

Assessment of phenotypic correlations and prediction of body weights of New Zealand White and Californian White Rabbits using linear and quadratic models

Okon, B.^{1*}, Ibom, L. A.¹, Okon, F. I.², Nkerede, M. E.¹, Uzodima, O. L.¹ and Ibom, E. K.¹

¹Department of Animal Science, University of Calabar, Calabar, Nigeria.

²Department of Environmental Health, College of Health Technology, Calabar, Nigeria.

*Corresponding author. Email: profbasseyokon@gmail.com

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Received Date: 23 September 2025 | Accepted Date: 05 November 2025 | Published Date: 30 April 2026

ABSTRACT: A total of 104 rabbits generated from 24 sexually mature, 5 months purebred of the mating from New Zealand White (NZW) and Californian White (CAL), 12 per breed, which comprised 3 bucks and 9 does mated in a ratio 1:3, replicated thrice, were used in the study. Phenotypic traits measured were body weight (BWT), ear length (ELT), nose length (NTS), heart girth (HGT), shoulder to tail drop (STF), body length (BLT), tail length (TLT) and length of front leg (FLT) from 9 to 21 weeks of age were used to estimate phenotypic correlations and predict body weights using both linear and quadratic models for the two breeds of rabbits. Results of correlation coefficients of post-weaning traits investigated for NZW rabbits expressed mostly high, positive and negative but significant ($p < 0.01$) values for 9, 13, 17 and 21 weeks of age, with few low, positive significant ($p < 0.05$) values and non-significant ($p > 0.05$) values. Whereas, results of phenotypic correlations of CAL rabbits expressed mostly non-significant ($p > 0.05$), both positive and negative low values, with the exceptions of high, positive significant ($p < 0.01$) correlation coefficients between STF and HGT, between BLT and STF for week 17, between STF and NTS, between TLT and ELT, and between TLT and NTS for week 21 of age. The results of high phenotypic correlations mean that these traits could be used for improvement and selection. The regression estimates of parameters and coefficient of determination (R^2) for simple (one trait), multiple (two or more traits) and quadratic (X^2) for predicting body weights of NZW and CAL rabbits showed highly significant ($p < 0.01$) values associating interrelationships for both breeds of rabbits. Body weights were predicted with effluent accuracy from phenotypic traits of NZW and CAL rabbits using linear and quadratic models. It can therefore be recommended that, where measuring scales are unavailable, rabbits' body weights can be best predicted using BLT and TLT, and BLT and NTS in simple and quadratic models, respectively.

Keywords: Correlation, linear and quadratic models, phenotypic trait, prediction, rabbit.

INTRODUCTION

The efficiency of rabbit production is highly dependent on the growth rate and body weight of the animals. Phenotypic traits, such as body length, heart or chest girth and ear length, have been found to be associated with body weight in rabbits (Obasi *et al.*, 2019).

According to Suzuki (2022), phenotypic traits are measurable characteristics of an organism's form or structure, encompassing aspects such as size, shape, proportions and other physical features that can be

quantified and analysed. In domestic rabbits, these traits include body weight, body length, front leg length, ear width and hind leg length (Eshimutu *et al.*, 2023). Phenotypic correlation is a statistical technique used to examine the relationship between different phenotypic traits and body weight (Khan *et al.*, 2022). This statistical technique or approach has been widely used in animal breeding to identify the most important traits that influence body weight. Yakubu *et al.* (2022) reported that phenotypic

relationships between morphometric traits and body weight showed that body length, ear length and hind leg length were strongly correlated with body weight. These traits can be used as predictors of body weight in rabbits (Eshimutu *et al.*, 2023). Evaluation of phenotypic traits for accurate prediction of body weight in rabbits is very vital, as emphasised by Belabbas *et al.* (2023), and several models have been proposed for predicting body weight in rabbits, including linear and non-linear regression models (Brahmantiyo *et al.*, 2025).

Estimating body weight from morphometric traits in rabbits is crucial to breeding and management. This is because body weight is an important trait in selection, and in most farms, measuring scales are lacking and where available, precision is often a problem. Rabbits are an important source of meat and fur, and their growth rates can significantly impact the efficiency of rabbit production systems (Siddiqui *et al.*, 2024; Goswami *et al.*, 2025). Morphometric traits, such as body length, width, ear length and other physical characteristics, can provide valuable information about an individual rabbit's potential body weight (Eshimutu *et al.*, 2023; Sanah *et al.*, 2024). By understanding the relationship between these traits and body weight, breeders can make informed decisions regarding selection and breeding programs to improve overall productivity (Sánchez, 2025; Jiang *et al.*, 2025). In recent years, researchers have focused on developing methods to estimate body weight based on morphometric traits in rabbits. Linear models have been proposed as a simple approach to estimate body weights using easily measurable traits (Adejinmi *et al.*, 2013). However, quadratic models have also been suggested as a more accurate method for estimating body weight in rabbits (Becker *et al.*, 2025).

