p-ISSN 2615-787X e-ISSN 2615-790X
Accredited by Directorate General of Higher Education, Research, and Technology, Republic of Indonesia, No. 225/E/KPT/2022

Tropical Animal Science Journal, June 2024, 47(2):155-160
DOI: https://doi.org/10.5398/tasj.2024.47.2.155
Available online at https://journal.ipb.ac.id/index.php/tasj

Analysis of Growth Curve with Non-Linear Models of Gompertz and Logistics Model in Female Katjang X Boer Goats in Malaysia

R. M. Hifzan[a,b], K. Mamat Hamidi[a,d,*], M. T. Nur Aida[a], & M. S. Salisi[c]
[a]Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia
[b]Animal Science Research Centre, Malaysian Agricultural Research and Development Institute (MARDI), Ministry of Agriculture and Food Security, Persiaran MARDI-UPM, Serdang 43400, Selangor, Malaysia
[c]Department of Veterinary Preclinical Sciences, Faculty of Veterinary Medicine, Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia
[d]Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia
*Corresponding author: mamath@upm.edu.my
(Received 16-11-2023; Revised 29-01-2024; Accepted 05-02-2024)

ABSTRACT

This study aimed to predict the mature size specifically for body weight, body length, height at withers, and chest circumference in Katjang X Boer crossbred goats. The parameters of the growth curve, mature size (A), mature rate (k), and constant of integration (B) were estimated using Gompertz and Logistic non-linear growth models. A total of 228 heads of female Katjang X Boer goats were raised semi-intensively- weighed and measured monthly from birth to 54 months old. The coefficient of determination (R^2) was used to find the ideal growth model to estimate growth curve parameters. Gompertz's model demonstrated higher R2 values for body weight and height at withers (0.91, 0.99, respectively) than the logistic model (0.90, 0.97), while body length was comparable at 0.98. The Logistic model R^2 for chest circumference was greater than the Gompertz model (0.98 vs. 0.96). Gompertz model estimated mature size (A) for body weight, height at withers, body length, and chest circumference were 37.68±1.63 kg, 60.40±0.57 cm, 53.83±0.73, and 70.62±0.89 cm, respectively while Logistic model estimated 36.27±1.42 kg, 60.05±0.54 cm, 53.65±0.71 cm, and 70.20±0.85 cm respectively. Parameters A and k had negative correlations from -0.439 to -0.530 (Gompertz) and -0.259 to -0.474 (Logistic), showing that animals with larger mature sizes tend to grow slower. The highest correlation coefficient between body sizes is body weight-chest circumference (0.961). Thus, the Gompertz model predicts body weight and height at withers better than the Logistic model, which is fitted for chest circumference. Both models are ideal for estimating body length.

Keywords: body measurement; female Katjang X Boer goats; growth model; mature size

INTRODUCTION

Most native livestock breeds in third-world countries like Katjang goats are raised for meat (Khandoker *et al.,* 2021). In addition, goat milk can also be sold as a source of income or for personal consumption (Zainalabidin & Mustafa, 2023). The only indigenous goat breed in Malaysia is the Katjang goat (*Capra aegagrus hircus*) (Khandoker *et al.,* 2016). According to Ernie *et al*. (2021), other names for Katjang goats are Katchang, Licin, Kacang (pea), and also Kampung (village) goats. Although dark brown colors have also been observed in this species of goats, Katjang goats are predominantly black. It was also mentioned that Katjang goats also have a black stripe from shoulder to rump (Hifzan, 2018b). White patches might appear on the body and/or legs.

Anothaisinthawee *et al*. (2010) indicate a correlation between Katjang goats and indigenous goat breeds present in Indonesia, Thailand, the Philippines, Taiwan, India, South China, and Southwest Japan Island. The average body weight of males is around 25 kg, while females typically weigh around 20 kg (Hifzan *et al.,* 2018b). On average, individuals experience a daily weight increase of approximately 55 g daily. The range of birth weights for goats is from 1.0 to 2.0 kg, while mature weights for males and females are 18 to 27 kg and 25 to 32 kg, respectively. Despite their small size, these breeds are well-known for their remarkable ability to acclimatize to hot and humid tropical climates (Rosali *et al.,* 2019). One additional benefit of Katjang goats is their ability to thrive in harsh and low-input conditions (Pauzi *et al.,* 2019).

