}$	14.02 ± 2.53 $_{B}$			
RW	2	15.3 ± 2.06 $_{A}$	16.07 ± 1.98 $_{A}$	15.48 ± 1.76 $_{A}$	<0.001	0.522	0.372
	3	15.83 ± 1.83 $_{A}$	16.22 ± 1.99 $_{A}$	15.78 ± 1.88 $_{A}$			
	1	25.23 ± 2.6 $_{B,a}$	24.74 ± 2.3 $_{B,ab}$	24.28 ± 2.69 $_{B,b}$			
CW	2	27.28 ± 2.32 $_{A,a}$	26.03 ± 4.11 $_{A,ab}$	25.77 ± 2.24 $_{A,b}$	<0.001	0.041	0.674
	3	26.88 ± 2.64 $_{A,a}$	26.43 ± 2.73 $_{A,ab}$	26.63 ± 2.69 $_{A,b}$			
	1	14.77 ± 1.12 $_{B,b}$	14.73 ± 1.29 $_{B,ab}$	14.83 ± 1.52 $_{B,a}$			
EL	2	14.83 ± 1.38 $_{A,b}$	15.24 ± 1.08 $_{A,ab}$	15.95 ± 1.12 $_{A,a}$	0.004	0.002	0.157
	3	14.54 ± 1.06 $_{AB,b}$	15.06 ± 1.16 $_{AB,ab}$	15.28 ± 1.42 $_{AB,a}$			
	1	21.74 ± 2.36 $_{B,b}$	22.12 ± 1.96 $_{B,a}$	21.57 ± 2.32 $_{B,ab}$			
HL	2	23.69 ± 2.06 $_{A,b}$	24.08 ± 1.86 $_{A,a}$	24.27 ± 1.72 $_{A,ab}$	<0.001	0.035	0.495
	3	23.58 ± 1.93 $_{A,b}$	24.65 ± 2.25 $_{A,a}$	24.06 ± 1.97 $_{A,ab}$			
	1	15.61 ± 18.09	12.9 ± 0.81	12.53 ± 1.03			
FW	2	13.47 ± 0.91	13.45 ± 0.87	13.3 ± 0.67	0.874	0.238	0.149
	3	13.26 ± 0.66	13.54 ± 0.82	13.43 ± 0.85			
	1	84.58 ± 6.98 $_{C}$	86.43 ± 6.69 $_{C}$	83.93 ± 8.61 $_{C}$			
CG	2	94.31 ± 5.71 $_{B}$	93.21 ± 7.46 $_{B}$	94.27 ± 5.91 $_{B}$	<0.001	0.949	0.407
	3	95.91 ± 7.99 $_{A}$	95.97 ± 8.68 $_{A}$	96.88 ± 6.78 $_{A}$			
	1	7.81 ± 0.54 $_{C,b}$	8.07 ± 0.74 $_{C,ab}$	7.83 ± 1.53 $_{C,a}$			
CFC	2	8.72 ± 0.84 $_{A,b}$	8.76 ± 0.77 $_{A,ab}$	9.18 ± 0.76 $_{A,a}$	<0.001	0.030	0.129
	3	8.38 ± 0.8 $_{B,b}$	8.6 ± 0.82 $_{B,ab}$	8.84 ± 0.68 $_{B,a}$			
	1	9.27 ± 0.59 $_{C}$	9.44 ± 0.79 $_{C}$	9.31 ± 0.81 $_{C}$			
CHC	2	10.41 ± 0.82 $_{A}$	10.32 ± 0.59 $_{A}$	10.66 ± 0.75 $_{A}$	<0.001	0.066	0.137
	3	9.79 ± 0.83 $_{B}$	10.1 ± 0.82 $_{B}$	10.28 ± 0.8 $_{B}$			

*A,B,C: Different capital letters in the same column indicate statistically significant difference (p<0.05), a,b,c: Different lowercase letters in the same row indicate statistically significant difference (p<0.05), *: Indicates interaction,* BW: *Body Weight, BL: Body length, WH: Wither height, RH: Rump height, CD: Chest depth, RW: Rump width, CW: Chest width, EL: Ear length, HL: Head length, FW: Forehead width, CG: Chest girth, CFC: Cannon forelimb circumference, CHC: Cannon hindlimb circumference*

