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Research article

The meta-analysis of sheep body weight prediction with body measurement, breed and sex categories for practical livestock management purposes

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Abstract

Accurate body weight estimation is crucial for efficient livestock management practices in sheep. This meta-analysis systematically reviewed 295 studies to identify the most reliable and practical predictors of sheep body weight based on body measurements. After screening 267 papers, 22 eligible studies encompassing 8,825 sheep were selected for analysis. The results revealed strong correlations between body weight and heart girth (r=0.83), chest depth (r=0.83), chest width (r=0.72), body length (r=0.69), and wither height (r=0.64). Heart girth and chest depth exhibited the strongest correlations with body weight, particularly when considering breed-specific differences. These measurements can be used to accurately estimate body weight, leading to improved livestock management practices, including feeding strategies, reproductive management, and genetic selection. Future research should explore the use of advanced statistical techniques, such as multiple regression analysis and non-linear equations with meta-analysis, to further enhance the precision of body weight prediction models.

Keywords: Body measurements, Body weight, Correlation and Meta-analysis, Prediction, Sheep.

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INTRODUCTION

In global meat production, sheep are essential generating annual output of approximately 9 million tonnes (Mazinani and Rude, 2020). They are commonly raised in extensive systems, grazing natural pastures and herbs in mountainous, arid, and semi-arid regions (Simões et al., 2021). According to Firdaus et al. (2023a), traditional livestock management often relies on subjective assessments of body weight appearance. Accurate body weight estimation is essential for optimizing feed rations, monitoring growth, administering medications, and determining fair market prices. Therefore, innovative methods are needed to enhance the accuracy and reduce management errors.

The most widely used method for assessing livestock body weight is by weighing using a digital scale which is often expensive for small-scale farmers with limited infrastructure (Firdaus et al., 2023b). Therefore, alternative methods, including estimation using body measurements variables are needed. Several studies such as Contreras et al. (2024), Simone and Yeheyis (2024), and Kebede et al. (2024), adopted heart girth, wither height, chest depth, chest width, and body length measurements to assess sheep body weight. However, the correlation coefficients and coefficients of determination for predicting the body weight of sheep can vary depending on breed and sex. Based on the report by Sun et al. (2020), the correlation between of Jamuna basin sheep body weight with the wither height, body length, and heart girth, ranged from 0.57 to 0.62, 0.43 to 0.67, and 0.61 to 0.76, respectively. Rather et al. (2021) reported a moderate positive linear correlation between the body weight of Merino sheep with the body length (r=0.49) and heart girth (r=0.54). In a study by Sabbioni et al. (2019), a stronger positive linear relationship was observed between body weight with body length, heart girth, as well as wither height, at correlations of 0.86, 0.95, and 0.91, respectively. For comprehensive understanding of the correlation coefficients and coefficients of determination values in predicting sheep body weight, a global synthesis of related studies is needed.

Meta-analysis, which is a formal systematic and quantitative method was adopted to analyze study topic based on existing data (Shah et al., 2020). It comprises several protocol steps, such as defining the study question, outlining the strategy, establishing inclusion and exclusion criteria, selecting studies, extracting results, and assessing the risk of bias (Hernandez et al., 2020). The analysis was used to examine the correlation coefficient values between sheep body weight and measurements such as heart girth, wither height, body length, chest depth, and chest width, considering the categories of breed and sex.

MATERIALS AND METHODS

Database Development

This study followed systematic reviews and meta-analysis guidelines, as shown in Figure 1. The initial step included filtering relevant publications using scientific databases, such as PubMed, Science Direct, Scopus, and Google Scholar. The search terms adopted were "sheep," "body weight," "body measurements," and "correlation." Subsequently, duplicate papers were removed, and the titles, abstracts, and contents were reviewed. In the next stage, data were abstracted and tabulated by author category, year of publication, country, sample size, breed, sex, and correlation coefficient value. Body measurements variables considered were heart girth, wither height, chest depth, chest width, and body length. Furthermore, the study focused on papers published between 2012 and 2023. The document selection criteria, adapted from Trevi et al. (2023), were (1) original studies with sheep population, (2) written in English, and (3) presenting data on variable average values, correlation coefficients, coefficients of determination, and sample size.

