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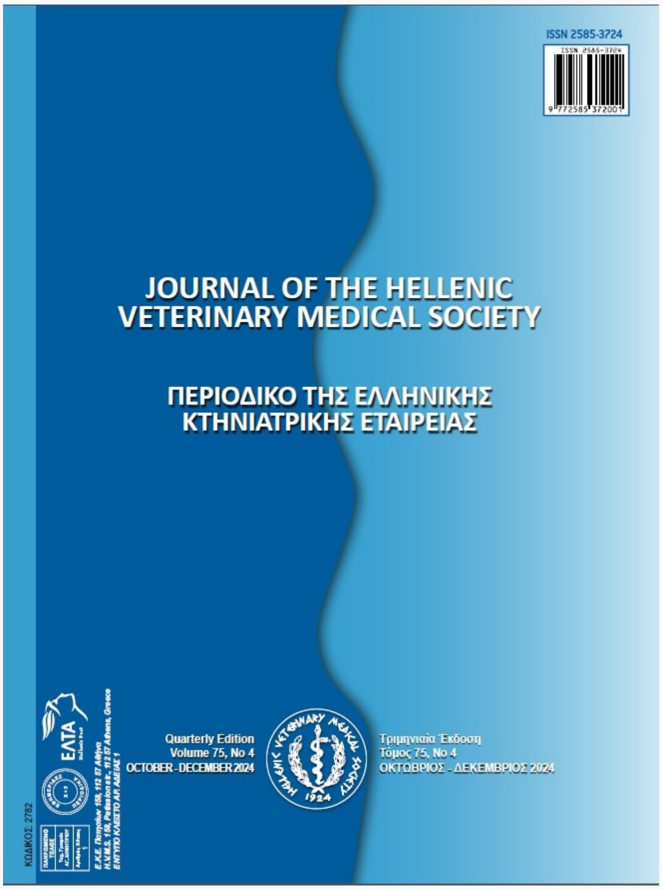


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# Comparative Analysis of Growth Function Models for Merino Crossbred Sheep in West Java, Indonesia

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**ABSTRACT**: This study aimed to compare the performance of five growth function models (Brody, von Bertalanffy, Logistic, Gompertz, and Morgan-Mercer-Flodin) in predicting the growth patterns of Merino crossbred sheep in West Java, Indonesia. This sheep are the outcome of grading-up program from a Merino ram (75%) and a Garut ewe (25%) and kept for meat production purpose. The analysis was conducted separately for male and female sheep, and the models were evaluated based on various statistical indicators. The Brody model yielded the highest coefficient of determination ($R^2$) of 0.64 for male sheep, with an associated root mean square error (RMSE) of 6.825. The Akaike's information criterion (AIC) and Bayesian information criterion (BIC) values were 16413.30 and 16429.56, respectively, indicating the goodness of fit for the model. The Durbin-Watson (DW) statistic was 1.52, suggesting the absence of autocorrelation. Among the other models, von Bertalanffy, Logistic, Gompertz, and Morgan-Mercer-Flodin also exhibited reasonably good fits, with comparable $R^2$ values and model evaluation criteria. In the case of female sheep, the growth function models showed different performance characteristics compared to males. The Logistic model produced the highest $R^2$ value of 0.63, indicating a good fit to the data. The RMSE was 5.036, and the AIC and BIC values were 10127.14 and 10143.25, respectively. The DW statistic was 0.93, indicating the absence of autocorrelation. Similar to the male sheep, the other models (Brody, von Bertalanffy, Gompertz, and Morgan-Mercer-Flodin) also demonstrated reasonable performance. These results provide valuable insights into the growth patterns of Merino crossbred sheep in West Java, Indonesia, and can assist in optimizing breeding and management strategies. The findings highlight the importance of selecting appropriate growth function models based on sex-specific characteristics to accurately predict sheep populations' growth trajectories. Further research is recommended to validate and refine these models for broader application in the sheep farming industry.