Katjang and their crossbreds make up the majority of the goat population in Malaysia (Zayadi, 2021). To increase the productivity of the only indigenous goat breed in Malaysia- the Katjang goats, numerous goat breeds have been introduced into the country by commercial farms and the government. Boer goats originated from South Africa, brought into Malaysia

Copyright © 2024 by Authors, published by Tropical Animal Science Journal.
This is an open-access article distributed under the CC BY-SA 4.0 License (https://creativecommons.org/licenses/by/4.0/).

for their reputation of robustness, high fertility, fast growth rate, and optimal meat production (Yusof *et al.*, 2022). Mature Boer buck weight ranges from 70 to 90 kg, while mature does range from 60 to 80 kg. The average fertility rate is high- around 130% to 150%. Boer goats are also known for their excellent meat production, which can reach 50% of the dressing percentage (Ab Jalal *et al.*, 2021).

The implementation of crossbreeding programs has been widely utilized across Southeast Asia countries to enhance the efficiency of indigenous breeds. This practice leads to the development of crossbred genotypes that possess diverse gene proportions derived from the initial foundation breeds (Khandoker, 2021). Based on Malan (2000), the utilization of Boer goats in crossbreeding initiatives has been employed to enhance the size dimensions, carcass, meat quality, and also productivity of indigenous goat populations, hence contributing to the potential to address food scarcity in developing nations. Meanwhile, Hafiz *et al*. (2021) stated a systematic crossbreeding program was undertaken, including mating Katjang bucks with Boer does, to determine the prospective merits of these emerging synthetic breeds. Hifzan *et al*. (2018[b]) claimed that by adding a better Boer goat gene, the heterotic impact on the meat quality as well as the growth rate of Katjang goats, would be enhanced.

Growth is described as an increase in new cells with an increase in fat and protein content influenced by feed, environment, and genetic factors. Growth is a critical factor in determining the livestock sector's success and excellent reproductive performance. The best age for breeding programs for meat production depends on several factors, including the growth rate of the chosen livestock breeds. The growth rate is important in breed selection to identify the ideal age and sizes for breeding programs. The study of the growth curve was also important in developing a strategic feeding regime to obtain the ideal weight at a minimum cost (Ariff *et al.*, 2010).

The growth, controlled by genetic and environmental factors, has been mathematically described by the Brody, Gompertz, Logistic, Richard's, von Bertalanffy, and Qubic growth models, each characterized as a non-linear regression function. Non-linear growth models are commonly used to characterize correlations between animal lifetime weight and age, allowing them to identify management issues and optimal slaughtering ages (Gautam *et al.*, 2018). The growth curve varies depending on the model and breed. In most cases, the researcher fits data collected into these mathematical models and examines the models for the different breeds such as cattle (Hafiz *et al.*, 2014), sheep (Simasiku *et al.*, 2019; Weber *et al.*, 2021), rabbit (Setiaji *et al.*, 2013), goat (García-Muñiz *et al.*, 2019; Tyasi *et al.*, 2022), and chicken (Wang *et al.*, 2014).

Despite several studies on growth models for various goat breeds, there is a shortage of information on female Katjang x Boer goat growth models. The objective of this study was to study the mature size for body weight, height at withers, body length, and chest circumference by using Gompertz and Logistic growth models of female Katjang x Boer goats.

MATERIALS AND METHODS

The study involved the collection of data on body weight, body length, height at withers, and chest circumference from a total of 228 Katjang X Boer does. These goats were sourced from the Malaysia Agricultural Research and Development Institute (MARDI) in Kluang, Johor, Malaysia. A systematic breeding program between purebred Katjang bucks with purebred Boer does was established to evaluate the potential of these crossbred goats. The animals were raised according to animal ethics and welfare. This research was approved by the MARDI Animal Ethics Committee (Approval ID: 20230622/R/MAEC00127).

The data collection covered from birth until the goats reached 54 months of age. The MARDI Kluang Research Station opened in 1972, and its coordinates are 2.0333° North and 103.3167° East. The station covers an area of about 1200 hectares with infrastructures for agricultural crop and animal research. The research station is located in a year-round hot and humid environment with relative humidity of 80%-90%. The temperature varies between 26 °C to 32 °C with an average annual rainfall of 2200 mm to 2500 mm. The rainfall rose from August to December and decreased from March to June. This is due to the influence of the Northeast Monsoon season.