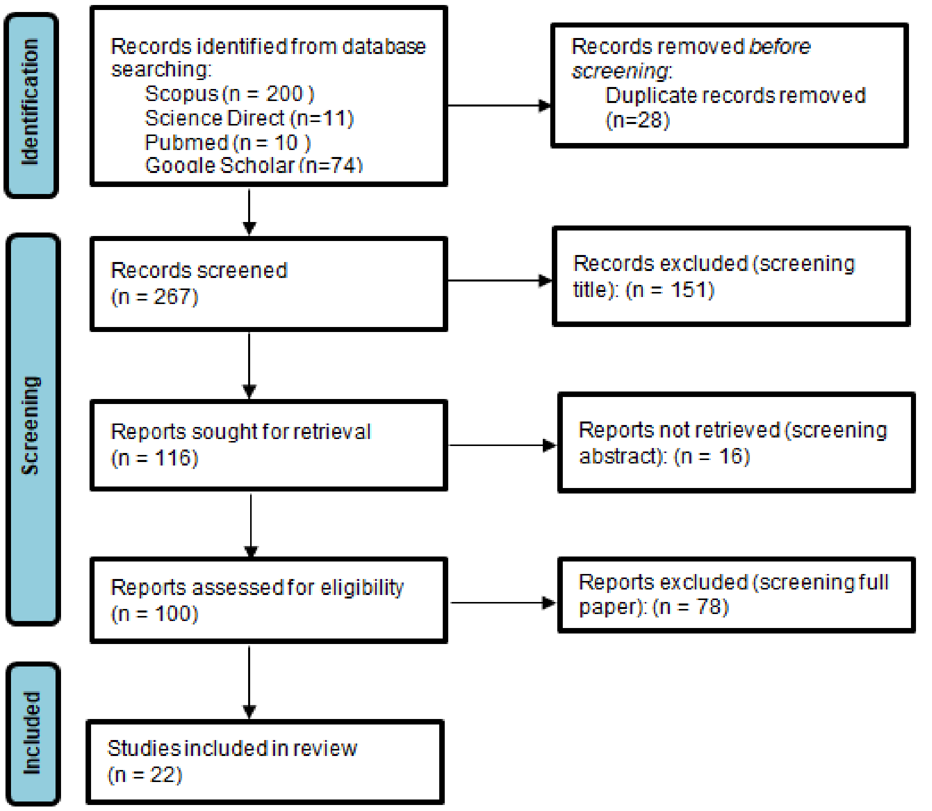

Figure 1 A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram detailing the literature search strategy and study selection for meta-analysis (Page et al., 2020).

Data Analysis

Data analysis was conducted using the OpenMEE software (Wallace et al., 2016). To calculate effect sizes, correlation coefficient values were standardized as mean differences, and the heterogeneity was calculated using Cochran's Q. Following data inspection, a random model was adopted to derive the overall effect. The following were the mathematical models used.

$$Y_i = \mu + \tau_i + \varepsilon_i \qquad (1)$$

$$Q = \sum(w_i\, ES_i^2) - \frac{(\sum(w_i ES_i))^2}{\sum w_i} \qquad (2)$$

$$\tau^2 = \frac{Q-df}{C} \qquad (3)$$

$$I^2 = \frac{(Q-(k-1))}{Q} \times 100 \qquad (4)$$

Where y_i is the diversity of the effect size, μ is the mean actual effect, τ_i is the diversity of the proper effect size, and ε_i is the sampling error (Retnawati et al., 2018). The measures of between-study heterogeneity were Cochran's Q, I^2 index, and tau-squared (τ^2). These represent variations between studies using the DerSimonian and Laird method. Where w_i is the weighting of each study, ES is the effect size value, k is the number of studies analyzed, df is the degree of freedom, and C is the estimated value. Finally, the cumulative effect size was recalculated into a correlation coefficient. The results of the meta-analysis were interpreted with a significant correlation ($P<0.05$) based on the results of the subgroup analysis. To identify any potential publication bias issues, an analysis was conducted using the Rosenthal Fail-safe N method, with the OpenMEE software.

