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Use of nonlinear regression in predicting body weight of female Saburai goat

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Abstract. This study aimed to evaluate the use of nonlinear regression in predicting body weight of female Saburai goats using body measurements. Thirty three female Saburai goat aged 1-3 years were used in this study. Body measurements including chest girth (CG), body length (BL), shoulder height (SH), hip height (HH), and hip width (HW) were regressed on body weight (BW) using nonlinear regression (exponential and polynomial regression). The prediction accuracy of nonlinear regression was compared to linear regression by evaluating their determination coefficient (R^2), adjusted R^2, residual standard error (RSE), Akaike information criterion (AIC), and Bayesian information criterion (BIC). Correlation and regression analysis between body measurements and body weight was done with the help of the R program using nls function and "ggplot2" package. The findings indicate that among the various linear and nonlinear regression models that make use of individual body measurements, the most efficient model for forecasting the BW of female Saburai goats is the linear regression model that employs CG as the measurement. This model is followed in terms of performance by the quadratic polynomial regression model using CG and the exponential regression model using CG, as determined by the best selection criteria. However, when considering a combination of body measurements and employing stepwise regression analysis for selecting parameters, the optimal predictor for BW is identified as a combination of CG, BL, SH, and HW. Additionally, for a more simplified model that still maintains statistical significance in its coefficient regression, the most suitable regression model for predicting the BW of female Saburai goats is one that combines CG and SH. The regression equation representing this model can be expressed as $\hat{Y}$ = -65.9639 + 1.0160CG + 0.4342SH.
Keywords: Body measurements, body weight prediction, female Saburai goat, nonlinear regression

1. Introduction

Goats, classified as small ruminant livestock, possess the capacity to be cultivated as meat producers, serving as a valuable source of animal protein. The strengths of goats encompass their adaptability to diverse environmental conditions, a notable reproductive capability, and the potential to give birth to multiple offspring simultaneously. At present, Lampung Province in Indonesia is actively engaged in advancing goat farming, capitalizing on its suitability for such agricultural development. Within

Lampung Province, Tanggamus Regency stands out as an area characterized by a substantial goat population. Based on data provided by the Directorate General of Livestock and Animal Health [1], the count of goats in Tanggamus Regency has surged to 184,859 individuals, primarily centered around the Saburai goats, which garners the highest prevalence among the community in Tanggamus Regency.

One approach to advancing the development of Saburai goats involves assessing their performance by examining their body weight. Body weight plays a crucial role in determining the value of livestock, especially within the context of goat selection programs [2,3]. The most accurate way to ascertain a goat's body weight is through direct weighing. However, obtaining weighing scales can be challenging, especially in rural farming settings. To address this issue, an alternative method involves estimating goat body weight through body measurements, as research findings have indicated a strong correlation between these measurements and actual body weight [4-11]. Additionally, predicting a goat's body weight based on its body measurements is a relatively straightforward and practical approach, especially in rural conditions.

In various countries and among different goat breeds, researchers have developed equations to predict body weight based on a range of body measurements. Among these measurements, chest girth is particularly popular because of its strong correlation with weight [2,3,10]. In the majority of these studies, linear regression has been the preferred method for deriving these prediction equations. However, a small number of authors have also investigated the application of nonlinear regression models, as evidenced by the works of Boujenane and Halhaly [2], Canul-Solis et al. [13], and Macedo-Barragán et al. [14], and Sultana et al. [15].

In recent years, the utilization of advanced statistical techniques has gained prominence in enhancing the accuracy of such predictions. One such technique, nonlinear regression, offers a powerful tool to model complex relationships between variables. This research focuses on harnessing the potential of nonlinear regression to predict the body weight of female Saburai goats, a breed known for its unique characteristics and importance in local agricultural practices. Through an investigation into the application of nonlinear regression within this specific context, the primary objective of this study is to employ nonlinear regression as a method for predicting the body weight of female Saburai goats, thereby offering valuable insights for goat farmers, breeders, and researchers alike.

2. Materials and Methods

This study was conducted in January 2023, at the Kelompok Ternak Makmur II, Gisting Atas village, Gisting Sub-district, Tanggamus Regency, Lampung Province, Indonesia. The tools used in this research were a digital scale with a capacity of 75 kg with accuracy of two decimal places, a measuring tape with a length of 150 cm with accuracy of 0.1 cm, a measuring stick of 200 cm high with an accuracy of 0.1 cm, and writing tools. The material used in this study consisted of 33 female Saburai goats aged 1-3 years old and not pregnant.