Semi-intensive grazing systems are used to rear the goats. The animals were allowed to graze *Panicum maximum* pasture for 5 hours, specifically from 1000 to 1500. Additionally, they were provided with supplemental concentrate consisting of 15% crude protein, 5% fat, 12% fiber, and 1% calcium. This concentrate was given to the animals at 200-300 grams per day per head. The animals were housed in slatted elevated floor-houses throughout the other hours of the day. Mineral blocks and water were made available without restriction.

Body weights were recorded using a portable digital weighing scale in kilograms (kg), while other body measurements were recorded in centimeters (cm) using standard measuring tape and a ruler. Height at the withers was measured from the platform surface to the highest point of the shoulder (Depison *et al.*, 2021). Body length was obtained by assessing the distance from the shoulder point to the posterior edge of the pin bone (Depison *et al.*, 2020). Chest circumference was determined by measuring the circumference of the chest, as seen in Figure 1. Before being released to the pasture, the animals underwent a process of weighing and measuring.

For the estimation of mature size (A), constant of integration (B), and rate of maturing (k) for body weight, body length, height at withers, and chest circumference of Katjang X Boer goats, the data were fitted to two non-linear models, Gompertz and Logistic. These models were selected because of their' ease of computation and are widely used by other researchers to describe growth patterns in goat breeds (Dilliwar *et al.*, 2016; Cak *et al.*, 2017; Sunwasiya *et al.*, 2020). The PROC NLIN module from SAS version 9.4 (SAS, 2005) has been used to estimate the growth parameters of the

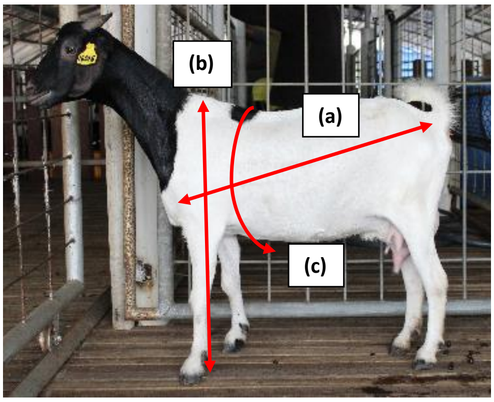

Figure 1. The body measurement of body length (a), height at withers (b), and chest circumference (c) of Katjang x Boer does.

non-linear growth model presented below:

Gompertz model: $Wt=Ae^{-Be^{-kt}}$

Logistic model: $Wt = A / (1+B * \exp(-k*t))$

where k is the growth rate from birth to maturity, W is the size measured at age t in months, A is the asymptote for the size measured (body weight, body length, height at the withers, and chest circumference), and B is the constant of integration (Ariff *et al.*, 2010). The greatest coefficient of determination (R^2) was defined as the best model for each body measurement (Domínguez-Viveros *et al.*, 2019). A linear regression analysis was used to calculate the coefficient of determination between observed and expected body sizes, with expected body sizes as the dependent variable and measured body sizes as the independent variable.

RESULTS

Table 1 presents the estimated growth parameters (A, B, and k) obtained from the Gompertz and Logistic models, as well as the coefficient of determination (R^2), for several physical attributes - body weight, height at withers, body length, and chest circumference of the Katjang X Boer does. The R^2 values for the Gompertz vs Logistic model for body weight, height at withers, body length, and chest circumference were 0.91, 0.99, 0.98, 0.96, and 0.90, 0.97, 0.98, and 0.98, respectively.

There is a significant difference in estimated mature weight derived from the Gompertz model compared to the Logistic model (37.68 vs. 35.27 kg). The Gompertz growth model estimates a 2.41 kg or 6.39% higher body weight at maturity compared to the Logistic model. There are no significant differences between Gompertz and Logistic models for height at withers, body length, and chest circumference of Katjang x Boer does. The estimated height at withers, body length, and chest circumference derived from the Gompertz and Logistic model for Katjang x Boer does were 60.40 cm, 53.83 cm, and 70.62 cm, respectively, and 60.05 cm, 53.65 cm, and 70.20 cm, respectively.

The animal's growth rate until it reaches asymptotic size is indicated by the maturing rate (k value). The Gompertz model's rate of maturing varied from 0.108 to 0.393, whereas the Logistic model's range was 0.159 to 0.486. The rate of maturing (k) value was lower in the Gompertz model than in the Logistic model for all parameters, which caused Gompertz to estimate a larger mature size and reach it later than the Logistic model (Figure 2). The Gompertz, Logistic models, and actual data intercept at 24 months with a body weight of 33 kg. After the interception, the growth becomes plateaued when the animals reach 30 months (Logistic model) and 36 months (Gompertz model), respectively.