RESULTS

Based on the data presented in Figure 1, the study started with collecting data that was adjusted to the objectives, before obtaining papers from Scopus (n = 200), Science Direct (n = 11), Pubmed (n = 10), and Google Scholar (n = 74). Following the removal of duplicate records, 267 papers were selected. Subsequently, the title of the paper was reviewed in accordance with the study objectives, leading to 116 eligible papers for the next process. The abstract screening was conducted to verify the availability of data needed for the meta-analysis process, narrowing down the selection to 100 eligible papers. A final screening of the full paper was then performed to ensure complete data input for meta-analysis, leading to 22 eligible papers for the process. This meta-analysis included data from ten countries, namely Algeria, Bangladesh, Brazil, Ethiopia, India, Indonesia, Mexico, Pakistan, Qatar, and Türkiye, as shown in Table 1. All selected documents provided data on sample size and correlation coefficient values, derived from linear regression modeling. The included studies featured breed and sex-specific data, with a total sample size of 8,825 sheep. Based on meta-analysis results in Table 2, heart girth and chest depth had the strongest correlation coefficients (P<0.05) with body weight, as determined by the meta-analysis subgroup. It is important to acknowledge that wither height showed the lowest correlation coefficient value.

Table 1 Database of studies of predicting body weight of sheep used in meta-analysis.

No	Authors	Country	Breed	Sex	N
1	Arsalan et al. (2021)	Pakistan	Indigenous	M, F	291
2	Atac and Altincekic (2023)	Turkiye	Chios	M	60
3	Atta et al. (2024)	Qatar	Awassi, Najdi, Erbi	M, F	324
4	Ávalos-Castro et al. (2023)	Mexico	Criollo	M, F	720
5	Bekele and Tadesse (2021)	Ethiopia	Horro	M, F	1,619
6	Castillo et al. (2023)	Mexico	Merino	M, F	219
7	Canaza-Cayo et al. (2021)	Brazil	Corridale	F	100
8	Djaout et al. (2022)	Algeria	Algerian Tazegzawt	M, F	54
9	Esen and Elmaci et al. (2021)	Turkiye	Kivircik and others*	M, F	202
10	Faraz et al. (2021)	Pakistan	Thalli	M, F	155
11	Hussain et al. (2019)	India	Kenguri	M	60
12	Ibrahim et al. (2021)	Indonesia	Batur	F	79
13	Iqbal et al. (2019)	Pakistan	Harnai	M	757
14	Jannah et al. (2023)	Indonesia	Sakub	F	150
15	Macedo-Barragán et al. (2021)	Mexico	Pelibuey	M, F	393
16	Málková et al. (2021)	Mexico	Charollais, Kent	M, F	101
17	Özen et al. (2019)	Turkiye	Awassi	F	270
18	Santos et al. (2020)	Brazil	DorperXSanta	F	25
19	Sun et al. (2020)	Bangladesh	Jamuna Basin	M, F	520
20	Worku (2019)	Ethiopia	Arsi Bale	M, F	600
21	Wamatu and Alkhtib (2021)	Ethiopia	Adilo, Bonga and Horro	M, F	2,016
22	Yağanoğlu (2022)	Turkiye	Morkaraman	M, F	110

M= male, F= female, N= total heads, *others=Bandirma, Karacabey Merino, Hampshire DownxMerione crossbred, Ramlic.

Meta-analysis showed significant differences (P<0.05) in the correlation coefficients between body measurements and body weight among sheep breed, as presented in Table 3. Merino sheep had the strongest correlations, while Algerian Tazegzawt, Chios, and Arsi Bale featured the weakest. Despite these variations, the overall correlation coefficient values for different breeds remained reasonably high, supporting the development of predictive models. Meta-analysis results showed that sex did not have a significant effect (P>0.05) on the correlation between body weight and body measurements. Several studies reported sex-based differences, but the analysis using sample sizes ranging from 100 to 2,000 individuals had no significant disparities (Table 4). Male sheep tended to be heavier than female sheep with no statistically significant differences. This suggests that the correlation between body weight and body measurements was comparable across the sexes.

The publication bias analysis, conducted using the file drawer method, showed no evidence for the variables of body length, wither height, heart girth, chest width, and chest depth (Table 5). The fail-safe N value represented the minimum number of studies with null results but needed to be included in the meta-analysis to reduce the significance level to α = 0.05.

Table 2 Meta-analysis of the correlation of various body measurements with body weight of sheep.