The collected data (body weight = BW, chest girth = CG, body length = BL, shoulder height = SH, hip height = HH, and hip width = HW) underwent examination through correlation analysis and nonlinear regression techniques, which encompassed models such as linear, exponential, quadratic, cubic, and higher-order polynomial equations. The linear and nonlinear regression models are outlined below:

$Y = a + bX_1 + \varepsilon$
$Y = a + bX_2 + \varepsilon$
$Y = a + bX_3 + \varepsilon$
$Y = a + bX_4 + \varepsilon$
$Y = a + bX_5 + \varepsilon$
.
.
.
$Y = a + bX_1 + bX_2 + bX_3 + bX_4 + bX_5 + \varepsilon$
$Y = a*\exp(bX) + \varepsilon$

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$Y = a + bX + cX^2 + \varepsilon$
.
.
.
$Y = a + b_1X + b_2X^2 + b_3X^3 + \ldots + b_nX^n + \varepsilon$
where Y = BW is the dependent variable (body weight), X is the independent variable (body measurements), X_1 = CG, X_2 = BL, X_3 = SH, X_4 = HH, X_5 = HW, a is constant, b, c, b_1, b_2, …, b_n are the coefficients of regression or the polynomial terms, n is the degree of the polynomial, which determines the highest power of X in the equation, and ε represents the error term, which accounts for the variability in the data that is not explained by regression or the polynomial equation.

The R programming language, along with the "nls" and "lm" function and the "ggplot2" package, was utilized to conduct an analysis that explored the correlations and regression relationships between body measurements and body weight [16,17]. The accuracy of predictions made using nonlinear regression was assessed in relation to those made with linear regression through the examination of metrics such as the determination coefficient (R^2), adjusted R^2, residual standard error (RSE), Akaike information criterion (AIC), and Bayesian information criterion (BIC). The higher r, R^2, and adjusted-R^2 and the lower the RSE, AIC, and BIC, the better the model in predicting BW of female Saburai goat. Linear and nonlinear regression models in R (example for chest girth, CG) are as follows.

```
data <- read.csv("SaburaiGoat.csv", header=TRUE)
1. LinearCG <- lm(BW ~ CG, data = data) #for linear regression
2. start_values <- c(a=100, b=0.1)
   ExponentialCG <- nls(BW ~ a * exp(b * CG),data=data,
            start = start_values,
            algorithm = "port",
            control = nls.control(maxiter = 1000)) #for Exponential regression
3. QuadraticCG <- lm(BW ~ poly(CG, 2), data = data) # for quadratic polynomial regression
4. CubicCG <- lm(BW ~ poly(CG, 3), data = data) # for cubic polynomial regression
```

3. Results and Discussion

3.1. Body Measurements and Their Inter-correlation
The data presented in Figure 1 illustrate the characteristics of female Saburai goats, including body weight (BW), chest girth (CG), body length (BL), shoulder height (SH), hip height (HH), and hip width (HW). The figures reveal that the body weight and measurements of female Saburai goats follow a normal distribution, except for some outlier data points in the case of SH and HW. The Shapiro-Wilk normality test confirms that most of the data adhere to a normal distribution, except for HW, which deviates from this pattern.

On average, the female Saburai goats had a BW of 34.69 kg, a CG of 71.15 cm, a BL of 68.55 cm, a SH of 65.33 cm, a HH of 67.55 cm, and a HW of 16.42 cm. This outcome suggests that there is a notable variation in both body weight and body measurements among these female Saburai goats. This variation could be attributed to factors such as age, which ranged from 1 to 3 years, and differences in their genetic potential for growth. It's worth noting that their environmental factors, such as feeding and rearing management, were relatively consistent across the study population. This variability in body characteristics indicates that a selection program could be successful in this population.

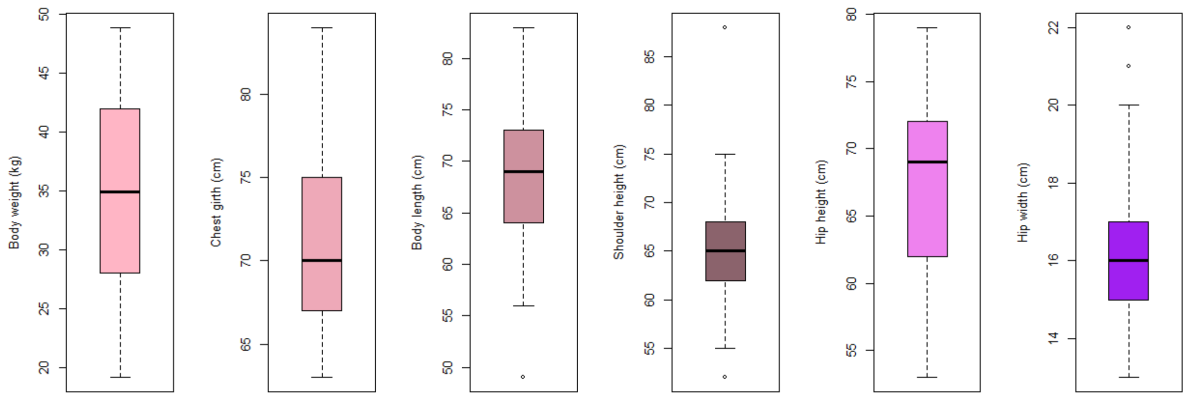

Figure 1. Boxplot of variables studied

The current study's findings reveal notable variations in measurements when compared to previous research conducted by Dakhlan et al. (2020). Specifically, when examining adult female Ettawa Grade (EG) goats, our study recorded measurements that trended on the lower end of the spectrum. In the study by Dakhlan et al. [2], they reported considerably higher measurements for BW, BL, CG, and SH, with values of 37.07 kg, 71.27 cm, 78.33 cm, and 73.86 cm, respectively.

