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Research article

The development of a body weight prediction method for Ongole Crossbred cattle using a meta-analysis and field experiment approach

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Abstract

This study aims to develop and validate a model for predicting the body weight (BW) of Ongole Crossbred (OC) cattle using body measurements. To achieve this, a combination of meta-analysis and field experiments was employed. The meta-analysis involved identifying relevant keywords and databases, reviewing titles and abstracts, extracting data, and subsequently tabulating and analyzing the data. A total of 1,141 animal records were included in the quantitative synthesis process. Following the meta-analysis, a BW prediction model for OC cattle was developed. The model incorporated recommendations obtained from the meta-analysis, considering body measurement, age, and sex. Data from 507 animals were utilised to construct the model. Finally, a field experiment was conducted on 35 animals to assess the accuracy of the model. The meta-analysis revealed that body volume (BV) (r=0.96) and heart girth (HG) (r=0.89) exhibited stronger correlations with BW compared to body length (BL) (r=0.68). Linear regression modeling of OC cattle BW, demonstrated that HG yielded high correlation coefficients for both male (r=0.98) and female (r=0.94) cattle. Similarly, BV showed strong correlations for male (r=0.99) and female (r=0.95) cattle. Furthermore, the analysis revealed that both HG and BV were effective predictors across different age groups, with high correlation coefficients observed for cattle aged 1-12 months and over 24 months. The field experiment confirmed the high reliability of the model, achieving an accuracy of 90.8% for HG and 91% for BV. In conclusion, HG and BV are strong predictors of OC cattle BW, with categorization by breed further improving prediction accuracy.

Keywords: Body weight prediction, Body measurements, Field experiments, Meta-analysis, Ongole Crossbred cattle.

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INTRODUCTION

The increasing demand for beef in Indonesia is associated with population growth and a rising incomes. However, domestic production currently meets only around 65% of total demand, while the remaining 35% is obtained through imports of feeder cattle and processed meat. Smallholder farmers form the backbone of the Indonesian beef industry, contributing 90% of the beef cattle population, while commercial livestock enterprises account for less than 10% (Agus and Widi, 2018). These smallholder farmers are concentrated on the island of Java, primarily raising crossbred (*Bos indicus x Bos taurus*) cattle (Widi, 2015). Ongole Crossbred (OC) cattle are a prominent breed, having existed since the 19th century, with 90% of the population currently concentrated in Central Java and Yogyakarta. These cattle are renowned for their adaptability to low-input systems and are the most common type of cattle raised by smallholder farmers (Sutarno and Setyawan, 2015). The comparatively larger body size (Ngadiyono et al., 2019; Widi et al., 2021) highlights their potential as terminal dams in crossbreeding programs with *Bos taurus* cattle (Widyas et al., 2022). Therefore, enhancing the productivity of OC cattle and improving the capacity of farmers to monitor performance is essential for maximizing economic and genetic potential.

Regular body weight measurements are a practical way to detect changes in cattle condition and enable timely responses (Qiao et al., 2021) without disrupting production performance. In this context, accurate assessment is essential for optimizing beef cattle productivity, such as improving feed efficiency and evaluating growth responses (Wangchuk et al., 2018). Digital scales are the most accurate method for determining body weight. However, scales are often not affordable weighing equipment, and they require technical maintenance and lack portability for smallholder farmers. In contrast, visual evaluation to estimate cattle body weight is quite subjective, and accuracy depends on experience (Simanungkalit et al., 2020). The unavailability of weighing equipment often leads farmers and buyers to rely on visual assessments to determine the selling price or economic value of livestock (Ibrahim et al., 2021; Firdaus et al., 2023) under this circumtense farmer often in inferior position again buyer.

