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Relationship of body measurements with body weight at different ages in local (Dharuri) sheep under field conditions in Beed district of Maharashtra

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ABSTRACT

The relationship of body measurements with body weight was studied in 1,487 local (Dharuri) sheep (484 males, 1,003 females) maintained under field conditions in four blocks of Beed district, Maharashtra, with the aim of developing age-specific equations for predicting body weight. Animals were grouped into five age classes (0–3, 4–6, 7–12, 13–36 and above 36 months), and phenotypic correlations and simple and multiple linear regressions of body weight on height at withers, chest girth and body length were computed within each age class and sex. All correlations among the traits were positive and highly significant ($P < 0.01$); correlations of body weight with the three measurements ranged from 0.93 to 0.99. Chest girth had the highest correlation with body weight at 0–3, 7–12 and above 36 months, height at withers at 4–6 months, and body length at 13–36 months. The coefficients of determination (R^2) of simple regressions ranged from 0.868 to 0.980, chest girth giving the highest R^2 at three of the five ages (0.955–0.980). Including all three measurements raised R^2 only marginally (by 0.004–0.018, to 0.953–0.984), and the strong intercorrelation among predictors produced unstable, sometimes negative, partial coefficients. Regression slopes did not differ between sexes except at 7–12 months ($P < 0.01$). Chest girth is recommended as the single most practical predictor of body weight in local sheep under field conditions. As body weights of some animals were estimated rather than weighed, the equations should be validated on independently weighed animals before wider use.

Keywords: Body weight prediction, Chest girth, Correlation, Dharuri sheep, Linear body measurements, Regression

Introduction

Sheep rearing is an important part of the livestock-based rural economy of Maharashtra, particularly in semi-arid areas where crop production is constrained by low rainfall, seasonal feed scarcity and small landholdings. Local sheep populations, having evolved under the prevailing environmental and management conditions, are able to produce under extensive and semi-extensive systems. The local sheep of Beed district, known as Dharuri, are maintained mainly under field conditions by sheep-rearing households, but information on their growth and on the relationship between their body measurements and body weight is limited. Body weight is a key indicator of growth and productivity in sheep. It determines market price and is needed for monitoring nutritional status, selecting replacement stock and calculating doses of veterinary medicines. Weighing balances, however, are rarely available to farmers under field conditions, and easily recorded linear body measurements offer a practical alternative for estimating live weight. Prediction equations based on body measurements have been developed for several Indian sheep breeds, including Nellore (Rani *et al.*, 2016) [1], Harnali (Kumar *et al.*, 2018) [2], Malpura (Kumar *et al.*, 2021) [3] and Gurez (Rather *et al.*, 2022) [4], as well as for sheep in other countries (Abbas *et al.*, 2021; Ibrahim *et al.*, 2021; Mekonnen *et al.*, 2024) [5, 6, 7].

Chest (heart) girth has frequently been identified as the best single predictor of body weight because it reflects the development of the thoracic region, musculature and overall body mass. In Harnali sheep, Kumar *et al.* (2018) [2] concluded that heart girth was the most important trait for estimating live weight ($R^2 = 0.87$), and Ravimurugan *et al.* (2013) [8] identified chest girth as the strongest single predictor in Kilakarsal sheep. A recent meta-analysis also reported that heart girth was more closely correlated with body weight ($r = 0.83$) than body length ($r = 0.69$) or height at withers ($r = 0.64$) (Firdaus *et al.*, 2025) [9]. In Deccani sheep, Narsimham *et al.* (2003) [10] reported positive associations between body weight and biometric measurements.

The present study was undertaken to estimate the phenotypic correlations between body measurements and body weight at different ages in local (Dharuri) sheep of Beed district, and to develop age- and sex-specific regression equations for predicting body weight under field conditions.

Materials and Methods

Study area and animals

The study was conducted in Beed district of Maharashtra, in the semi-arid Marathwada region of the Deccan plateau. Four sheep-rearing blocks, namely Adas, Wadhwani, Dharur and Neknoor, were selected, and sheep maintained under farmers' extensive or semi-extensive grazing systems were recorded. A total of 1,487 local sheep (484 males and 1,003 females) were studied: 348 from Adas, 392 from Wadhwani, 428 from Dharur and 319 from Neknoor. The animals were grouped into five age classes (Table 1).