However, our study's measurements align closely with the outcomes presented by Dakhlan et al. [3] concerning female Saburai goats aged 3-4 years. These particular measurements, including 32.10 kg for BW, 68.02 cm for CG, 61.16 cm BL, and 58.79 cm for SH, are consistent with our own findings. This congruence indicates a shared trend between our study and Dakhlan et al.'s [3] investigation, suggesting that our results are reliable and can be considered representative within this context.

Furthermore, a similar alignment is observed between our study's measurements and those presented by Dakhlan et al. [10], who examined female Saburai goats aged 9-12 months. Their reported measurements for BW, CG, BL, and SH were 31.77 kg, 68.30 cm, 59.48 cm, and 60.63 cm, respectively. These measurements closely mirror our own findings, reinforcing the consistency of results across studies.

While discrepancies between our study and Dakhlan et al.'s [2] findings exist, the substantial agreement with Dakhlan et al.'s [3,10] research highlights the validity of our measurements within the context of female Saburai goats. These consistent outcomes contribute to a more comprehensive understanding of the physical dimensions of these animals, particularly concerning body weight, chest girth, body length, and shoulder height.

Overall, our study's measurements deviated from Dakhlan et al.'s [2] findings for adult female Ettawa Grade goats, but closely aligned with Dakhlan et al.'s [3,10] results for female Saburai goats. This shared consistency underlines the accuracy and reliability of our measurements and contributes to the growing body of knowledge regarding the physical characteristics of these goat breeds.

Figure 2. Correlation matrix inter-variables (body weight (BW), chest girth (CG), body length (BL), shoulder height (SH), hip height (HH), and hip width (HW) of female Saburai goat)

The study conducted a Pearson's correlation analysis to assess the relationships between various body measurement variables, including BW, CG, BL, SH, HH, and HW. The results of this analysis, as depicted in Figure 2, provide valuable insights into the associations among these variables in the studied population.

The most notable finding of this study is the strong correlation observed between CG and BW. This correlation was found to be the highest among all the measured variables. In practical terms, this implies that there exists a robust positive relationship between an animal's chest girth and its body weight. Specifically, as chest girth increases, the body weight tends to increase as well. This finding is of considerable significance, as it suggests that chest girth can be utilized as a reliable predictor of an animal's body weight in the context of this study.

Remarkably, the observed correlation pattern aligns closely with the findings of several prior studies. Notably, Dakhlan et al. [2], Dakhlan et al. [3,10], Ibrahim et al. [18], Chitra et al. [19], and Shoimah et al. [11] have independently reported similar results in their research on goats, sheep, and cattle. In each of these studies, CG consistently emerged as the body measurement most strongly correlated with body weight (BW). This convergence of findings across multiple studies reinforces the robustness and reliability of this relationship.

The significance of this correlation between CG and BW cannot be overstated. It has practical implications in various fields, including animal husbandry, veterinary science, and livestock management. Farmers and breeders can use chest girth measurements as a quick and effective means to estimate the body weight of animals, which can be crucial for monitoring health, nutrition, and overall management.

Overall, the present study's correlation analysis has unveiled a strong positive association between CG and BW in the studied population, corroborating similar findings in existing literature. This reaffirms the utility of chest girth as a valuable predictor of body weight in goats, sheep, and cattle, offering practical benefits for animal management and research in these species.

3.2. Linear Regression

Table 1, showcases the results of the linear regression model used for predicting BW based on various body measurements. Upon examining Table 1, it becomes evident that when using a single body measurement as the predictor, the linear model employing CG emerges as the most effective in

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forecasting the BW of female Saburai goats. This conclusion is drawn from its superior performance in terms of the highest correlation coefficient (r), coefficient of determination (R^2), and adjusted-R^2, coupled with the lowest values for residual standard error (RSE), Akaike information criterion (AIC), and Bayesian information criterion (BIC). Following CG in terms of predictive accuracy are BL, HH, SH, and HW, in that order.

However, when considering a combination of body measurements and employing stepwise regression analysis for parameter selection, the optimal predictor for BW is determined to be a combination of CG, BL, SH, and HW. This combination yields the highest correlation coefficient (r), coefficient of determination (R^2), and adjusted-R^2, while maintaining the lowest values for RSE, AIC, and BIC. For a more streamlined model that still maintains statistical significance in its coefficient regression, the best regression model for predicting the BW of female Saburai goats is the one that combines CG and SH. The regression equation for this model is represented as Y = -65.9639 + 1.0160CG + 0.4342SH.