The result demonstrated a negative correlation between the mature weight (A) and maturating rate (k) of Katjang X Boer does, with values of -0.439 for the Gompertz model and -0.259 for the Logistic model (Table 2). The estimated mature size and rate of maturing for height at withers, body length, and chest circumference were also discovered to have a negative correlation in both models. The correlation coefficient for height at withers, body length, and chest circumference in the Gompertz model were -0.514, -0.530, and -0.488, whereas for the Logistic model were -0.259, -0.432, -0.474, and -0.415. Referring to the negative correlation between mature size (A) and rate of maturing (k), does with lower mature sizes mature faster than animals with higher maturation rates.

Table 3 shows the correlation coefficients between body weight, height at withers, body length, and chest circumference of Katjang X Boer does. The results ranging from 0.884 to 0.961 suggests that all body measurements had a positive correlation with body

Table 1. The estimates of growth parameters (A, B, and K) and coefficient of determination (R^2) for body weight, height at withers, length of body, and chest circumference of Katjang x Boer goats derived by Gompertz and Logistic models

Size measurement	Parameter	Gompertz	Logistic
Body weight (kg)	A	37.68±1.63 [b]	35.27±1.42[a]
	B	1.857±0.084	4.285±0.372
	K	0.108±0.011	0.159±0.014
	R^2	0.91	0.9
Height at withers (cm)	A	60.40±0.57 [a]	60.05±0.54 [a]
	B	0.772±0.024	1.131±0.048
	K	0.267±0.016	0.340±0.019
	R^2	0.99	0.97
Body length (cm)	A	53.83±0.73 [a]	53.65±0.71 [a]
	B	0.809±0.042	1.206±0.088
	K	0.393±0.034	0.486±0.0402
	R^2	0.98	0.98
Chest circumference (cm)	A	70.62±0.89 [a]	70.20±0.85 [a]
	B	0.884±0.056	1.324±0.112
	K	0.281±0.027	0.353±0.033
	R^2	0.96	0.98

Note: Means in the same row with different superscripts differ significantly ($p<0.05$). A= Asymptotic measure of size (mature size), B= Constant of integration, k= Rate of maturing, R2= Co-efficient of determination.

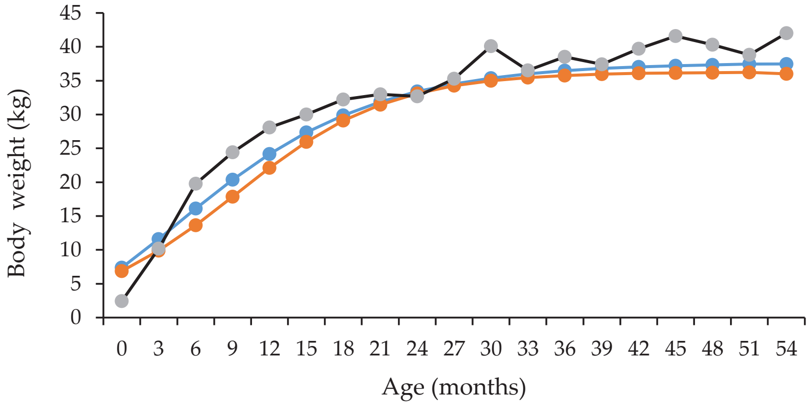

Figure 2. Body weight growth curve of Katjang x Boer does that was estimated by Gompertz and Logistic models.

Table 2. The correlation coefficients between the mature size (A) and maturing rate (k) derived from non-linear growth models (Gompertz and Logistic) for body weight, height at withers, body length, and chest circumference in Katjang x Boer does goats

Size measurements	Gompertz	Logistics
Body weight	-0.439	-0.259
Height at withers	-0.544	-0.432
Body length	-0.530	-0.474
Chest circumference	-0.488	-0.415

Table 3. Correlation coefficients between body weight, height at withers, body length, and chest circumference in Katjang x Boer does

Parameters	Body weight	Height at withers	Body length	Chest circumference
Body weight	1.000			
Height at withers	0.925	1.000		
Body length	0.85	0.884	1.000	
Chest circumference	0.961	0.944	0.905	1.000

weight, where chest circumference had the highest correlation (0.961), followed by the height at withers (0.925) and body length (0.850). This suggests that chest circumference was the most reliable predictor of body weight compared to height at withers, body length, and chest circumference when utilizing a single predictor.