Table 1. Age- and sex-wise distribution of the sheep studied

Age group (months)	Male	Female	Total
0–3	216	193	409
4–6	95	118	213
7–12	87	107	194
13–36	39	382	421
Above 36	47	203	250
Total	484	1,003	1,487

The marked fall in the number of males in the older age classes reflects the practice of selling male lambs at a young age while retaining females for breeding.

Body measurements

Height at withers (HW), chest girth (CG) and body length (BL) were measured to the nearest 0.1 cm with a flexible tape, with the animal standing squarely on level ground, generally in the morning before grazing. Body weight (BW) was recorded with a 100 kg spring balance wherever the owner permitted weighing. Where direct weighing was not possible, body weight was estimated from age-specific regression equations based on body measurements.

Statistical analysis

All analyses were carried out separately within each age class. Phenotypic (Pearson product-moment) correlations among BW, HW, CG and BL were computed, and their significance was tested against tabulated values of r at $(n - 2)$ degrees of freedom (Steel *et al.*, 1960) [11].

Simple linear regressions of body weight on each measurement were fitted as $Y = a + bX$, where Y is body weight (kg), X is the body measurement (cm), a is the intercept and b the regression coefficient. Multiple regressions were fitted as $Y = a + b_1X_1 + b_2X_2 + b_3X_3 + e$, where X_1 , X_2 and X_3 are HW, CG and BL, respectively, b_1 to b_3 the partial regression coefficients and e the residual. The significance of regression coefficients was tested by the t -test and goodness of fit was assessed by the coefficient of determination (R^2). Simple and multiple regressions were also fitted separately for males and females.

Homogeneity of the regression slopes of males and females was tested by fitting the model $BW = a + bX + c \cdot \text{Sex} + d(X \times \text{Sex})$ and testing the significance of the interaction term (d) by an F -test with 1 and $(n - 4)$ degrees of freedom; a non-significant F indicates that a common slope adequately describes both sexes.

Results and Discussion

Phenotypic correlations

Phenotypic correlations among body weight and body measurements are presented in Table 2. All correlations were positive and highly significant ($P < 0.01$) at all ages. Correlations of body weight with the three measurements ranged from 0.93 to 0.99. Chest girth had the highest correlation with body weight at 0–3 (0.98), 7–12 (0.98) and above 36 months (0.99); height at withers had the highest correlation at 4–6 months (0.97); and height and body length were equally correlated with body weight at 13–36 months (0.97). The strong positive relationships indicate that increases in body size were closely matched by increases in body weight, and support the use of chest girth as a field measurement.

Table 2. Phenotypic correlations among body measurements and body weight of local (Dharuri) sheep at different ages

Age group (months)	Trait	Chest girth	Body length	Body weight
0–3 ($n = 409$)	Height at withers	0.96	0.99	0.94
	Chest girth		0.98	0.98
	Body length			0.96
4–6 ($n = 213$)	Height at withers	0.99	0.99	0.97
	Chest girth		0.99	0.93
	Body length			0.94
7–12 ($n = 194$)	Height at withers	0.99	0.99	0.96
	Chest girth		0.98	0.98
	Body length			0.96
13–36 ($n = 421$)	Height at withers	0.98	0.98	0.97
	Chest girth		0.95	0.96
	Body length			0.97
Above 36 ($n = 250$)	Height at withers	0.95	0.93	0.93
	Chest girth		0.97	0.99
	Body length			0.96

All correlations are significant at $P < 0.01$.

Chest girth has similarly been identified as the strongest single correlate of body weight in Kilakarsal (Ravimurugan *et al.*, 2013) [8] and Harnali sheep (Kumar *et al.*, 2018) [2]. The magnitude of the correlations in the present study (0.93–0.99), however, is considerably higher than that usually reported for sheep under field conditions; for example, Kumar *et al.* (2018) [2] reported phenotypic correlations of 0.32 to 0.59 between linear measurements and adult body weight in Harnali sheep. Because the body weights of some animals were themselves estimated from body measurements, the present correlations

are likely to be inflated and are not directly comparable with studies based entirely on directly measured weights.