Table 1. Linear regression model along with parameter selection for fitting prediction for BW using body measurements

Linear regression model	r	R^2	Adj.R^2	RSE	AIC	BIC
Y= -49.9974 + 1.1903CG***	0.80	0.642	0.631	5.049	204.46	208.95
Y= -24.8560 + 0.8687BL***	0.74	0.551	0.537	5.657	211.96	216.45
Y= -11.2769 + 0.7036SH***	0.58	0.340	0.319	6.861	224.69	229.18
Y= -27.9433 + 0.9273HH***	0.71	0.501	0.485	5.964	215.44	219.93
Y= -0.0109 + 2.1129HW**	0.53	0.279	0.256	7.170	227.60	232.09
Y= -52.3840 + 0.8203CG*** + 0.4189BL*	0.83	0.709	0.689	4.634	199.72	205.70
Y= -65.9639+ 1.0160CG*** + 0.4342SH***	0.83	0.758	0.742	4.222	193.56	199.55
Y= -61.0605 + 0.8764CG ***+ 0.4944HH**	0.85	0.740	0.723	4.375	195.91	201.90
Y= -51.9843 + 1.3601CG*** -0.6147HW	0.77	0.653	0.630	5.057	205.47	211.46
Y=-34.6455 + 0.7049BL*** + 0.3217SH	0.76	0.603	0.576	5.411	209.94	215.92
Y= -38.4697 + 0.5702BL** + 0.5045HH*	0.80	0.634	0.610	5.190	207.19	213.17
Y= -26.7382 + 0.7860BL*** + 0.4598HW	0.75	0.559	0.530	5.698	213.35	219.33
Y= -29.7990 + 0.1631SH + 0.7970HH**	0.69	0.510	0.477	6.011	216.88	222.87
Y= -32.1116 + 0.5959SH*** + 1.6971HW**	0.67	0.511	0.479	5.997	216.73	222.72
Y=-42.5610 + 0.7959HH*** + 1.4306HW**	0.78	0.619	0.594	5.299	208.56	214.54
Y= -64.4518 + 0.8540CG *** + 0.2173BL + 0.3594SH**	0.85	0.772	0.749	4.165	193.54	201.02
Y= -60.0635 + 0.7354CG *** + 0.2345BL + 0.3902HH*	0.86	0.757	0.731	4.307	195.76	203.25
Y=-55.8086 + 1.0402CG*** + 0.4720BL** -0.9659HW	0.82	0.733	0.706	4.508	198.77	206.25
Y=-39.6434 + 0.5627BL** + 0.1153SH + 0.4179HH	0.78	0.639	0.601	5.248	208.81	216.29
Y=-38.3548 + 0.5680BL** + 0.3532SH* + 0.6718HW	0.78	0.620	0.580	5.384	210.49	217.97
Y=-44.3521 + 0.1594SH + 0.6687HH** + 1.4284HW**	0.74	0.627	0.588	5.332	209.86	217.34
Y=-64.9287 + 0.8074CG*** + 0.1841BL + 0.2705SH + 0.1760HH	0.85	0.778	0.747	4.183	194.68	203.66
Y= -66.1517 + 1.0195CG*** + 0.2733BL + 0.3321SH* - 0.7381HW	0.85	0.787	0.756	4.104	193.42	202.40
Y=-67.2492 + 1.0407CG*** + 0.3225SH + 0.1888HH – 0.3611HW	0.84	0.772	0.739	4.244	195.62	204.60
Y= -44.8327 + 0.3763BL + 0.1290SH + 0.4690HH + 0.8293HW	0.80	0.664	0.616	5.150	208.40	217.38
Y= -66.18273+0.97764CG***+0.25070BL+0.29241SH+0.08484HH-0.65176HW	0.85	0.788	0.749	4.168	195.24	205.71

Note: r = coefficient of correlation, R^2 = coefficient determination, Adj.R^2 = adjusted R^2, RSE = residual standard error, AIC = Akaike information criterion, BIC = Bayesian information criterion, BW = body weight, CG = chest girth, BL = body length, SH = shoulder height, HH = hip height, HW = hip width.

The findings of our current study align with the outcomes reported in prior research by Adeyinka and Mohammed [20], Dakhlan et al. [2], and Dakhlan et al. [3,10], indicating that CG serves as the most effective single body measurement for predicting the live body weight of female Nigerian Red Sokoto goats, Ettawa Grade goats, and Saburai goats, respectively.

However, our present study, which employed a more concise model combining CG and SH, diverges from the results presented by Dakhlan et al. [10], where they found that a combination of CG and BL constituted the most effective and parsimonious regression model for forecasting the BW of female Ettawa Grade goats. In our study, this combination resulted in a lower coefficient of determination (R^2) at 0.758 compared to the higher R^2 of 0.941 in their study. Similarly, our model had a lower adjusted R^2 (0.742 vs. 0.938) and a higher RSE (4.22 vs. 2.842) than their model. Nevertheless, our model did yield a lower AIC value (193.56 vs. 216.73) and BIC value (199.55 vs. 223.78) compared to theirs.

Additionally, when we compared our regression equation utilizing the combination of CG and SH to that of a study involving adult female Malabari goats which used a combination of BL, CG, and height at withers, our model achieved a higher R^2 (0.758) in contrast to the R^2 of 0.721 in their study.