Alternatively, body weight can be predicted both manually and digitally (Weber et al., 2020a; Wang et al., 2021). In the manual method, data can be collected on independent variables such as body measurement, using measuring tape and sticks, facilitating the prediction of the dependent variable namely body weight. The digital method uses computer technology to capture images, followed by a digitization and modeling process to formulate and predict body weight (Weber et al., 2020b). Previous studies on body weight prediction typically focused on specific categories like breed, sex, or age, and varied in the number of samples analyzed (Cominotte et al., 2020). To assess the robustness of various body weight prediction models and refine the categorization system, a meta-analysis approach was employed as a valuable tool. This method involves collecting diverse studies that adhere to specific methodological standards and subjecting them to statistical testing (Retnawati et al., 2018). This analysis offers an efficient means to summarize results while uncovering previously unidentified associations (Littell et al., 2008). Following the outcome of the analysis, field testing the model is crucial. A meta-analysis of the correlation between cattle body weight and body volume, reported by Firdaus et al. (2023), revealed a 96% accuracy rate when compared to the field experiment conducted by Dakhlan et al. (2024).

This study aimed to develop a method for predicting the body weight of OC cattle by utilizing various body measurement variables. The study involved three stages: meta-analysis, body weight prediction modeling, and field experimentation.

MATERIALS AND METHODS

This study employed meta-analysis of data collected over the past 10 years and a field experiment conducted between 2022 and 2023 at the Livestock Development Center and the Center for Agrotechnology Innovation, Universitas Gadjah Mada. The study received ethical approval from the Animal Care and Use Committee (approval number 070/EC-FKH/Eks/2022).

Meta-analysis

A meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The process involved four stages: (1) determining keywords and search databases; (2) reviewing titles and abstracts; (3) extracting paper information; and (4) tabulating and analyzing data. Keywords were defined using the PICO framework (Population: *OC cattle*; Intervention: *correlation*; Comparison: *body measurements*; Outcome: *body weight*). Data were tabulated based on paper category, year of publication, sex, age, correlation coefficient, and sample size. The input correlation coefficient values represented the relationship between body length (BL), heart girth (HG), and body volume (BV) and the body weight (BW) of OC cattle.

The selected studies included papers published in both English and Indonesian, focusing on OC cattle. These papers provided information on breed, sex, age, sample size, correlation coefficient, year of publication, and country of origin. Simple linear regression was employed for modeling, while meta-analysis testing was conducted by calculating the effect size using correlation coefficient data and sample size. Correlation coefficient values were standardized as mean differences to facilitate this analysis. The heterogeneity of the effect size was assessed using Cochran's Q test. Following data inspection, a random effects model was applied to derive the overall effect. The following mathematical models were adopted:

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

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

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

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

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 analysis considered 3 between-study heterogeneity, namely Cochran's Q, I^2 index, and tau-squared (τ^2). These metrics assessed variation 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 subsequently transformed into a correlation coefficient. The results of the meta-analysis were interpreted with a significant correlation ($P<0.05$) based on the subgroup analysis. To identify potential publication bias issues, the Rosenthal Fail-safe N method was adopted. Meta-analysis was conducted using OpenMEE software (Wallace et al., 2017)

Field experiment

The field experiment was conducted in two stages.

Stage 1: Model Development

A body weight prediction model was developed by measuring the body dimensions of 507 OC cattle. Simple regression analysis was performed using JASP 0.14 software to determine the coefficient of determination (R^2) and Root

Mean Squared Error (RMSE) values, supporting the prediction modeling of OC cattle body weight.

Stage 2: Model Validation

To validate the model's accuracy, 35 animals (25 OC cattle and 10 other breeds) were measured. The tools used were a measuring tape, measuring stick, digital scale, and an Android application prototype. Body weight was determined using a digital scale (kg). Body measurements included heart girth (HG), measured using a measuring tape around the chest (cm), and body length (BL), measured as the distance from the humerus tuberosity to the ischial tuberosity using a measuring stick (cm). Body volume (BV) was estimated using a cylindrical formula: BV = BL × π × $(LD/2\pi)^2$ to approximate the body shape of cattle. This formula was then converted to liters (dm^3) to yield BV = (BL × LD^2) / (4000π). The coefficient of determination (R^2) was used as the statistical criterion for evaluating model accuracy. Finally, the following equation was applied to determine the accuracy of body weight (BW) prediction based on HG and BV:

$$\text{Accurate BW-HG (\%)} = \frac{|BW\ prediction\ (HG) - BW\ actual|}{BW\ actual} \times 100\%$$

$$\text{Accurate BW-BV (\%)} = \frac{|BW\ prediction\ (BV) - BW\ actual|}{BW\ actual} \times 100\%$$

The real difference test includes analysis of variance and T-test, with a confidence level of 95%. T-test analysis was performed using JASP 0.14 software.