DISCUSSION

The Gompertz growth model demonstrates superior goodness of fit for two factors: body weight (0.91 vs. 0.90) and height at withers (0.99 vs. 0.97). In contrast, the Logistic model has a higher R^2 value when considering chest circumference (0.98 vs. 0.96). Additionally, there is no difference in the R^2 value for the body length of Katjang x Boer does (0.98). This suggests that these two models could explain 98% of the variation in body length of Katjang x Boer does. Simasiku *et al.* (2019) and Demir & Sahinler (2021) found an almost similar value of the coefficient of determination (R^2) in the research on Damara, Dorper, and Swakara sheep breed (ranging 0.95–0.98), and Morkaram sheep (0.99). A high R^2 value (>0.90) obtained from this research indicated that the Gompertz and Logistic model can accurately predict the body size of Katjang x Boer goats from birth to 54 months.

Asymptotic mature size, A values provided the best opportunities to directly compare between various models (Hafiz *et al.*, 2019). Meanwhile, Tsukahara *et al.* (2008) reported a lower mature weight of Katjang purebred (27.0 kg-Logistic model, 28.1 kg–Gompertz model) and Katjang x German Fawn crossbred goat (31.2 kg-Logistic model, 31.8 kg- Gompertz) compared to mature weight of Katjang x Boer obtained from this research (Gompertz- 37.68 kg; Logistic- 35.27 kg). In comparison, Ariff *et al.* (2010) reported a higher body weight, height at withers, and body length derived from the Gompertz and von Bertalanffy model for Boer and Jamnapari goats.

The studies using the Gompertz model conducted by Hifzan *et al.* (2015) and Hifzan *et al.* (2018a) found that Kalahari Red goats and Dorper sheep raised semi-intensively in Malaysia expressed higher mature weight, height at withers, and body length compared to Katjang x Boer does (Kalahari Red- mature weight- 48.90 kg, height at withers- 65.30 cm, and body length- 73.70 cm; Dorper sheep- mature weight- 60.34 kg, height at withers-66.90 cm, and body length- 67.06 cm). Animals with a slow maturing rate will attain their mature sizes at a later age than those with a faster rate (Hafiz *et al.*, 2014). Due to that, Katjang x Boer goats, which are smaller in size, matured faster than Kalahari Red (Hifzan *et al.*, 2015) and Dorper (Hifzan *et al.*, 2018a) but slower than Malaysia indigenous Katjang goats (Tsukahara *et al.*, 2008) and Kacang in Indonesia (Wiradarya *et al.*, 2020). The Gompertz and Logistic models suggest that the Katjang x Boer does can achieve 60% of mature weight as early as 11 months of age and can be used in breeding programs (Figure 2). The Katjang x Boer does approximately weight 21.76 kg (Logistic model) and 22.61 kg (Gompertz model) at this age. The medium-sized Katjang-Boer goat with a mature weight of 35.27 to 37.68 kg is aligned to develop a compact-size of goat breed for fulfilling Malaysia market demand.

The growth curve depicts and describes the change in live weight over time. Information obtained from the analysis of growth curves may be applied to strategize feeding regimes and animal management to achieve faster mature weight for breeding purposes (Bhatti *et al.,* 2007). The growth curves for body weight based on the best-fit models revealed the differences in growth curves between the model and the observed data illustrated in Figure 2.

The most important biological relation in a non-linear growth model function is between mature weight and maturing rate, as mentioned by McManus *et al*. (2003). This was observed in studies conducted by Hifzan *et al*. (2015), Da Silva *et al*. (2012), Hifzan *et al*. (2018[a]), Tsukahara *et al*. (2008), Ariff *et al*. (2010), and Hafiz *et al*. (2019). They found a negative correlation between mature size and maturing rate in Santa Ines sheep, Dorper sheep, Katjang and its crosses, Boer and Jamnapari goats, and Kedah-Kelantan (KK) cattle. This negative correlation illustrates that animals with a faster-maturing rate had a lower mature size and attained faster mature size.