3.3. Nonlinear Regression

The nonlinear regression model for predicting BW based on body measurements is detailed in Table 2. From the information presented in Table 2, it becomes evident that among the various nonlinear regression models assessed, the Quadratic regression model utilizing CG emerged as the most effective model for forecasting the BW of female Saburai goats. This conclusion is drawn from its notably high correlation coefficient (r) and coefficient of determination (R^2), coupled with the highest adjusted-R^2, and the lowest values for RSE, AIC, and BIC.

While higher-order polynomial regression models resulted in higher values for r and R^2, it's worth noting that they tended to yield lower adjusted-R^2 values and higher values for RSE, AIC, and BIC. Consequently, the Quadratic regression model stands out as the optimal choice for predicting the BW of female Saburai goats in this study.

Table 2. Nonlinear regression model along with parameter selection for fitting prediction for BW using body measurements

Nonlinear regression model	r	R^2	Adj.R^2	RSE	AIC	BIC
Y = 3.502210*exp(0.032011CG)***	0.79	0.63	0.619	5.132	205.53	210.02
Y = 5.37058*exp(0.02696BL)***	0.76	0.58	0.569	5.454	209.54	214.03
Y = 11.780666*exp(0.016451SH)**	0.54	0.29	0.271	7.104	226.99	231.48
Y = 5.367557*exp(0.027421HH)***	0.71	0.49	0.481	5.985	215.68	220.17
Y = 14.38344*exp(0.05326HW)**	0.51	0.26	0.234	7.277	228.58	233.07
Y = 34.6921 + 37.6818CG*** - 1.1361CG^2	0.802	0.643	0.619	5.128	206.40	212.39
Y = 34.6921 + 37.6818CG*** - 1.1361CG^2 - 3.6931CG^3	0.806	0.649	0.613	5.171	207.83	215.31
Y = 34.692 + 34.903BL*** + 10.566BL^2	0.776	0.602	0.575	5.417	210.02	216.00
Y = 34.6921 + 34.9032BL*** + 10.5655BL^2 - 9.1499BL^3	0.799	0.639	0.602	5.241	208.72	216.20
Y = 34.692 + 27.408SH ***- 16.385SH^2*	0.679	0.461	0.425	6.300	219.98	225.96
Y = 34.692 + 27.408SH*** - 16.385SH^2*- 9.153SH^3	0.707	0.499	0.447	6.178	219.57	227.05
Y = 34.6921 + 33.2823HH*** + 0.7108HH^2	0.708	0.501	0.468	6.061	217.43	223.41
Y = 34.6921 + 33.2823HH*** + 0.7108HH^2 - 5.0302HH^3	0.716	0.513	0.463	6.093	218.66	226.14
Y = 34.692 + 24.827HW** - 13.323HW^2	0.599	0.359	0.316	6.871	225.71	231.69
Y = 34.692 + 24.827HW** - 13.323HW^2 + 5.661HW^3	0.611	0.374	0.309	6.909	226.95	234.44

Note: r = coefficient of correlation, R^2 = coefficient determination, Adj.R^2 = adjusted R^2, RSE = residual standard error, AIC = Akaike information criterion, BIC = Bayesian information criterion, BW = body weight, CG = chest girth, BL = body length, SH = shoulder height, HH = hip height, HW = hip width.

The findings of this study resembled the outcomes reported by Macedo-Barragán et al. (2021), demonstrating that the utilization of nonlinear models (specifically, the incomplete gamma and exponential models) led to the formulation of equations that exhibited the highest level of accuracy and precision in estimating the body weight (BW) of Pelibuey ewes, with equation of BW= $0.077CG^{1.108}exp^{(0.016CG)}$ (R^2 = 0.82, mean square error (MSE) = 18.64) and BW= $3.5759exp^{(0.0292CG)}$ (R^2 = 0.82, MSE = 18.65), respectively. The R^2 values of 0.82 indicate that a substantial proportion of the variability in body weight can be explained by these equations.

3.4. Comparison between Linear and Nonlinear Regression Model

In Figure 3-7, you can observe scatter plots and regression lines depicting the application of both linear and nonlinear regression models utilizing various body measurements to predict the body weight (BW) of female Saburai goats. Based on the data presented in Figures 3-7 and Tables 1 and 2, it was determined that among these regression models, when a single body measurement (referred to as "CG") is employed as a predictor, the linear regression model was found to be the most effective in predicting the BW. Following closely in performance were the quadratic polynomial regression model using "CG" as a predictor and the exponential regression model using "CG." These models displayed the most favorable selection criteria or parameters for the task.