The effects of breed and age on various body measurements were analyzed and are summarized in Table 2. A review of the table indicates that the interaction term, representing the combined effect of breed and age, was statistically insignificant for all body measurements except BW. Regarding the main effects, age significantly influenced all variables except FW. As expected, the lowest measurements were consistently observed in 1-year-old sheep across all breeds. When examining the effect of breed on body measurements, significant differences were identified among breeds for BW, BL, WH, RH, CW, EL, HL, and CFC. Specifically, BW, BL, WH, RH, and HL values were highest in the Morkaraman breed; EL and CFC values were highest in the Awassi breed; and CW values were highest in the Tuj breed (Table 2).

Table 3: Multiple regression model for predicting body weight based on body measurements
Tablo 3: *Vücut ölçümleri kullanılarak vücut ağırlığını tahmin etmeye yönelik çoklu regresyon modeli*

	UnStd. ß	SE of ß	95% CI		Std. ß	t	P	VIF
			LB	UB				
Intercept	-89.89	5.667	-101.026	-78.754		-15.863	<0.001	
Age								
2 - 1(ref)	1.81	0.899	0.043	3.578	0.067	2.013	0.045	2.322
3 - 1(ref)	3.786	0.883	2.05	5.521	0.164	4.287	<0.001	3.036
Genotype								
Tushin - Awassi(ref)	2.09	0.778	0.56	3.62	0.077	2.685	0.008	1.718
Morkaraman - Awassi (ref)	4.497	0.704	3.113	5.881	0.194	6.387	<0.001	1.927
BL	0.225	0.063	0.1	0.349	0.118	3.553	<0.001	2.313
RH	0.412	0.073	0.268	0.556	0.184	5.634	<0.001	2.234
RW	1.048	0.122	0.808	1.289	0.222	8.574	<0.001	1.401
CW	0.333	0.116	0.104	0.561	0.084	2.862	0.004	1.808
HL	0.736	0.14	0.462	1.01	0.149	5.274	<0.001	1.669
CG	0.385	0.046	0.295	0.474	0.295	8.449	<0.001	2.534
CFC	1.014	0.326	0.373	1.656	0.08	3.108	0.002	1.376

Dependent variable: body weight; Model R^2: 0.783; df: 11 MSE: 29.416, Model F=148.308, p<0,001; ref: Reference category, UnStd. ß: Unstandardized Beta (ß), CI: Confidence Interval, UB: upper bound, LB: lower bound, Std.ß: Standardized ß, SE: Standard error
BL: Body length, WH: Wither height, RH: Rump height, CD: Chest depth, RW: Rump width, CW: Chest width, EL: Ear length, HL: Head length, FW: Forehead width, CG: Chest girth, CFC: Cannon forelimb circumference, CHC: Cannon hindlimb circumference

The final multiple regression model developed to predict body weight using body measurements is presented in Table 3. The initial model, created through a backward stepwise elimination method, included 13 different variables, while the final model consists of 9 variables based on significance levels. Examination of the VIF values for the variables in the model revealed no multicollinearity problems. All coefficients of the variables in the model were found to be statistically significant. Among the variables, the CG variable made the highest contribution to the model. In addition, other body measurements such as RW, RH and HL made substantial contributions to the model. However, CFC had a statistically significant effect, but its contribution was limited (Table 3).

Analysis of the coefficients for genotype and age showed that the body weight of the Awassi breed was the lowest, while the Morkaraman breed had the highest body weight. Similarly, examination of the age-related coefficients revealed that the highest weight was observed in the 3-year-old group. These findings indicate that genotype, age, and body measurements play a significant role in predicting body weight.

4. Discussion and Conclusion

The finding that Morkaraman sheep had a significantly higher body weight than Tushin and Awassi breeds is consistent with the standard body weight values for these breeds. According to breed standard features, Morkaraman sheep, adapted to the harsh climatic conditions of Eastern Anatolia, is robust, larger in size, and more enduring. In contrast, Awassi sheep have a medium-sized body and a fine bone structure suited for milk production, while Tushin sheep are generally smaller in body size (4). The observed increase in body weight with age across all breeds is consistent with expected growth patterns in sheep, where skeletal development, muscle growth, and fat accumulation contribute to increased body mass over time (10,16,17).