Despite these advancements, there is still a need for further research on the morphometric traits and body weights in rabbits, New Zealand White (NZW) and Californian White Rabbit (CAL). Previous studies have primarily focused on a single breed of rabbit or a limited number of morphometric traits (Sanah *et al.*, 2024; Sattar *et al.*, 2024). Additionally, there is limited information available on how genetic variations impact the relationship between morphometric traits and body weight in different breeds of rabbits. To address these gaps in knowledge, this study aims to investigate the relationship between morphometric traits and body weight in two breeds of rabbits: New Zealand White (NZW) and Californian White Rabbits (CAL).

MATERIALS AND METHODS

Experimental site

The research was carried out in Unique Batonia Farms in Calabar. Calabar is located in the South-South region of Nigeria at latitude 4°57'N of the equator and longitude

8°19'E of the Greenwich Meridian with annual rainfall ranging from 3000 – 3500 mm, annual temperature ranging from 25 – 30°C, with relative humidity of 70 – 90% at an elevation above sea level of 42 meters (NMA, 2024).

Experimental animals and management

A total of twenty-four (24) sexually mature, five (5) months old purebred, twelve (12) each of New Zealand White and Californian White rabbits were used for the mating. At the commencement of the research, all the animals were administered Ivomec^(TM) to treat both internal and external parasites at a recommended dosage of 0.2 ml per animal. The rabbits were housed in individual pens/cages constructed with hardwood and iron with a dimension of 60 x 60 x 60 cm³. The pens were cleaned daily at 7 – 8 am, concentrate (Top grower pellets) and fresh forages (*Tridax procubens* and *Centrosema pubescens*) leaves and clean drinking water were given to the animals *ad libitum*.

In the morning, pelletized Top grower feed with 16% crude protein (CP) and 2700 Kcal/kg metabolizable energy (ME), 8% crude fibre (CF) was fed, followed by fresh forages in the evening. The forages were soaked and rinsed in brine (saltwater) for 10 minutes before feeding the animals in the evening to prevent larvae from being ingested.

Mating scheme

The mating pattern (Table 1) used was three (3) bucks and nine (9) does per group of New Zealand White (NZW) and Californian White rabbits (CAL) at the mating ratio of 1:3 (1 buck and 3 does) replicated thrice. The mating was carried out in the morning hours of 7 – 8 am. Pregnancy diagnosis was carried out after fourteen (14) days of fertile mating by abdominal palpation; those that were not pregnant were re-mated immediately. At twenty-four (24) days after fertile mating, before kindling, wooden nesting boxes with some clean dry furs removed from the pregnant doe's stomach (exposing the teats) and neck were provided to help the does in preparing a warm, comfortable nest for kindling. Their kittens/kits obtained from three parities (Table 1) per group were handled with latex disposable hand gloves rubbed on the doe's body to avoid rejection.

All kittens were weaned at the same age (6 weeks of age). A total of 104 kits survived and were used for the study. Routine management operations were carried out on a daily basis.

Data collection

The following data on phenotypic traits were measured from the two breeds of rabbits.

Table 1. Mating scheme for the production of offspring (progeny).

Group	Mating type	Number of bucks	Number of does	Number of mating	Number of offspring
A	NZW x NZW	3	9	1	18
				2	16
				3	17
				1	17
B	CAL x CAL	3	9	2	18
				3	18
Total		6	18		104

NZW = New Zealand White, CAL = Californian White.

Body weight (BWT): The body weight was taken using a sensitive scale (0.01 g) for each rabbit on a 5,000 g Big Boss (™) weighing scale.

Ear length (ELT): Length from the tip of the ear to the junction of the ear at the level of the skull (cm).

Nose length (NTS): Length from the back of the skull (cervical vertebra) to the tip of the nose (cm).

Heart girth (HGT): The circumference of the chest region directly below the elbow (cm).

Shoulder to the tail-drop (STF): Length from the cervical vertebra to the coccygeal vertebra (cm).

Body length (BLT): Length from the tip of the shoulder to the tip of the tail (cm).

Tail length (TLT): Length from the junction of the pelvic (hip) to the tip of the tail (cm).

Length of front leg (FLT): Length from the acromion to the phalanges (cm).

The phenotypic traits were measured using a measuring tape graduated in centimeters. Measurements were conducted for 21 weeks from weaning, following the procedure of Abe *et al.* (2019).