The result on correlation coefficients between body size obtained from this research is similar to the study conducted by Esen & Elmaci (2021) on three Turkiye meat-type sheep breeds, namely Bandirma, Karacabey, and Ramlic that reported a higher correlation between body weight and chest circumference- ranging from 0.802 to 0.892. However, Dakhlan *et al*. (2021) and Hifzan *et al*. (2015) found a greater relationship between body weight with height at withers in Boer X Ettawa breed called Saburai goats in Indonesia (0.967) and Kalahari Red goats (0.96). The findings from this study revealed that chest circumference and height at withers can be employed as body weight predictors and indicators for selection to increase genetic merit in Katjang x Boer breed does body weight. This variation may be brought about by variations in goat breeds, management practices, environmental factors, and herd-feeding practices (Dakhlan *et al.,* 2020). Goat body weight and measures are significantly influenced by the environment, causing a wide range of body dimensions, even within the same breed (Saleh *et al.,* 2022).

CONCLUSION

In conclusion, the Gompertz model exhibits superior fit for body weight and height at withers, while the Logistic model excels in chest circumference prediction. Body length shows comparable R^2 values (0.98) in both models. Parameters from the Gompertz model consistently have higher body measurements than the Logistic model. Slower growth rates correlate with larger mature sizes, as evidenced by the negative relationship between parameters A and k. Katjang-Boer does surpass native Katjang goats in mature weight but lower than the foundation breeding stock of Boer goats. Non-linear regression effectively condenses the weight-age relationship into biologically meaningful parameters. The strong correlation between body weight and chest circumference suggests its potential as a predictive tool for body weight in Katjang x Boer does.

CONFLICT OF INTEREST

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

REFERENCES

Ab Jalal, I. B., M. H. Rosali, & M. H. A. Wahab. 2021. Pencirian karkas kambing Katjang, Boer dan kacukan Katjang-Boer (BK). Buletin Teknologi MARDI 23:45-53.

Anothaisinthawee, S., K. Nomura, T. Oishi, & T. Amano. 2010. Goat genetic resources and breeding strategies in Thailand. J. Anim. Genet. 38:41-48. https://doi.org/10.5924/abgri.38.41

Ariff, O. M., R. M. Hifzan, A. B. M. Zuki, A. J. Jiken, & S. M. Lehan. 2010. Maturing pattern for body weight, body length and height at withers of Jamnapari and Boer goats. Pertanika J. Trop. Agric. Sci. 33:269-276.

Bhatti, S. A., M. Sarwar, M. S. Khan, & S. M. I. Hussain. 2007. Reducing the age at First calving through nutritional manipulations in dairy buffaloes and cows: A review. Pakistan Vet. J. 27:42-47.

Cak, B., O. Yilmaz, S. Keskin, T. Bayril, & M. M. Tariq. 2017. Determination of appropriate growth models for early selection possibilities in goats. Pak. J. Zool. 49:543-547. https://doi.org/10.17582/journal.pjz/2017.49.2.505.509

Dakhlan, A., M. D. I. Hamdani, D. R. Putri, S. Sulastri, & A. Qisthon. 2021. Prediction of body weight based on body measurements in female Saburai goat. Biodiversitas 22:1391-1396. https://doi.org/10.13057/biodiv/d220341

Dakhlan, A., M. Hamdani, & S. Sulastri. 2020. Regression models and correlation analysis for predicting body weight of female Ettawa Grade goat using its body measurements. Adv. Anim. Vet. Sci. 8:1142-1146. https://doi.org/10.17582/journal.aavs/2020/8.11.1142.1146

Demir, Y. & Z. Sahinler. 2021. Comparison of growth curves using non-linear models in morkaraman male lambs subjected to different feeding regimes. J. Anim. Plant. Sci. 31:665-670.

Depison, D., W. P. Putra, G. Gushairiyanto, Y. Alwi, & H. Suryani. 2020. Morphometric characterization of Kacang goats raised in lowland and highland areas of Jambi Province, Indonesia. J. Adv. Vet. Anim. Res. 7:734-743. https://doi.org/10.5455/javar.2020.g475

Depison, D., W. P. Putra, G. Gushairiyanto, Y. Alwi, & H. Suryani. 2021. Morphometrics characterization of Thin-Tail sheep in lowland and highland areas. Trop. Anim. Sci. J. 44:386-398. https://doi.org/10.5398/tasj.2021.44.4.386