RESULTS

Meta-analysis

The meta-analysis examined the correlation between body measurement variables (BL, HG, and BV) and body weight in OC cattle. Data from 1,141 cattle across 8 selected studies were analyzed, as shown in Table 1. The studies included both male and female cattle and categorized ages into U1, U2, and U3. The analyzed articles spanned 8 years, from 2015 to 2023, with sample sizes ranging from tens to hundreds.

Table 1 Research paper on the correlation of body weight with body measurement in Ongole Crossbred cattle used in meta-analysis

Paper	Country	Sex	Age	Body measurements	N (head)
Laya et al., 2020	Indonesia	F	U3	HG, BL	340
Paputungan et al., 2015	Indonesia	F	U3	HG, BL, BV	363
Ersi et al., 2018	Indonesia	M	U1	HG, BL	30
Sarwono et al., 2019	Indonesia	F	U1	HG, BL	97
Ramona et al., 2023	Indonesia	F	U3	HG, BL	30
Hartati and Putra, 2022	Indonesia	F	U3	HG	200
Kusuma et al., 2019	Indonesia	F	U2	HG	33
Firdaus et al., 2023	Indonesia	M, F	U2	HG, BV	48

Age: U1 (1-12 months), U2 (>12-24 months), U3 (>24 months); HG=heart girth, BL=body length, BV=body volume; N=number of samples; F=female, M=male.

The meta-analysis results (Table 2) revealed significant differences ($p < 0.05$) among BL, HG, and BV. Body volume exhibited the highest average correlation coefficient (0.96) with a total sample of 411, followed by HG (0.89) and BL (0.68). Based on these findings, BV and HG can be considered suitable body measurement variables for predicting the body weight of OC cattle. The results of the BW prediction model (Table 3), developed using data from 507 OC cattle, indicate that both HG and BV are strong predictors of body weight. For male OC cattle, HG explained 47% to 98% of the variation in body weight, while BV explained 55% to 97%. Additionally, R^2 values were consistently higher for male cattle compared to female cattle, and the highest R^2 values were observed in the U1 age group.

Table 2 Meta-analysis of the correlation between body measurement and body weight of Ongole Crossbred cattle

Variable	Coefficient correlation			*p-Value*	I^2 (%)	Fail drawer analysis			N (head)
	Estimation	Lower	Upper			Ns	Fail-safe N value	Significance of bias	
BL	0.68[a]	0.47	0.81	<0.001	94.95	10	2,022	NS	860
HG	0.89[b]	0.82	0.94	<0.001	95.33	15	11,015	NS	1,141
BV	0.96[c]	0.92	0.98	<0.001	91.60	7	3,616	NS	411

[a,b,c] Different superscripts in the rows indicate significant differences based on the meta-analysis subgroups; BL=body length, HG=heart girth, BV=body volume; I^2=heterogeneity; Ns= number of studies; NS=not significant; N=number of samples.

Table 3 Regression model and coefficient determination of body measurement and body weight of Ongole Crossbred cattle

Variable	N (head)	Body measurement (cm)	Body weight (kg)	Regression modeling	R^2	RMSE (kg)
Heart girth						
Male						
U1	33	42.4±35.3	76.27±17.3	2.013HG-111.147	0.98	5.7
U2	7	260.6±77.7	145.42±11.9	6.279HG-652.534	0.93	22.6
U3	82	481.7±95.4	183.37±13.3	6.731HG-752.607	0.88	33.3
Female						
U1	57	66.1±50.7	87.54±25.7	1.867HG-97.341	0.90	16.4
U2	41	228.4±44.8	143.53±13.2	2.325HG-105.304	0.47	33.1
U3	287	351.5±69.9	163.66±10.6	5.914HG-616.329	0.80	31.2
Body volume						
Male						
U1	33	42.4±35.3	36.2±31.2	1,115BV+2.069	0.97	5.9
U2	7	260.6±77.7	224.8±61.9	1,182BV-5.025	0.89	28.8
U3	82	481.7±95.4	399.5±79.0	1,091BV+46.002	0.82	41.1
Female						
U1	57	66.1±50.7	59.2±52.4	0.881BV+13.996	0.83	21.1
U2	41	228.4±44.8	208.9±51.3	0.651BV+92.286	0.55	30.3
U3	287	351.5±69.9	293.1±46.6	1.264BV-19.085	0.71	37.6

Age = U1 (1-12 months), U2 (>12-24 months), U3 (>24 months); R^2 (coefficient of determination). N=number of samples. RMSE= Root Mean Squared Error.