Simple linear regression

Simple regressions of body weight on each body measurement are given in Table 3. All regression coefficients were highly significant ($P < 0.01$) at every age, and R^2 ranged from 0.868 to 0.980. Chest girth gave the highest R^2 at 0–3 (0.955), 7–12 (0.961) and above 36 months (0.980), height at withers at 4–6 months (0.935) and body length at 13–36 months (0.949). The best single predictor thus varied

slightly with age, but chest girth was the most consistently useful. The regression coefficients increased with age, indicating that each centimetre of increase in a body dimension corresponded to a greater

gain in body weight as the animals matured; this supports the use of age-specific rather than pooled equations.

Table 3. Simple linear regression of body weight (kg) on individual body measurements (cm) of local (Dharuri) sheep at different ages

Predictor	Statistic	0–3 months	4–6 months	7–12 months	13–36 months	Above 36 months
Height at withers	<i>a</i>	–13.072	–19.762	–21.775	–44.210	–49.336
	<i>b</i> ± SE	0.520 ± 0.010	0.687 ± 0.013	0.744 ± 0.015	1.116 ± 0.014	1.261 ± 0.031
	<i>R</i> ²	0.880	0.935	0.929	0.941	0.868
Chest girth	<i>a</i>	–12.470	–16.829	–22.184	–45.615	–39.561
	<i>b</i> ± SE	0.470 ± 0.005	0.582 ± 0.015	0.657 ± 0.010	0.949 ± 0.014	0.939 ± 0.009
	<i>R</i> ²	0.955	0.872	0.961	0.919	0.980
Body length	<i>a</i>	–12.900	–15.563	–16.643	–42.674	–12.153
	<i>b</i> ± SE	0.537 ± 0.008	0.634 ± 0.016	0.665 ± 0.014	1.055 ± 0.012	0.718 ± 0.014
	<i>R</i> ²	0.926	0.876	0.924	0.949	0.918

a, intercept; *b*, regression coefficient (kg/cm); *R*², coefficient of determination. All regression coefficients were significant at *P* < 0.01.

Multiple regression

Multiple regressions of body weight on all three measurements are presented in Table 4. Fitting the three measurements together raised *R*² to 0.953–0.984, an improvement of only 0.004 to 0.018 over the best single predictor at each age. Such a small gain does not justify recording three measurements in the field instead of one.

Height at withers, chest girth and body length were very highly inter-correlated (0.93–0.99), and variance inflation factors computed from

the correlations in Table 2 exceeded 10 at every age, indicating severe multicollinearity. As a result, several partial regression coefficients were negative (e.g., –0.386 for chest girth at 4–6 months and –0.259 for height above 36 months). These negative coefficients are a statistical artefact of multicollinearity and do not imply that an increase in a body dimension reduces body weight. The multiple regression equations therefore have good overall fit but unstable individual coefficients and are not recommended for field use; stepwise or ridge regression could be used if more than one predictor is required.

Table 4. Multiple regression of body weight (kg) on height at withers, chest girth and body length (cm) of local (Dharuri) sheep at different ages

Parameter	0–3 months	4–6 months	7–12 months	13–36 months	Above 36 months
Intercept (<i>a</i>)	–11.918 (0.280)	–22.239 (0.816)	–26.632 (1.038)	–45.641 (0.858)	–34.904 (1.331)
Height at withers (<i>b</i> ₁)	–0.129 (0.036)	1.312 (0.071)	0.312 (0.091)	0.136 (0.074)	–0.259 (0.043)
Chest girth (<i>b</i> ₂)	0.388 (0.032)	–0.386 (0.089)	0.715 (0.063)	0.393 (0.057)	1.101 (0.037)
Body length (<i>b</i> ₃)	0.210 (0.048)	–0.079 (0.100)	–0.206 (0.066)	0.629 (0.046)	0.031 (0.026)
<i>R</i> ²	0.959	0.953	0.968	0.963	0.984
Gain in <i>R</i> ² over best single predictor	0.004	0.018	0.007	0.014	0.004

Figures in parentheses are standard errors of the partial regression coefficients.

Sex-wise regression and homogeneity of slopes

Sex-wise simple regressions (Table 5) showed close relationships between body weight and all three measurements in both sexes, with *R*² ranging from 0.825 to 0.989. Chest girth gave the highest *R*² in both sexes at 0–3, 7–12 and above 36 months, and in males at 13–36 months; the highest values were recorded above 36 months (0.989 in males and 0.977 in females). Sex-wise multiple regressions (Table 6) gave *R*² values of 0.938 to 0.992 and showed the same instability of partial coefficients as the pooled equations.