Dilliwar, L., M. R. Verma, Y. P. Singh, V. B. Sharma, S. Kumar, & A. Shukla. 2016. Nonlinear modelling of sheep and goat populations in India. Journal Applied Natural Science 8:1766-1769. https://doi.org/10.31018/jans.v8i4.1037

Domínguez-Viveros, J., E. Canul-Santos, F. A. Rodríguez-Almeida, M. E. Burrola-Barraza, J. Á. Ortega-Gutiérrez, & F. Castillo-Rangel. 2019. Defining growth curves with nonlinear models in seven sheep breeds in Mexico. Rev. Mex. Cienc. Pecu. 10:664-675. https://doi.org/10.22319/rmcp.v10i3.4804

Ernie Muneerah, M. A., N. A. Md Tamrin, M. S. Salisi, S. Zulkifly, M. S. S. Shaidatul, J. J. Temuli, M. H. Rosali, S. Nazari, W. M. K. Wan Nik, & K. Mamat-Hamidi. 2021. Microsatellite-based genetic characterization of the indigenous Katjang goat in peninsular Malaysia. Animals 11:1328. https://doi.org/10.3390/ani11051328

Esen, V. K. & C. Elmaci. 2021. The estimation of live weight from body measurements in different meat-type lambs. J. Agric. Sci. 27:469-475. https://doi.org/10.15832/ankutbd.719037

García-Muñiz, J. G., R. Ramírez-Valverde, R. Núñez-Domínguez, & J. A. Hidalgo-Moreno. 2019. Dataset on growth curves of Boer goats fitted by ten non-linear functions. Data in Brief 23:103672. https://doi.org/10.1016/j.dib.2019.01.020

Gautam, L., V. Kumar, H. A. Waiz, & R. K. Nagda. 2018. Estimation of growth curve parameters using non-linear growth curve models in Sonadi sheep. International Journal Livestock Research 8:104-113. https://doi.org/10.5455/ijlr.20180131044656

Hafiz, A. W. M., I. Idris, & H. Yaakub. 2014. Growth pattern for body weight, hip height and body length of Brakmas cattle. Pak. J. Biol. Sci. 17:952-955. https://doi.org/10.3923/pjbs.2014.952.955

Hafiz, A. W. M., A. M. Marini, S. M. Rosly, R. M. Hifzan, A. J. Izuan Bahtiar, & S. Shanmugavelu. 2019. Describing growth pattern of selected Kedah-Kelantan cows using non-linear regression models. Malaysian Journal Animal Science 22:47-54.

Hafiz, A. W. M., R. M. Hifzan, A. J. Izuan Bahtiar, & M. O. Nurulhuda. 2021. Evaluation of principal component analysis in animal breeding and selection in the breed improvement program of male Katjang-Boer crossbred. Malaysian Journal Animal Science 24:33-38.

Hifzan, R. M., I. Idris, & H. Yaakub. 2015. Growth pattern for body weight, height at withers and body length of kalahari red goats. Pak. J. Biol. Sci. 18:200-203. https://doi.org/10.3923/pjbs.2015.200.203

Hifzan, R. M., A. W. M. Hafiz, A. J. Izuan Bahtiar, J. M. Nasir, B. Taufikurahman, I. Fadzlirahimi, I. Noraini, A. M. N. Nor Amna, & S. Nooraisyah. 2018a. Non-linear growth pattern for body weight, height at withers and body length of Dorper sheep. Malaysian Journal Animal Science 21:11-17.

Hifzan, R. M., A. M. N. Nor Amna, A. J. Izuan Bahtiar, A. B. Amie Marini, & A.W. M. Hafiz. 2018b. Manipulating of Katjang goat genetic material for sustainable goat industry in Malaysia. FFTC Agricultural Policy Platform (FFTC-AP) 1-9. Available online: https://ap.fftc.org.tw/article/1364

Khandoker, M. A. M. Y., M. Syafiee, & M. S. R. Rahman. 2016. Morphometric characterization of Katjang goat of Malaysia. Bangladesh Journal Animal Science 45:17-24. https://doi.org/10.3329/bjas.v45i3.31035

Khandoker, M., T. Akter, & L. Lan. 2021. Preferences on Breeding Practices and Breeds of Cattle and Goat in Sandakan, Sabah, Malaysia. Journal of Bangladesh Agricultural University 19:340-347. https://doi.org/10.5455/JBAU.76867