***Keywords:*** body weight; coefficient of determination; growth curve; merino crossbred sheep; non-linear regression

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## INTRODUCTION

Sheep are one of the animals that have an important place throughout human history. Sheep, which have great economic and cultural value, attract attention with their various usage areas (Sujarwanta et al., 2024). Sheep products are valuable resources offering numerous benefits to societies. Sheep's wool provides warmth and comfort in clothing, home textiles and carpets. In addition, the meat of sheep is a nutritious food source rich in protein content used in various dishes (Mohapatra and Shinde, 2018). Sheep milk is an important raw material for cheese, yoghurt and other dairy products. Moreover, skins of sheep are highly valued being used to produce various leather products in the leather industry. For these reasons, the products provided by sheep are an important resource for improving the quality of life of societies, generating economic income and sustainably using resources (Simoes et al., 2021).

Indonesia is an important country in sheep breeding and is active in this sector. Sheep farming occurs across various regions of the country and has great potential for commercial purposes while meeting the local people needs. While sheep farming contributes to Indonesia's economy and increases employment opportunities, it also plays an important role in ensuring food security and fostering sustainability within the local agricultural sector (Udo and I.G.S. Budisatria, 2011). Sheep breeds typically raised in Indonesia are domestic breeds obtained by crossbreeding various breeds or selecting those with high productivity and adaptability, such as the Merino crossbreds (Putra et al., 2023). Furthermore, sheep farming contributes to Indonesia's wool and meat production, increasing both domestic consumption and export potential for these products (Yamin and Rahayu, 2012). The sheep farming industry in Indonesia is constantly growing, evolving modern breeding methods, improved veterinary services, and leveraging technological advances. Consequently, Indonesia contributes to the local economy and also supports rural development by utilizing its sheep breeding potential.

Merino is a typical dual-purpose sheep which is kept for meat and wool production in many countries. As the meat type, Merino can produce a hot carcass of about 15.93±0.50 kg to 17.65±0.46 kg with a dressing percentage of about 47.32±0.61% to 49.61±0.27% (Karabacak et al., 2015). Recently, Merino sheep are used for the crossbreeding program to aim many composite sheep breeds with desirable wool quality (Francis et al., 2000; Li et al., 2016), meat quality (Pajor et al., 2009; Rodriguez et al., 2010), as well as improved growth traits and feed conversion (Schiller et al., 2015). In Indonesia, Merino sheep have been used for the crossbreeding program with local Thin-tailed ewes for several decades, particularly by the farmers in Central Java and are known as Batur sheep (Ibrahim et al., 2020). According to Margawati et al. (2002), a grading-up program between Merino rams and local thin-tailed Garut ewes was developed in West Java decades ago for research purposes.

However, developing Merino crossbred sheep in West Java for commercial purposes is important in increasing breeders' income. Breeders commonly choose sheep breeds that exhibit rapid growth for both breeding and fattening purposes. Growth is one of the most important traits for livestock and is defined as an increase in body size per unit of time (Balan et al., 2017). Body growth is related to an increase in cell number and volume. Age-related changes can be observed in the weight or size of organs, in the composition of tissues, in cell size and number, as well as in live weight (Tariq et al., 2013).

The growth of sheep can be evaluated by assessing the growth curve characteristics (Dominguez-Viveros et al., 2019; Iqbal et al., 2019). Growth curves explaining the relationship between weight and age in sheep are influenced by breed, management practices, environment factors, and selection procedures. These growth curve models hold great importance in animal production, offering essential information for frame strategic plans aimed at improving management practices, determining nutritional requirements, investigating optimal feeding programs, determining the ideal slaughtering age and assessing the effects of selection on curve parameters and liveweight at certain ages (Lupi et al., 2015).

Commonly, three non-linear regression functions, namely von Bertalanffy, Logistic and Gompertz have been used to obtain growth curve models for crossbred sheep in Indonesia (Suparyanto et al., 2001; Inounu et al., 2007). This study aimed to determine the suitable growth curve model for Merino crossbred sheep (75% Merino; 25% Garut) based on five non-linear regression functions (Brody, von Bertalanffy, Logistic, Gompertz, Morgan-Mercer-Flodin). Hence, understanding the growth curve parameters is important for developing appropriate management system and selection program for Merino crossbred sheep in the future.