The test of homogeneity of slopes (Table 7) showed that the regression slopes of males and females did not differ significantly at 0–3, 4–6, 13–36 and above 36 months, so a single equation can be used for both sexes at these ages. At 7–12 months, the slopes differed significantly for all three measurements (*P* < 0.01), the female slopes being steeper than the male slopes. This age coincides with the sale of fast-growing male lambs, and selective removal of males may have altered the body weight–body size relationship among the males that remained; this explanation, however, remains speculative. Separate equations for males and females are therefore recommended at 7–12 months.

Table 5. Sex-wise simple linear regression of body weight (kg) on body measurements (cm) of local (Dharuri) sheep at different ages

Age (months)	Sex (n)	Predictor	<i>a</i>	<i>b</i> ± SE	<i>r</i>	<i>R</i> ²
0–3	Male (216)	HW	–13.375	0.531 ± 0.013	0.941	0.885
		CG	–12.680	0.476 ± 0.007	0.980	0.961
		BL	–13.064	0.543 ± 0.010	0.963	0.928
	Female (193)	HW	–12.622	0.506 ± 0.014	0.936	0.876
		CG	–12.172	0.463 ± 0.008	0.973	0.947
		BL	–12.623	0.528 ± 0.011	0.961	0.924

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Age (months)	Sex (n)	Predictor	a	b ± SE	r	R ²
4–6	Male (95)	HW	–21.755	0.717 ± 0.024	0.953	0.908
		CG	–17.711	0.592 ± 0.028	0.908	0.825
		BL	–16.851	0.652 ± 0.031	0.909	0.826
	Female (118)	HW	–19.037	0.678 ± 0.014	0.975	0.951
		CG	–16.498	0.579 ± 0.018	0.947	0.896
		BL	–15.085	0.629 ± 0.019	0.949	0.901
7–12	Male (87)	HW	–18.789	0.705 ± 0.018	0.974	0.948
		CG	–18.512	0.612 ± 0.014	0.979	0.958
		BL	–13.466	0.622 ± 0.017	0.970	0.941
	Female (107)	HW	–25.587	0.795 ± 0.020	0.968	0.937
		CG	–25.006	0.692 ± 0.012	0.984	0.969
		BL	–19.672	0.705 ± 0.020	0.962	0.925
13–36	Male (39)	HW	–42.149	1.094 ± 0.039	0.978	0.956
		CG	–38.790	0.874 ± 0.023	0.988	0.975
		BL	–43.639	1.072 ± 0.041	0.974	0.949
	Female (382)	HW	–44.673	1.122 ± 0.015	0.969	0.940
		CG	–46.132	0.955 ± 0.015	0.957	0.916
		BL	–42.924	1.057 ± 0.013	0.974	0.949
Above 36	Male (47)	HW	–54.468	1.325 ± 0.062	0.955	0.911
		CG	–41.050	0.954 ± 0.015	0.995	0.989
		BL	–13.825	0.737 ± 0.029	0.967	0.935
	Female (203)	HW	–47.877	1.243 ± 0.036	0.925	0.856
		CG	–39.116	0.934 ± 0.010	0.989	0.977
		BL	–11.652	0.712 ± 0.016	0.955	0.913

HW, height at withers; CG, chest girth; BL, body length; *a*, intercept; *b*, regression coefficient. Prediction equation: $BW \text{ (kg)} = a + b \times \text{measurement (cm)}$; e.g., for females above 36

months, $BW = -39.116 + 0.934CG$. All *b* values significant at $P < 0.01$. Equations are valid only within the age and sex group from which they were derived.

Table 6. Sex-wise multiple regression of body weight (kg) on height at withers, chest girth and body length (cm)