Malan, S. W. 2000. The improved Boer goat. Small Rumin. Res. 36:165-170. https://doi.org/10.1016/S0921-4488(99)00160-1

McManus, C., C. Evangelista, L. A. C. Fernandes, R. D. Miranda, F. E. Moreno-Bernal, & N. D. Santos. 2003. Curvas de crescimento de ovinos Bergamácia criados no Distrito Federal. Revista Brasileira Zootecnia 32:1207-1212. https://doi.org/10.1590/S1516-35982003000500022

Pauzi, M. A., M. H. Rosali, S. M. Rosly, M. Predith, Noor, S. M. Azlan, & N. A. M. Azhan. 2019. Jangkitan helmin pada baka kambing Katjang Hibrid. Buletin Teknologi MARDI 16:29-35.

Rosali, M. H., A. A. M. N. Nor, I. B. B. Jalal, A. M. A. Bakar, & M. H. A. Wahab. 2019. Manipulasi kambing Katjang bagi menjamin kelestarian industri ruminan kecil di Malaysia. Buletin Teknologi MARDI 16:1-10.

SAS. 2005. SAS/ STAT User's Guide (9.4). SAS Inst. Inc., Cary NC, USA.

Saleh, A. A., A. M. Rashad, N. N. Hassanine, M. A. Sharaby, & Y. Zhao. 2022. Morphological body measurements, body indices, and their genetic background for several Chinese goat breeds. Trop. Anim. Health Prod. 54:204. https://doi.org/10.1007/s11250-022-03203-w

Setiaji, A., S. Sutopo, & E. Kurnianto. 2013. Growth analysis in rabbit using Gompertz non-linear model. J. Indones. Trop. Anim. Agric. 38:92-97. https://doi.org/10.14710/jitaa.38.2.92-97

Simasiku, L., V. Charamba, & E. Lutaaya. 2019. Modeling and comparison of the maturing rates of Damara, Dorper and Swakara sheep at Neudamm Farm. Welwitschia International Journal Agricultural Sciences 1:41-48. https://doi.org/10.32642/wijas.v1i0.1367

Sunwasiya, D. K., L. Gautam, V. Kumar, & P. Garhwal. 2020. Comparison of non-linear growth curve models in Sirohi goat. Ruminant Science 1:145-150.

Tsukahara, Y., Y.Chomei, K. Oishi, A. K. Kahi, J. M. Panandam, T. K. Mukherjee, & H. Hirooka. 2008. Analysis of growth patterns in purebred Kambing Katjang goat and its crosses with German Fawn. Small Rumin. Res. 80:8-15. https://doi.org/10.1016/j.smallrumres.2008.07.030

Tyasi, T. L., A. Yakubu, O. M. Akinsola, & J. Ng'ambi. 2022. Evaluation of growth curve for South African non-descript indigenous goats using non-linear models. Acta. Agric. Scand. A. Anim. Sci. 71:82-88. https://doi.org/10.1080/09064702.2022.2112752

Wang, F., X. Li, & K. Wu. 2014. Fitting of growth curve and correlation analysis on body weight and body size of Bawang chicken. Journal Southern Agriculture 45:870-874.

Weber, S. H., S. K. Dos Santos, B. C. Heinzen, N. P. Viana, & C. S. Sotomaior. 2021. Comparison of nonlinear mathematical models for lamb growth analysis. Trop. Anim. Health Prod. 53:1-9. https://doi.org/10.1007/s11250-021-02597-3

Wiradarya, T. R., W. P. B. Putra, A. E. Harahap, & A. Suska. 2020. The growth curve of body weight in Kacang goats managed by smallholders at Tambang District of Indonesia. International Journal Agriculture Environment Food Sciences 4:334-339. https://doi.org/10.31015/jaefs.2020.3.12

Yusof, A. M., M. H. M. Amin, & M. L. M Isa. 2022. Peternakan Kambing Secara Komersial. 1st Ed. Dewan Bahasa dan Pustaka, Kuala Lumpur. pp. 9-12.

Zainalabidin, N. A. F. & F. B. Mustafa. 2023. Aktiviti Penternakan Kambing dan Cabaran Di Kuantan, Pahang. Malays. J. Trop. Geogr. 49:68-91.

Zayadi, R. A. 2021. Current outlook of livestock industry in Malaysia and ways towards sustainability. Journal Sustainable Natural Resources 2:1-11. https://doi.org/10.30880/jsunr.2021.12.02.001