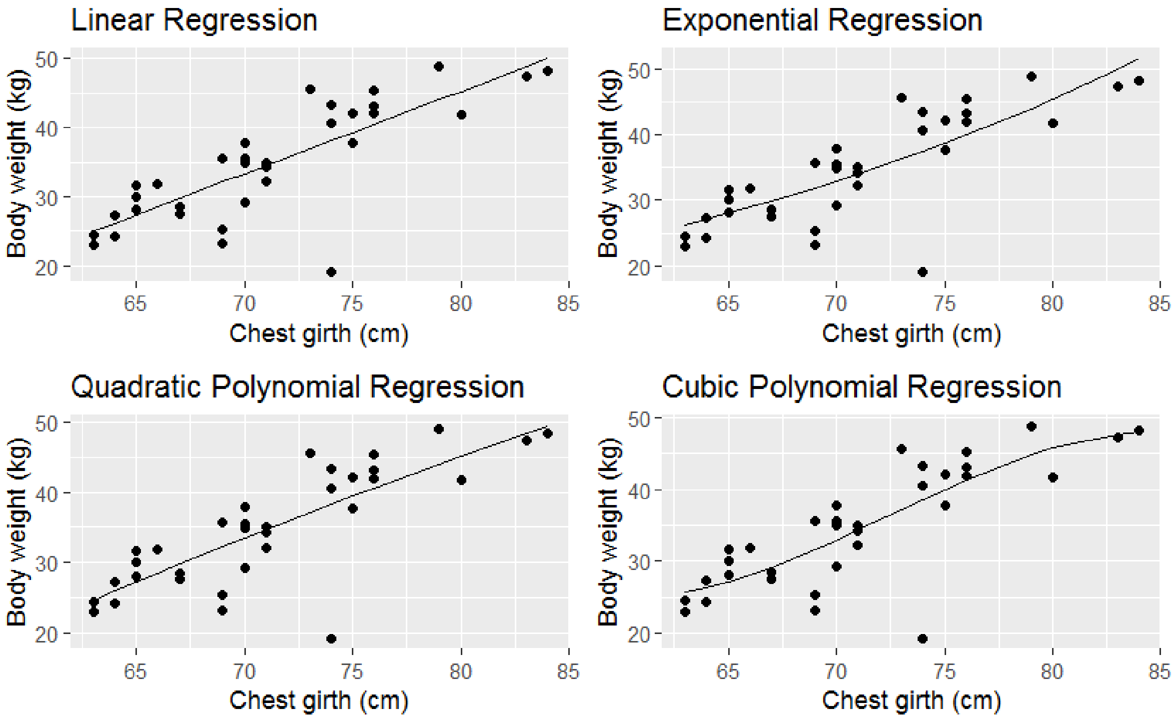

Figure 3. Scatter plot and regression line of linear and nonlinear models for prediction body weight (BW) of female Saburai goat using chest girth (CG).

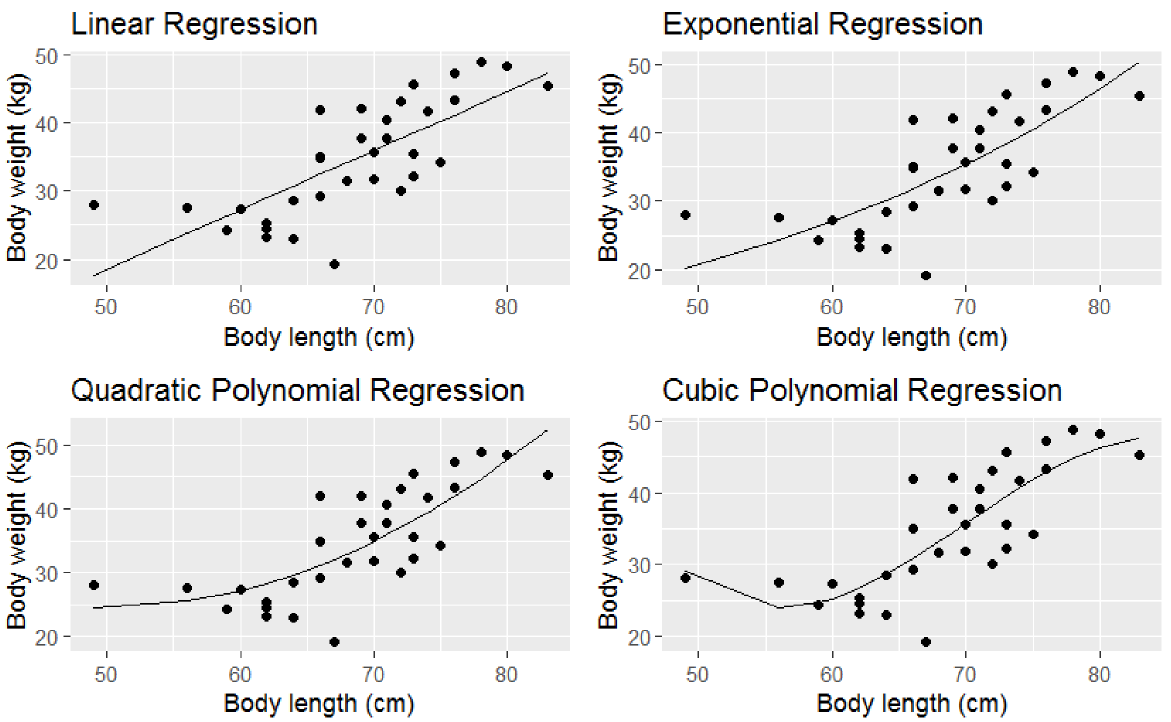

Figure 4. Scatter plot and regression line of linear and nonlinear models for prediction body weight (BW) of female Saburai goat using body length (BL).