Age (months)	Sex (n)	Intercept (a)	HW (b ₁)	CG (b ₂)	BL (b ₃)	R ²
0–3	Male (216)	–12.474 (0.329)	–0.113 (0.056)	0.452 (0.037)	0.140 (0.080)	0.961
	Female (193)	–12.099 (0.364)	–0.151 (0.046)	0.387 (0.039)	0.240 (0.062)	0.952
4–6	Male (95)	–22.866 (1.201)	1.365 (0.109)	–0.816 (0.140)	0.273 (0.120)	0.938
	Female (118)	–21.963 (0.801)	1.417 (0.086)	0.020 (0.108)	–0.731 (0.140)	0.971
7–12	Male (87)	–18.937 (1.363)	0.221 (0.129)	0.434 (0.093)	–0.011 (0.109)	0.960
	Female (107)	–25.957 (1.084)	–0.028 (0.099)	0.921 (0.085)	–0.218 (0.082)	0.972
13–36	Male (39)	–38.998 (2.381)	–0.122 (0.337)	0.877 (0.167)	0.116 (0.276)	0.976
	Female (382)	–45.760 (0.945)	0.222 (0.077)	0.214 (0.049)	0.633 (0.049)	0.960
Above 36	Male (47)	–39.009 (2.556)	–0.250 (0.082)	1.190 (0.075)	–0.056 (0.051)	0.992
	Female (203)	–33.474 (1.515)	–0.297 (0.045)	1.084 (0.042)	0.040 (0.029)	0.982

Figures in parentheses are standard errors of the partial regression coefficients.

Table 7. Test of homogeneity of regression slopes of body weight on body measurements between sexes

Age (months)	Predictor	b (male)	b (female)	Difference	F (1, n–4)	P	Inference
0–3	HW	0.531	0.506	+0.025	1.71	0.192	Homogeneous
	CG	0.476	0.463	+0.013	1.63	0.202	Homogeneous
	BL	0.543	0.528	+0.016	1.06	0.304	Homogeneous
4–6	HW	0.717	0.678	+0.038	1.95	0.164	Homogeneous
	CG	0.592	0.579	+0.012	0.13	0.718	Homogeneous
	BL	0.652	0.629	+0.023	0.41	0.524	Homogeneous
7–12	HW	0.705	0.795	–0.090	10.15	0.002	Differ
	CG	0.612	0.692	–0.080	18.41	< 0.001	Differ

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Age (months)	Predictor	b (male)	b (female)	Difference	F (1, n-4)	P	Inference
13–36	BL	0.622	0.705	−0.084	9.47	0.002	Differ
	HW	1.094	1.122	−0.028	0.21	0.645	Homogeneous
	CG	0.874	0.955	−0.081	2.08	0.150	Homogeneous
Above 36	BL	1.072	1.057	+0.014	0.07	0.794	Homogeneous
	HW	1.325	1.243	+0.082	1.17	0.280	Homogeneous
	CG	0.954	0.934	+0.020	0.96	0.328	Homogeneous
	BL	0.737	0.712	+0.025	0.57	0.450	Homogeneous

F tests the measurement $\times$ sex interaction in the model $BW = a + bX + c \cdot \text{Sex} + d(X \times \text{Sex})$. HW, height at withers; CG, chest girth; BL, body length.