Field experiment

The field application of the body weight prediction model on 35 cattle demonstrated an accuracy of 90.8% for 25 OC cattle using the heart girth (HG) variable (BW-HG), with an RMSE value of 36.6 kg. When applied to 10 cattle of another breed, the model achieved an accuracy of 78.6% with an RMSE value of 18.3 kg, as shown in Table 4. Using body volume variables (BW-BV), the prediction of body weight for OC cattle and other breeds achieved accuracies of 81.9% and

91%, respectively, with RMSE values of 32.6 kg and 27.0 kg, respectively. Significant differences ($p < 0.05$) were observed in the accuracy of body weight prediction between different breeds, with OC cattle demonstrating higher accuracy than other breeds. However, no significant differences were found based on age and sex categorizations. These findings align with the results of the meta-analysis using the heart girth variable, as presented in Table 5.

Table 4 Accuracy of predicting body weight for Ongole Crossbred cattle using heart girth and body volume variables.

Variable	N (head)	BW actual (kg)	BW-HG			BW-BV		
			Prediction (kg)	Accuration (%)	RMSE	Prediction (kg)	Accuration (%)	RMSE (kg)
Breed								
OC	25	301±102	314±102	90.8[b]	36.6	310±109	91.0[b]	32.6
Others	10	217±166	235±173	78.6[a]	18.3	237±200	81.9[a]	27.0
Age (month)								
1-12	7	80±14	89±22	81.1	10.5	69±19	83.9	9.2
13-24	6	223±40	230±27	93.3	9.1	208±40	92.6	17.8
>24	22	355±75	372±71	89.1	39.5	382±71	88.7	38.8
Sex								
Male	9	254±175	271±176	90.4	16.3	269±204	84.6	30.6
Female	26	285±109	298±112	87.5	36.1	297±118	89.7	33.5

BW-HG: prediction of body weight using the HG variable; BW-BV: prediction of body weight based on BV variables; N=number of samples; OC (Ongole Crossbred); [a,b] different letters in the same column indicate differences ($p<0.05$). RMSE= Root Mean Squared Error.

Table 5 Meta-analysis of the correlation between heart girth and body weight of Ongole Crossbred cattle with categorization based on sex and age.

Variable	Coefficient correlation			*p*-Value	I^2 (%)	Fail drawer analysis			N (head)
	Estimation	Lower	Upper			Ns	Fail-safe N value	Significance of bias	
Sex									
Female	0.87	0.76	0.93	<0.001	96.06	12	7,428	NS	1,004
Male	0.96	0.86	0.99	<0.001	84.34	3	350	NS	137
Age									
U1	0.88	0.40	0.99	0.136	98.59	2	98	NS	127
U2	0.88	0.61	0.97	<0.001	83.32	3	113	NS	81
U3	0.90	0.83	0.94	<0.001	94.32	10	83	NS	933

Age = U1 (1-12 months), U2 (>12-24 months), U3 (>24 months); I^2=heterogeneity; Ns= number of studies, NS=not significant; N=number of samples.

DISCUSSION

Body volume and HG were identified as potential predictors of cattle body weight. Heart girth, related to bone growth, ceases development upon reaching optimal maturity. However, ribs, the last bones to fully develop, continue to grow, contributing to the expansion of this variable (Aziz et al., 2022). As a single predictor, HG's effectiveness has been demonstrated in various studies: Jabres cattle (Haq et al., 2020), Batur sheep (Ibrahim et al., 2021), Sakub sheep (Jannah, 2023), and Katjang goats (Putra and Ilham, 2019). When combined with other variables, body volume, calculated from HG and BL, exhibits the highest estimated value. This combination reflects the cumulative development of ribs, muscles, and fat, which correlates with increases in carcass fat and rib-eye weight (Ibrahim et al., 2021).