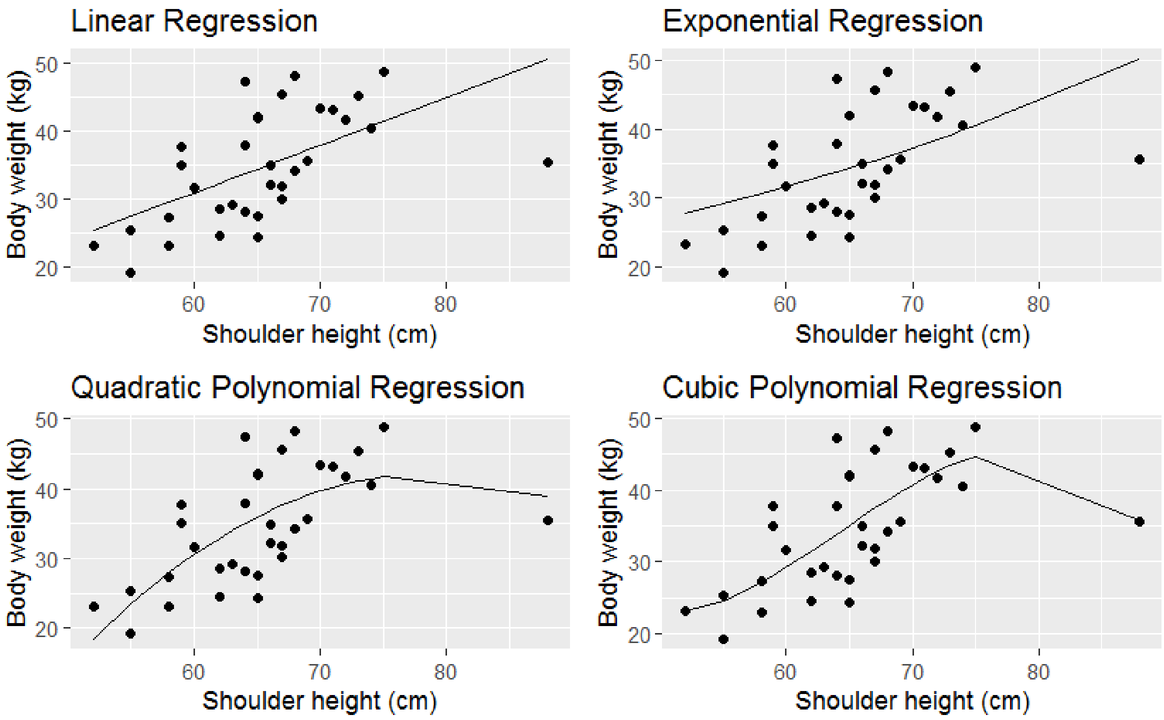

Figure 5. Scatter plot and regression line of linear and nonlinear models for prediction body weight (BW) of female Saburai goat using shoulder height (SH).