## MATERIALS AND METHODS

### Experimental Area and Management of Animals

A total of 4342 data records on body weight (BW) in Merino crossbred sheep belonging to 2,241 records of rams and 2,101 records of ewes were used in the present study. These Merino crossbred sheep were the outcome of a grading-up program involving a Merino ram (75%) and a thin-tailed Garut ewe (25%). The sheep were generally managed in colony stalls with a mating system. The sheep were raised at the Cimanglid Research Park (birth to weaning period) and subsequently transferred to the Research Center for Biotechnology (LIPI) in West Java, Indonesia.

The feed ration for the sheep primarily consisted of Elephant grass (Pennisetum purpureum) supplemented with commercial concentrate containing 14% crude protein, 4% fat, 7% crude fiber, 8% ash, 12% digested protein and 12% total digestible nutrient (TDN). Water was given ad libitum, and health examinations were conducted every month. The BW of animal was recorded using a hanging weight scale. Initially, weighing was performed at birth and weaning age (about 5 months of age). Subsequently, regular weighing time was performed every two weeks after weaning period until reaching adult age (about 12 months of age).

### Statistical Analysis

Five non-linear regression models, such as Brody, von Bertalanffy, Logistic, Gompertz, and Morgan-Mercer-Flodin were used to obtain the growth curve of sheep by using R software (R Core Team 2022). For performing the aforementioned growth curve models, the “minpack.lm” package was used in the present study (Elzhov et al., 2023). In addition, to visualize growth models, the “ggplot2” package was used (Wickham, 2016). The non-linear equations for Brody, von Bertalanffy, Logistic, Gompertz, and Morgan-Mercer-Flodin functions were presented in Table 1 to define the growth patterns of animals (Gompertz 1825; Von Bertalanffy 1957; Tariq et al. 2013; Hossein Zadeh and Golshani 2016).

For comparing the all-nonlinear functions, various goodness-of-fit criteria were used. In this context, coefficient of determination ($R^2$), the root of mean square error (RMSE), Akaike’s information criterion (AIC), Bayesian information criterion (BIC) and Durbin-Watson (DW) statistics were used. In addition, Shapiro-Wilk’s normality test was used for testing the normality of errors for each nonlinear model.

## RESULTS

The descriptive statistics of the data for each sex were shown in Table 2. According to Table 2, these data show the weight changes of male and female ewes’ from birth to maturity. In this context, the mean weight changes were found to be statistically significant ($p < 0.05$). First, the mean weight of male ewes at birth is significantly higher than that of female ewes (3.19 kg vs. 2.97 kg). Subsequently, over the following months, a continuous increase in weight is observed in both sexes.

While the average weight of male sheep is 8.65 kg in the first month, the average weight of female sheep is 7.87 kg. This difference indicates that male sheep tend to exhibit faster compared to females. Likewise, in the second month, the average weight of male sheep increases to 14.15 kg, whereas the weight of female sheep is 12.41 kg on average. The difference in weight between male and female sheep gradually decreases in the following months. For instance, at 3 months, male sheep have an average weight of 18.44

**Table 1.** The growth curve function of Brody, von Bertalanffy, Logistic, Gompertz, Morgan-Mercer-Flodin

| Functions | $W_t$ |
|---|---|
| Brody | $W_t = A\left(1 - Be^{-kt}\right)$ |
| von Bertalanffy | $W_t = A\left(1 - Be^{-kt}\right)^3$ |
| Logistic | $W_t = \frac{A}{1 + Be^{-kt}}$ |
| Gompertz | $W_t = Ae^{-Be^{-kt}}$ |
| Morgan-Mercer-Flodin | $W_t = A - \frac{A - B}{1 + (kt)^{\delta}}$ |

$W_t$= body weight of sheep (kg) at t month of age; A= asymptotic weight which considered as mature weight; B= an integration constant related to initial animal weight; e= constanta (2.72); k= maturation rate;t= time (month) kg, while the average weight of female sheep is 16.05 kg. By the 4th month, this difference was further reduced, with male sheep averaging 21.41 kg, and female sheep averaging18.40 kg. From the first month onwards, male and female ewes gradually approach equality, although weight gain continues in both sexes. For example, in the 5th month, the average weight of male sheep is 23.11 kg, while the average weight of female sheep is 20.52 kg.