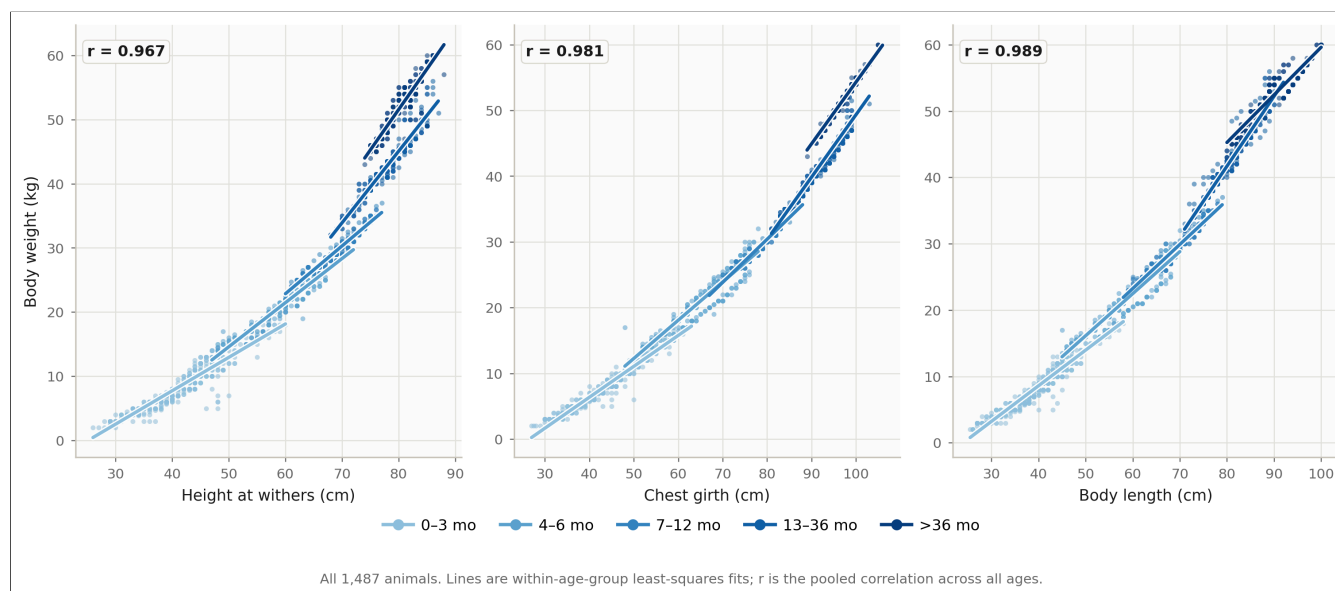


Figure 1. Relationship of body weight with height at withers, chest girth and body length in local (Dharuri) sheep, with least-squares regression lines fitted within each age group ($n = 1,487$); r is the correlation pooled across all ages.

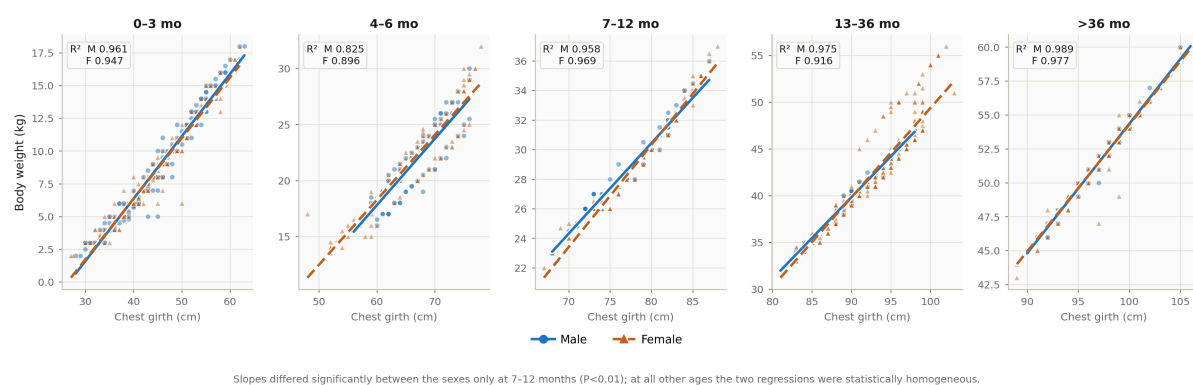


Figure 2. Relationship of body weight with chest girth in males and females of local (Dharuri) sheep at different ages, with separate least-squares regression lines for each sex.

Practical implications

Chest girth can be recorded quickly with a tape and, used in age-specific equations, gives a reliable estimate of body weight in local sheep. Such estimates can help farmers market animals on the basis of approximate live weight, allow field workers to monitor growth and nutritional status and to calculate doses of weight-dependent drugs, and permit selection for body weight in flocks without weighing facilities.

Limitations

The study was cross-sectional, so differences between age classes are comparisons among different animals rather than longitudinal records of the same animals. Body weights of some animals were estimated when direct weighing was not permitted, which is likely to have in-

flated the correlations and R^2 values. The equations were not validated on an independent set of animals. They should therefore be validated on directly weighed animals from the same population before being adopted as a substitute for weighing.

Conclusion

Body weight of local (Dharuri) sheep of Beed district was closely and positively correlated with height at withers, chest girth and body length at all ages. Chest girth was the most consistent single predictor, giving the highest R^2 at three of the five ages, while adding height and body length improved prediction only marginally and produced unstable coefficients because of multicollinearity. A single equation served both sexes at all ages except 7–12 months. Age-specific chest-girth equations are recommended for estimating body weight of local

sheep under field conditions, subject to validation on directly weighed animals.

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Data availability

The data supporting the findings of this study are available from the corresponding author on reasonable request.

Ethical statement

The study involved only non-invasive recording of body measurements and body weight of farmers' sheep, with the owners' consent. No experimental treatment was imposed on the animals.

Conflict of interest

The authors declare that they have no conflict of interest.

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