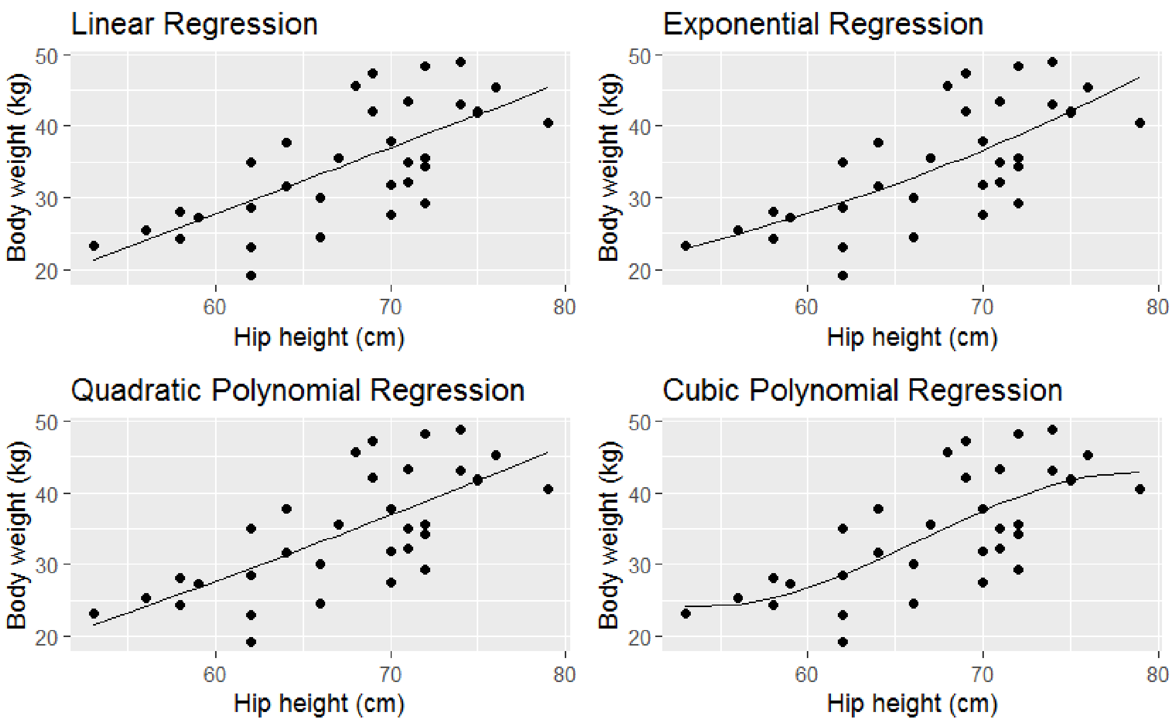

Figure 6. Scatter plot and regression line of linear and nonlinear models for prediction body weight (BW) of female Saburai goat using hip height (HH).

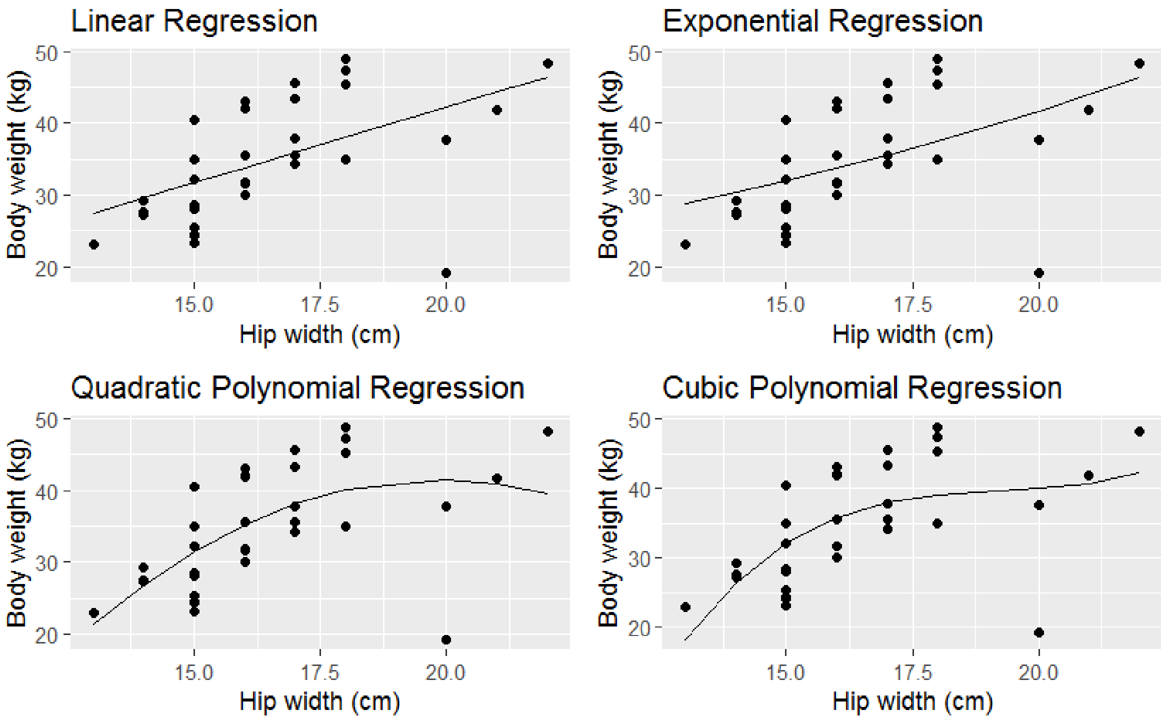

Figure 7. Scatter plot and regression line of linear and nonlinear models for prediction body weight (BW) of female Saburai goat using hip width (HW).

Furthermore, the outcomes of an ANOVA examination that contrasted the linear regression model with the quadratic polynomial regression model, both utilizing the body measurement (CG), revealed no statistically noteworthy distinction between these two models (P>0.05). This observation remained consistent even though the linear model demonstrated better adjusted R^2, residual standard error (RSE), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) values in comparison to the quadratic polynomial regression model.

4. Conclusion
Among the various linear and nonlinear regression models that utilize individual body measurements, the most effective model for predicting the body weight (BW) of female Saburai goats is the linear regression model employing the measurement of chest girth (CG). It is followed in performance by the quadratic polynomial regression model using CG and the exponential regression model using CG, based on the best selection criteria. However, when considering a combination of body measurements and utilizing stepwise regression analysis for parameter selection, the optimal predictor for BW is determined to be a combination of chest girth (CG), body length (BL), shoulder height (SH), and hip width (HW). Moreover, for a more streamlined model that still maintains statistical significance in its coefficient regression, the most suitable regression model for predicting the BW of female Saburai goats is one that combines CG and SH. The regression equation for this model can be represented as follows: Y = -65.9639 + 1.0160CG + 0.4342SH.

5. Acknowledgments
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