Variable	BM (cm)	Body weight (kg)	Coefficient correlation			Q	*Het. p-Value*	Heterogeneity (I²)	N
			Estimate	Lower	Upper				
BL	52.95	23.24	0.69^{ab}	0.64	0.74	591.51	<0.001	90.03%	5,666
WH	56.22	25.32	0.64^{a}	0.57	0.69	864.36	<0.001	92.6%	6,500
HG	62.41	24.20	0.83^{b}	0.80	0.85	494.88	<0.001	88.08%	7,600
CW	16.66	20.19	0.72^{ab}	0.66	0.76	79.58	<0.001	57.28%	1,319
CD	21.78	19.96	0.83^{b}	0.73	0.90	83.03	<0.001	74.71%	273

N= total sample to be analyzed; $^{a,ab,\ b}$=different letters in the diagram show significant differences based on meta-analysis subgroups (*p<0.05*); BM=body measurement; BL= body length; WH= wither height; HG= heart girth; CW=chest width; CD=chest depth.

Table 3 Meta-analysis of the correlation between various body measurements with body weight with categorization based on sheep breeds.

Variable	BM (cm)	Body weight (kg)	Coefficient correlation			Q	*Het. p-Value*	Heterogeneity (I²)	N (head)
			Estimate	Lower	Upper				
				Heart girth					
Algerian Tazegzawt	109.0	73.75	0.58^{a}	0.18	0.81	2.28	0.131	56.17%	54
Harnai	46.72	32.88	0.82^{ab}	0.58	0.93	43.57	<0.001	97.70%	757
Arsi Bale	71.39	27.89	0.82^{ab}	0.77	0.87	17.72	0.013	60.49%	600
Merino	55.51	14.59	0.91^{b}	0.79	0.95	40.78	0.003	53.41%	219
				Chest depth					
Algerian Tazegzawt	38.10	73.75	0.60^{a}	0.39	0.75	0.07	0.804	0.00%	54
Merino	20.15	14.59	0.85^{ab}	0.74	0.92	72.47	<0.001	73.78%	219
				Chest width					
Chios	15.83	31.91	0.60^{a}	0.46	0.71	1.17	0.279	14.58%	120
Arsi Bale	26.39	27.89	0.62^{a}	0.54	0.69	11.77	0.108	40.52%	600
Merino	12.17	14.59	0.82^{b}	0.73	0.88	34.52	0.016	44.96%	219
				Wither height					
Criollo	57.21	21.14	0.91^{b}	0.84	0.95	12.62	<0.001	92.08%	720
Harnai	46.36	32.88	0.74^{b}	0.69	0.79	2.09	0.148	52.19%	757
Arsi Bale	62.61	27.89	0.32^{a}	0.24	0.40	7.78	0.353	10.00%	600
Merino	49.78	15.61	0.66^{ab}	0.54	0.76	27.43	0.095	30.73%	369
				Body length					
Arsi Bale	62.87	27.89	0.49^{a}	0.38	0.59	15.07	0.035	53.54%	600
Harnai	42.62	32.88	0.76^{ab}	0.63	0.85	11.11	<0.001	91.00%	757

N= total sample; ^{a,ab,b} different letters in the diagram show significant differences based on meta-analysis subgroups; BM= body measurement.

Table 4 Meta-analysis of the correlation between various body measurements with body weight with categorization based on sheep sex.

Variable	BM (cm)	Body weight (kg)	Coefficient correlation			Q	Het. p-value	Heterogeneity (I^2)	N (head)
			Estimate	Lower	Upper				
				Heart girth					
Male	60.50	26.26	0.84	0.78	0.88	148.18	<0.001	85.83%	1,603
Female	65.56	22.98	0.80	0.76	0.84	70.74	<0.001	70.32%	1,995
				Chest depth					
Male	22.60	23.11	0.88	0.75	0.94	42.26	<0.001	76.34%	144
Female	20.97	16.82	0.77	0.55	0.89	33.79	<0.001	70.40%	129
				Chest width					
Male	16.55	21.51	0.72	0.60	0.80	39.48	<0.001	62.00%	325
Female	16.78	18.77	0.70	0.62	0.77	34.74	0.002	59.70%	884
				Wither height					
Male	56.20	25.98	0.68	0.58	0.75	185.87	0.002	87.63%	1,902
Female	56.07	24.95	0.54	0.39	0.66	492.63	<0.001	94.93%	2,871
				Body length					
Male	50.34	22.78	0.71	0.64	0.76	71.84	<0.001	72.16%	1,587
Female	54.59	23.45	0.60	0.48	0.69	238.31	<0.001	90.35%	2,352

N= total sample; BM= body measurement

Table 5 File drawer analysis.