Furthermore, these data show that male sheep exhibit faster growth traits compared to females during the period from birth to maturity. However, it is noteworthy that the weight difference between the sexes gradually decreases over the following months. These findings provide valuable insights for understanding growth trends, adjusting feeding programs and optimizing breeding strategies in sheep breeding.

In general, the body weight in males was higher than females because of sex-dimorphism effect. The asymptotic weight (A) value of Merino crossbred was 33.34/31.44/32.61 kg for males and 29.38/27.68/28.73 kg for females as shown in Table 3 and Figure 1. The table presents the parameters and statistical measures of various growth patterns for male and female sheep. First, when the $R^2$ values of the models are examined, we observes that each model provides a measure of how much of the data it explains. The closer the $R^2$ value is to 1, the better the model fits the data. Notably, there is no significant difference between the $R^2$ values presented in the table. Therefore, $R^2$ values alone are not a sufficient criterion for model selection.

The AIC and BIC values serve as indicators of how well the different models fit the data, while also providing a balance to avoid overfitting. Lower AIC and BIC values present better model fit and more reliable predictions. For AIC and BIC values presented in the table, it is observed that the von Bertalanffy model has the lowest values for both male and female sheep.

**Table 2.** Means (±SD) of body weight (kg) of Merino crossbred sheep from birth to 11 months of age

| Age (months) | N | Male | N | Female |
|---|---|---|---|---|
| Birth | 139 | 3.19±0.07 | 132 | 2.97±0.06 |
| 1 | | 8.65±0.22 | | 7.87±0.21 |
| 2 | | 14.15±0.35 | | 12.41±0.33 |
| 3 | | 18.44±0.44 | | 16.05±0.41 |
| 4 | | 21.41±0.91 | | 18.40±0.43 |
| 5 | | 23.11±0.57 | | 20.52±0.45 |
| 6 | | 26.09±0.60 | | 22.45±0.47 |
| 7 | | 27.87±0.66 | | 24.46±0.50 |
| 8 | | 30.38±0.67 | | 26.51±0.54 |
| 9 | | 30.4±0.63 | | 26.08±0.49 |
| 10 | | 32.11±0.64 | | 28.05±0.52 |
| 11 | | 33.06±0.68 | | 28.94±0.56 |

**Table 3.** The growth parameters of body weight in Merino crossbred sheep

| Sex | Function | A | B | k | $R^2$ | RMSE | AIC | BIC | DW |
|---|---|---|---|---|---|---|---|---|---|
| Male | Brody | 35.62±1.01 | 0.24±0.02 | 1.43±0.12 | 0.64 | 6.825 | 16413.30 | 16429.56 | 1.52 |
| | von Bertalanffy | 37.15±1.01 | 0.19±0.01 | 0.53±0.09 | 0.65 | 6.818 | 11145.41 | 11167.09 | 1.52 |
| | Logistic | 32.20±0.41 | 3.83±0.09 | 1.90±0.08 | 0.63 | 6.921 | 11195.16 | 11216.84 | 1.52 |
| | Gompertz | 33.36±0.54 | 1.03±0.05 | 0.36±0.02 | 0.64 | 6.859 | 16429.90 | 16446.17 | 1.52 |
| | Morgan-Mercer-Flodin | 34.91±1.07 | 0.13±0.01 | 1.24±0.06 | 0.65 | 6.829 | 11150.79 | 11172.47 | 1.52 |
| Female | Brody | 31.36±0.83 | 0.23±0.02 | 1.35±0.09 | 71.37 | 5.036 | 10127.14 | 10143.25 | 0.93 |
| | von Bertalanffy | 32.52±0.79 | 0.19±0.01 | 0.47±0.08 | 71.44 | 5.029 | 9620.674 | 9641.67 | 0.93 |
| | Logistic | 28.14±0.32 | 3.83±0.08 | 1.95±0.08 | 70.29 | 5.129 | 9682.624 | 9704.095 | 0.97 |
| | Gompertz | 29.18±0.42 | 0.99±0.04 | 0.35±0.02 | 70.97 | 5.070 | 10148.895 | 10164.998 | 0.95 |
| | Morgan-Mercer-Flodin | 30.78±0.89 | 0.13±0.01 | 1.21±0.05 | 71.33 | 5.038 | 9626.305 | 9647.776 | 0.94 |