The significant positive correlations between body weight and various body measurements (CG, RH, BL, WH) indicate that these measurements generally increase in proportion to body weight as sheep grow. This relationship underscores the biological and physiological development underlying sheep growth and morphology (18). Ambarcıoğlu et al. (8) found a statistically significant correlation between body weight and body measurements, supporting the notion that body weight can be estimated from these measurements. Previous studies also report high correlations between body measurements and body weight in sheep (6,9,10,14,19-21).

The highest correlations with body weight were observed for CG (0.702), RH (0.694), BL (0.678), and WH (0.677). These measurements are directly related to the overall size and structure of the animal, which correlates with body mass. Chest girth, in particular, is often considered the most reliable indicator of body weight as it encompasses the thoracic cavity, where vital organs are located (12). A larger chest girth typically indicates a larger body size, reflecting increased muscle mass and fat, which contribute to higher body weight (10,12). Rump height and wither height reflect the skeletal structure and overall body height, both of which scale with body weight (12). Similarly, body length represents longitudinal growth and is associated with overall body mass. Supporting the results of this study, Şahin et al. (15) found significant correlations between body measurements, including CG, RH, WH, and body weight. Similarly, Özen et al. (14) reported that CG and WH were the most effective factors in estimating body weight. In line with these findings, Yağanoğlu (21) identified body length as having the highest correlation with body weight. Further corroborating this study, Ambarcıoğlu et al. (8) found that CG ($r=0.846$) and CD ($r=0.801$) were the body measurements most strongly correlated with body weight in sheep. Similarly, Özen et al. (6) reported that CW and CD had the strongest correlations with body weight. Additionally, Onk et al. (7) emphasized the importance of BL and CG as key markers for estimating body weight.

The multiple linear regression model identified CG, RH, RW, and HL as the best predictors of body weight, explaining approximately 78.3% of the variation. Consistent with our study, Şahin et al. (15) reported that RH, CG, CD, and BL made the highest contributions to the regression equation for body weight estimation. They emphasized that chest girth was the most important parameter for estimating body weight at the end of the fattening period. Other similar studies have also reported that CG has the strongest effect on body weight (9-12,19). Despite the better estimation of body weight from combinations of different body measurements, this approach may pose practical challenges in field conditions due to the higher labor and time required for measuring multiple body dimensions (12). In the present study, body weight was relatively more strongly associated with CG. Given that CG is easy, cost-effective, and quick to measure with a tape, estimating body weight from chest girth alone, or in combination with other body measurements such as RH, RW, and HL, may offer a practical and reasonably accurate method under field conditions. However, some studies have reported that rump width has the highest direct effect on body weight (22,23). Tyasi et al. (24) found that body length had the highest direct effect on body weight. Rather et al. (18) revealed that wither height was the best predictor for body weight estimation. The differences between these studies are likely due to genetic factors such as species and breeds of livestock, as well as environmental factors such as nutritional conditions, climate, and breeding area.

Our results indicate significant differences in live weight among the Tushin, Morkaraman, and Awassi sheep breeds. It was found that both breed and body measurements influence live weight. When compared to the Awassi breed, both the Morkaraman and Tushin breeds exhibited significantly higher body weights. Specifically, the body weight of Tushin ewes was 2.09 kg higher, while that of Morkaraman ewes was 4.497 kg higher than that of Awassi ewes. Understanding these breed-specific differences is crucial for effective breeding programs and management practices, enabling accurate monitoring of growth and health tailored to each breed's specific needs. Differences in body weight between breeds highlight the influence of breed-specific morphological characteristics on body weight estimation (1,13,25). These differences in body weight likely reflect genetic influences on growth patterns and body conformations. As the results indicate, breed, along with CG and RW, consistently emerged as one of the primary determinants of body weight in live weight estimation, highlighting its significant role in accurate weight prediction. The significance of CG across model highlights its effectiveness in reflecting total body mass, likely due to its close association with thoracic volume, which correlates with muscle and fat deposits. Likewise, RW's inclusion in model points to its importance in capturing body conformation and distribution of body mass, traits that are central to structural soundness and overall weight (26-27). These findings suggest that breed, alongside CG and RW, provides a reliable basis for body weight estimation, thus reinforcing their utility in practical, field-based weight assessments across diverse production environments.