Item	Ns	Fail-safe N value	Significance of bias
BL	45	23699	Not significant
WH	50	28933	Not significant
HG	44	45507	Not significant
CW	31	5947	Not significant
CD	22	2114	Not significant

Ns= total study to be analyzed; BL= body length; WH= wither height; HG= heart girth; CW=chest width; CD=chest depth.

DISCUSSION

Canul-Solís et al. (2023), showed the accuracy of heart girth in predicting Pelibuey sheep body weight, with a correlation coefficient value of 0.94. Firdaus et al. (2023a) reported that the correlation between heart girth and body weight, based on 5,162 cattle, ranged from 0.86 to 0.91. The substantial correlation coefficient values associated with heart girth, were possibly due to the use of two dimensions, compared to body length and wither height, which are based on a single cross-sectional dimension. Collectively, the results suggest that heart girth can be a reliable predictor.

Wither height and body length variables had lower correlation coefficients with sheep body weight, due to the cessation of bone growth at certain stages of livestock development. Conversely, heart girth, which incorporates both bone and soft tissue dimensions, had stronger correlations. Body length parameter may not be as optimal as heart girth for predicting body weight, but can still be valuable in certain contexts, such as mountainous areas without scales (Madikadike and Tyasi, 2024) or traditional breeding practices. Correlation coefficients for body length typically ranged from 0.64 to 0.74, falling within the moderate category. The combination of body length with heart girth to calculate body volume can enhance the accuracy of predicting the body weight of livestock (Firdaus et al., 2023a).

Suliman et al. (2021) observed differences in backfat thickness and myofibril fragmentation index among breeds of sheep. Additionally, breeds vary in the time taken to reach body maturity, which is associated with feed conversion efficiency. Marković et al. (2019) reported variations in body length, chest depth, and chest width among different sheep breed. Wamatu and Akhtib (2021) recommend using heart girth to predict sheep body weight regardless of age or sex. Conversely, Ibrahim et al. (2020) observed that sex significantly influenced body length and wither height but had no significant impact on heart girth. The results are consistent with reports of Mathapo and Tyasi (2021), who adopted the classification and regression tree method to show the importance of sex in predicting body weight in Boer goats. According to Washaya et al. (2023), male sheep had higher average daily gains (ADG) than females during weaning and post-weaning periods. Sabbioni et al. (2016) also observed differences between male and female sheep. The results showed that females had earlier allometric coefficients for chest width and chest depth. Future studies should conduct a meta-analysis of sheep body weight predictions by sex and age category. For specific age groups, it may be necessary to investigate whether significant differences exist in correlations and regressions between males and females.

Future studies should consider conducting a meta-analysis of sheep body weight prediction using multiple regression analysis and non-linear modeling. According to Sharif et al. (2021), the prediction using Brody's non-linear modeling was particularly suitable for sheep. This is because their growth rate accelerates until puberty, and decelerates when body maturity approaches. The curve reached its maximum at this stage, signifying the cessation of muscle, bone, and organ growth. Additionally, Salazar-Cuytun et al. (2022), stated that body volume can be used to predict sheep body weight with a correlation coefficient of r=0.96. Future investigations could also explore the use of digital image-based modeling, incorporating top-view variables, body length, and chest depth, considering breed and sex categories (Firdaus et al., 2024). An intelligent precision method using biometric parameters, developed with Kinect sensors and neural network-based modeling, could enhance sheep body weight prediction (Chay-Canul et al., 2024).

CONCLUSIONS

In conclusion, this meta-analysis showed that heart girth and chest depth were the most reliable predictors of sheep body weight, particularly when considering breed-specific variations. Future studies should explore the use of multiple regression analysis and non-linear equations to develop more comprehensive and accurate prediction models.

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AUTHOR CONTRIBUTIONS

This work was a collaborative effort among all authors. FF, TSP, YA, NHK, BAA, RW, and MM contributed equally to this research. FF conception and design of the study, acquisition of data, analysis and/or interpretation of data, and drafting of the manuscript. TSP, YA, MM, NHK, BAA, and RW designed the study, validated data, contributed to the interpretation of results, BAA supervised and reviewed the final version of the manuscript. FF, TSP, YA, NKH, BAA, RW, and MM, have given final approval of the version to be published and agree to be accountable for all aspects of the work.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest in any financial, personal, or relationships with other people or organizations related to the material discussed in the manuscript.

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