Experimental design and statistical analysis

The experimental design was a completely randomised design (CRD), with offspring phenotypic traits and body weights as the factors of interest. The SPSS (2015) software package was used to perform stepwise and quadratic variable selection to determine the most appropriate model for predicting body weight from linear body measurements. The statistical model used for the experiment was as follows:

$$Y_{ij} = \mu + A_i + e_{ij}$$

Where: Y_{ij} = Parameter of interest, μ = Overall mean, A_i = Mean effect of the i^{th} phenotypic traits, e_{ij} = Random error.

The data were analysed using SPSS (2015) to assess phenotypic correlations between body weight and other phenotypic traits at 9, 13, 17, and 21 weeks of age. The model used for Pearson's correlation, as outlined by Obike *et al.* (2016), was:

$$r = \frac{\sum X_i Y_j}{\sqrt{\sum X_i^2 \cdot \sum Y_j^2}}$$

Where: r = Pearson correlation, X_i = First random variable of the i^{th} body weights of the rabbit breed, Y_j = Second random variable of the j^{th} phenotypic traits of the rabbit breed

The simple linear regression model used for the prediction of body weights was:

$$Y_{ij} = a + b_i X_i + e_{ij}$$

Where: Y_{ij} = Body weight or dependent variable, a = Constant in the regression equation, b_i = Regression coefficient of the i^{th} independent variable, X_i = The value of the i^{th} independent variable of various phenotypic traits, e_{ij} = Error term

The quadratic regression analysis model used for the prediction of body weights was:

$$Y_{ij} = a + b_i (X_i) + b_i (X_i)^2 + e_{ij}$$

Where: Y_{ij} = Body weight or dependable variable, a = Constant in the regression equation, b_i = Regression coefficient of the i^{th} independent variable, X_i = The value of the i^{th} independent variable, $(X_i)^2$ = The value of the i^{th} quadratic independent variable, e_{ij} = Error term, X_1 = Body weight (BDW), X_2 = Ear length (ELT), X_3 = Nose length (NTS), X_4 = Heart girth (HGT), X_5 = Shoulder to tail-drop (STF), X_6 = Body length (BLT), X_7 = Tail length (TLT), X_8 = Length of front leg (FLT),

$$X_i = X_1 + X_2 + \dots + X_8$$

Table 2. Phenotypic coefficients of correlations (r_p) of post-weaning traits between New Zealand White (NZW) and Californian White (CAL) rabbits at nine (9) weeks.

New Zealand White Rabbits								
	BWT	ELT	NTS	HGT	STF	BLT	TLT	LFT
BWT	1	0.927**	0.900**	0.972**	0.973**	0.985**	0.489 ^{ns}	0.868**
ELT	0.354 ^{ns}	1	0.904**	0.903**	0.884**	0.941**	0.443 ^{ns}	0.847**
NTS	0.291 ^{ns}	0.830**	1	0.846**	0.816**	0.890**	0.355 ^{ns}	0.822**
HGT	0.526 ^{ns}	-0.383 ^{ns}	-0.145 ^{ns}	1	0.958**	0.973**	0.628*	0.839**
STF	0.509 ^{ns}	-0.331 ^{ns}	-0.387 ^{ns}	0.733*	1	0.966**	0.433 ^{ns}	0.870**
BLT	0.455 ^{ns}	-0.147 ^{ns}	-0.388 ^{ns}	0.347 ^{ns}	0.323 ^{ns}	1	0.477 ^{ns}	0.902**
TLT	-0.368 ^{ns}	0.279 ^{ns}	0.093 ^{ns}	-0.780*	-0.371 ^{ns}	-0.247 ^{ns}	1	0.150 ^{ns}
LFT	0.725*	0.272 ^{ns}	0.110 ^{ns}	0.559 ^{ns}	0.662*	0.602*	-0.252 ^{ns}	1

Californian White Rabbit								
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BWT = Body weight, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STF = Shoulder to tail drop, BLT = Body length, TLT = Tail length, LFT = Length of front leg. * = $p < 0.05$ (low significant), ** = $p < 0.01$ (high significant), ns = $p > 0.05$ (Non-significant).

Table 3. Phenotypic coefficients of correlations (r_p) of post-weaning traits between New Zealand White (NZW) and Californian White (CAL) rabbits at thirteen (13) weeks.