A: asymptotic weight which considered as mature weight (kg); B: an integration constant related to initial animal weight; k: maturation rate; $R^2$: coefficient of determination; RMSE: root of mean square error; AIC: Akaike's information criterion; BIC: Bayesian information criterion, DW: Durbin-Watson statistic

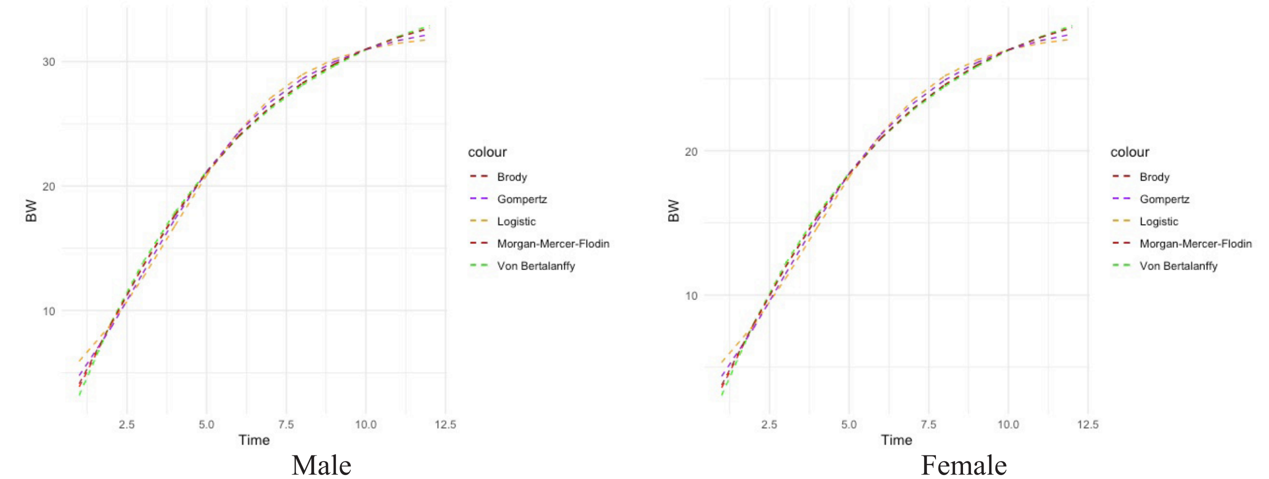


**Figure 1.** Visualization of the growth models

Therefore, the Brody model can be considered more reliable compared to other models based on these criteria. The analysis results show that the von Bertalanffy model is the most effective in explaining the growth trends of both male and female sheep and provides more reliable predictions. The performance of other models is similar, but the von Bertalanffy model may be preferred as it has lower RMSE, AIC and BIC values.

## DISCUSSION

In animal science, estimating growth with the growth curve model is very valuable for biological evaluation, research and understanding growth relationships (Ramos et al., 2013; Ibtisham et al., 2017). In this study, it was determined to choose the von Bertalanffy non-linear model was selected due to its, greatest results between the applied non-linear growth functions.