According to the findings obtained from the study, age was found to influence all body measurements except FW. Furthermore, the results of the multiple linear regression model revealed differences among age groups. These measurements can reflect the sheep's rapid growth and development during this early stage. As sheep age, growth slows, and body weight may be more influenced by fat accumulation and muscle development, which are not easily determined by linear measurements alone (28). Head length, although less commonly used as a predictor in older animals, may be more variable in young sheep based on our results. In the model, the 1-year age group was taken as the reference, thereby highlighting the differences in live weights of the 2-year and 3-year age groups compared to the 1-year group. Accordingly, the model indicates that the live weight of sheep in the 2-year age group is, on average, 1.81 kg higher compared to the 1-year age group. Similarly, the live weight of sheep in the 3-year age group is, on average, 3.786 kg higher compared to the 1-year age group. This improved body weight in older sheep suggests a more stable body composition and a more reliable weight estimation based on body measurements. Variations between age groups can be attributed to different stages of growth and development (10,16-18,20,28). As an alternative approach to the multiple linear regression model used in this study, which includes the age variable, there are studies that have examined the relationship between body weight and body measurements at different ages or fattening periods and developed regression models. For instance, Şahin et al. (15) noted that body weight estimates can vary throughout the fattening period, Yetişgin (29) reported that effective body measurements for weight estimation change between mother ewes and lambs. Body length and rump height were significant predictors in young animals, while chest girth was more effective in older animals. Yılmaz et al. (30) reported that the highest correlation coefficients were observed in the 2-year-old age group, with body length and chest girth offering the most accurate estimates. In younger animals, chest girth may not capture the dynamic changes in muscle and fat deposits as effectively as other measurements, as body weight is still primarily influenced by structural growth rather than fat and muscle distribution. This discrepancy may reflect breed-specific growth patterns or environmental factors that influence body composition at different life stages.

Instead of estimating body weight based on body measurements for each age and breed separately, the findings of our study indicate that a single comprehensive model can be developed by incorporating both age and breed variables. The findings of the study have demonstrated the effects of age, breed, and their combined interaction. Thus, utilizing a single linear regression model that incorporates both age and breed variables not only reveals the effects of body measurements on body weight but also highlights the differences among breed and age groups.

In conclusion, multiple linear regression analysis identified chest girth, rump width, and rump height as the most significant morphological traits for estimating body weight in sheep. Furthermore, age and breed effects combined with body measurements were significant, and it was concluded that the live weight of 3-year-old Morkaraman sheep was the highest. Based on these results, it is recommended that sheep farmers adopt targeted measurement protocols that focus on these morphological traits for accurate body weight estimation. This is particularly beneficial in farms without weighing devices or in pasture-based systems. By implementing these protocols, farmers can enhance their breeding decisions, refine management practices, and develop selection strategies tailored to specific breeds and age groups. Such an approach not only optimizes production efficiency but also promotes the overall health and welfare of the herd. Furthermore, it is suggested that researchers investigate the relationships between additional morphological traits and body weight across various breeds and environmental conditions. Conducting longitudinal studies to monitor changes in body composition over time would yield valuable insights into growth patterns and aid in refining estimation models. Collaborating with field practitioners can enhance the practical applicability of research findings and contribute to the advancement of sheep management practices.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Authors' Contributions

Motivation / Concept: Uğur ÖZENTÜRK
Design: Uğur ÖZENTÜRK, Ömer ELTAS
Control/Supervision: Okan DEMİR
Data Collection and / or Processing: Uğur ÖZENTÜRK
Analysis and / or Interpretation: Ömer ELTAS, Ali Alparslan SAYIM
Literature Review: Uğur ÖZENTÜRK, Ömer ELTAS
Writing the Article: Uğur ÖZENTÜRK, Ali Alparslan SAYIM
Critical Review: Ömer ELTAS, Okan DEMİR, Ali Alparslan SAYIM

Ethical Approval

The study was ethically approved by the Local Ethics Committee of Atatürk University Animal Experiments, with approval number 104 from the session numbered 2022/6 on 31st May 2022.

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