A more in-depth study of HG was conducted to determine whether categorization based on age and sex is necessary. Meta-analysis results (Table 3) revealed no significant differences, suggesting that predictive modeling of body weight can be based solely on breed with a sufficient sample size. When more data becomes available, categorization by age and sex may improve model precision. Predicting body weight based on body size should align with specific objectives and expected efficiency. Fewer independent variables are required, but applying the body weight prediction formula in the field becomes simpler with solid accuracy gains. According to the meta-analysis, chest girth and body volume, demonstrating strong correlation results, are recommended for predicting OC cattle body weight through the formulation of a regression model.

Based on a linear regression model, changes in body weight were strongly predictable with body measurements, specifically HG and BV, as indicated by an R^2 value range of 0.71-0.98 (Paputungan et al., 2013). The correlation between body measurements and BW was positive and significant, suggesting that body measurements can serve as markers to calculate BW using regression equations (Teye et al., 2016). A regression model with a single predictor of HG offers an alternative to estimate the body weight of OC cattle. Single-variable models are particularly useful for marketing and farmers. However, breeding strategies and growth performance evaluations require a more specific model incorporating multiple body measurement variables (Teye et al., 2016).

The positive correlation between body measurements and body weight in cattle signifies a direct proportionality, as stated by Fonseca et al. (2021). Haq et al. (2020) reported that the R^2 value for predicted body weight in male Jabres cattle was higher than in females, at 0.847 vs 0.980, respectively. Similarly, the R^2 value was higher for cattle below 1 year (0.969) compared to those above 1 year (0.858). These results align with the notion that male cattle exhibit greater proportional growth in forequarter muscle, often less economically valuable than hindquarter muscle. Male cattle also have a higher muscle-to-bone ratio than females, leading to heavier carcasses at a given fat level and reflecting a stronger drive for muscle growth (Pogorzelska-Przybyłek et al., 2020). In terms of age-related growth patterns, cattle in the U1 group (0-12 months) followed a linear trajectory, while those in the U3 group (over 24 months) exhibited a curved trajectory. Gano et al. (2015) noted that cattle growth after 2 years of age deviates from a linear pattern.

Multiple studies have shown a strong correlation between HG and BW in cattle. Paputungan et al. (2013) found that HG can predict body weight with an R^2 value ranging from 0.71 to 0.86. Rukmi et al. (2022) achieved an accuracy of 86.9%-97.4% in predicting the body weight of male Ongole cattle aged 2-6 years. Suliani et al. (2017) demonstrated a significant relationship between HG and BW, further supporting the significance of HG as a predictor. Using modeling data from the same breed (Ongole cattle), Firdaus et al. (2023) found that the average prediction accuracy (88.13%) was higher than that of farmers' visual assessments. This suggests that categorizing cattle based on breed can improve prediction accuracy, providing farmers with a valuable tool for comparison to their visual estimates. These results align with the findings of Ngadiyono et al. (2019) and Sidik et al. (2023), who noted that different cattle breeds, even when raised in similar conditions, exhibit distinct body measurement characteristics.

CONCLUSIONS

In conclusion, the meta-analysis results strongly support the use of body measurements, specifically HG and BV, as reliable predictors of Ongole cattle body weight. These variables were found to exhibit a higher correlation coefficient than BL. Moreover, categorizing cattle by breed significantly improved prediction accuracy. The field experiment demonstrated that using HG and BV to predict body weight in Ongole cattle achieved an accuracy exceeding 90%. These findings provide valuable insights for farmers and researchers, highlighting the effectiveness of body measurements in accurately estimating cattle weight.

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AUTHOR CONTRIBUTIONS

This work was a collaborative effort among all authors. FF, BAA, PJ, YA, TSP, NHK, BAA, RW, MM and FA 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. BAA and PJ supervised the study and provide the research funding. FF, BAA, PJ, YA, TSP, NHK, BAA, RW, MM and FA designed the study, validated data, contributed to the interpretation of results, and reviewed the final version of the manuscript. FF, BAA, PJ, YA, TSP, NHK, BAA, RW, MM and FA 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 author claim no conflicts of interest regarding this manuscript in terms of personal, organizational, financial, or material matters.

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