Upon examining the model parameters, it reports that the von Bertalanffy model exhibits highest values for parameter A in both genders. In all models used, parameter A, representing asymptotic adult weight, varied between 32.20 kg and 37.15 kg between estimation models. When comparing the A parameter estimates of various models, contrary to trends reported in previous studies on the subject, the Von Bertalanffy model emerged as the more appropriate choice (Keskin et al., 2009; Malhado et al., 2009; Kopuzlu et al., 2014; Hossein-Zadeh, 2015; Moreira et al., 2016; Sieklicki et al., 2016; Van der Merwe et al., 2019). The von Bertalanffy model tends to predict the highest A parameter values, followed by the Brody, Morgan-Mercer-Flodin, Gompertz and Logistic models, respectively. Specifically, in male Merino crossbred sheep, the A value for Brody, Logistic and Gompertz models was closely align with those reported for mixed-sex St. Croix (31.46/31.09/31.28 kg), mixed-sex Dorper cross (31.51/29.35/30.56 kg) and male Harnali (32.66/30.30/31.73 kg) sheep (Suparyanto et al., 2001; Malhado et al., 2009; Bangar et al., 2021). Meanwhile, in female Merino crossbred sheep, the A value for Brody, Logistic and Gompertz models were higher than those of local mixed-sex Sumatra (22.26/22.08/22.15kg), female Guilan (23.20/21.04/22.38 kg), female Mecheri (17.92/16.76/17.45 kg), female Sonadi (21.07/20.05/20.70 kg) and female Harnali (21.78/20.94/21.50 kg) sheep (Suparyanto et al., 2001; Hossein-Zadeh and Golshani, 2016; Balan et al., 2017; Gautam et al., 2018; Bangar et al., 2021). Species, sex and breed differences may cause these differences in results. However, in general, the A parameter value in sheep can be influenced by genetics, feed nutrition and environmental factors. Interestingly, previous studies have reported an $R^2$ value of 0.70 in Ongole cattle with Gompertz, Logistic, and von Bertalanffy models, which are closely reported to the present study (Maharani et al., 2017; Hartati and Putra, 2021). Despite this, Mohammadi et al. (2019) obtains the $R^2$ value about 0.72 in the growth curve of Gompertz model in male Kordi sheep which are closely to female sheep under study in the all models. Generally, the growth curve in livestock can be affected by factors such as management system, sex and breed type. Tariq et al., (2013) was performed a study using Gompertz, Logistic, von Bertalanffy, Richards, Weibull, Morgan-Mercer-Flodin growth curve models in the Mengali sheep breed. According to thats results, MMF model was the most suitable growth function for defining the growth of Mengali sheep. In addition, all results were close each other. However, the von Bertalanffy was emerged as the second-best fit model for defining the growth of Mengali sheep. According to this result, these differences are thought to be caused by sex, breed and management system differences.

## CONCLUSION

In conclusion, this study evaluated different growth patterns for male and female sheep comparing their parameters and statistical criteria. According to the presented data in the table, it is evident that the von Bertalanffy model explains suitable the growth trend of both male and female ewes and provides more reliable predictions. The von Bertalanffy model exhibits lower AIC and BIC values compared to the other models, making it a preferable option.

The performance of the other models is similar, but the Brody model is more reliable because it provides a better fit and lower prediction error, as indicated by RMSE. These findings suggest using the von Bertalanffy model to assess growth potential in the sheep farming industry, optimize nutrition and management strategies, as well as guiding genetic selection programs.

This study also highlights the importance role of growth models in sheep breeding. By providing more accurate and reliable growth forecasts, these models allow breeders to make better decisions, offering significant advantages in productivity, nutrition and genetic selection. The von Bertalanffy model stands out as the most reliable model that can be used for growth analysis in the sheep breeding industry.

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Statement declaring that there is no conflict of interest with any party related to the materials discussed in the paper.

## CONFLICT OF INTEREST

The authors of this manuscript declare that there is no conflict of interest for this research work.

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