New Zealand White Rabbits								
	BWT	ELT	NTS	HGT	STF	BLT	TLT	LFT
BWT	1	0.121 ^{ns}	0.816**	0.971**	0.924**	0.934**	-0.396 ^{ns}	0.734**
ELT	-0.100 ^{ns}	1	0.148 ^{ns}	0.093 ^{ns}	0.092 ^{ns}	0.050 ^{ns}	0.284 ^{ns}	0.187 ^{ns}
NTS	0.485 ^{ns}	-0.140 ^{ns}	1	0.760**	0.681*	0.706*	-0.172 ^{ns}	0.730*
HGT	0.795*	-0.305 ^{ns}	0.459 ^{ns}	1	0.965**	0.977**	-0.429 ^{ns}	0.712**
STF	-0.020 ^{ns}	0.352 ^{ns}	-0.132 ^{ns}	0.000 ^{ns}	1	0.978**	-0.521*	0.573*
BLT	0.697 ^{ns}	0.264 ^{ns}	-0.015 ^{ns}	0.457 ^{ns}	0.245 ^{ns}	1	-0.406 ^{ns}	0.618*
TLT	0.006 ^{ns}	0.536*	0.020 ^{ns}	-0.343 ^{ns}	-0.099 ^{ns}	-0.006 ^{ns}	1	-0.336 ^{ns}
LFT	0.312 ^{ns}	0.120 ^{ns}	-0.568*	0.113 ^{ns}	0.357 ^{ns}	0.393 ^{ns}	0.135 ^{ns}	1

Californian White Rabbit								
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BWT = Body weight, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STF = Shoulder to tail drop, BLT = Body length, TLT = Tail length, LFT = Length of front leg. * = $p < 0.05$ (Low significant), ** = $p < 0.01$ (High significant), ns = $p > 0.05$ (non-significant).

The goodness of fit (R^2) was used to determine the contribution of each of the independent variables to the prediction of the dependent variable, body weight. The accuracy of the regression equations was estimated by the residual (absolute value of the differences between the predicted weight using the developed equations and the actual weight measured with the scale).

RESULTS AND DISCUSSION

Phenotypic correlation coefficients of growth traits in New Zealand White (NZW) rabbits in week 9 are shown in Table 2 (upper diagonal). There were highly positive and significant ($p < 0.01$) phenotypic relationships in almost all phenotypic traits, with the exceptions of the relationships expressed between tail length (TLT) and body length (BLT) (0.477), length of front leg (LFT) and TLT (0.150), which were non-significant. These results agreed with

those of Okoro *et al.* (2010) and Akanno and Ibe (2006), who reported positive correlations in the body weight and phenotypic traits of rabbits studied in 9 weeks. This implies that an improvement in one phenotypic trait could lead to a simultaneous improvement in the other trait correlated with it. Correlation coefficients expressed for Californian White (CAL) rabbits at 9 weeks (lower diagonal) are mostly non-significant ($p > 0.05$) with the exceptions of high significant ($p < 0.01$) correlation coefficients expressed in ear length (ELT) and nose length (NTS) (0.830), and low significant ($p < 0.05$) coefficients expressed in body weight (BWT) and LFT (0.725), shoulder to tail drop (STF) and heart girth (HGT) (0.733), TLT and HGT (-0.780), LFT and STF (0.662) and LFT and BLT (0.602).

At 13 weeks of age, as shown in Table 3 (upper diagonal) for NZW rabbits, there were highly positive and significant ($p < 0.01$) phenotypic relationships in most phenotypic traits, with the exception of the relationship existing between TLT, ELT and all the other phenotypic

Table 4. Phenotypic coefficients of correlations (r_p) of post weaning traits between New Zealand White (NZW) and Californian White (CAL) rabbits at seventeen (17) weeks.

New Zealand White Rabbits								
	BWT	ELT	NTS	HGT	STF	BLT	TLT	LFT
BWT	1	0.225 ^{ns}	- 0.375 ^{ns}	0.932 ^{**}	0.926 ^{**}	0.945 ^{**}	0.667 [*]	0.786 ^{**}
ELT	- 0.246 ^{ns}	1	0.671 [*]	0.458 ^{ns}	0.276 ^{ns}	0.311 ^{ns}	- 0.425 ^{ns}	0.438 ^{ns}
NTS	0.424 ^{ns}	0.416 ^{ns}	1	- 0.568 ^{ns}	- 0.493 ^{ns}	- 0.425 ^{ns}	0.450 ^{ns}	- 0.311 ^{ns}
HGT	0.423 ^{ns}	0.200 ^{ns}	0.461 ^{ns}	1	0.933 ^{**}	0.964 ^{**}	- 0.793 ^{**}	0.759 ^{**}
STF	- 0.630 ^{ns}	0.229 ^{ns}	0.537 ^{ns}	0.847 ^{**}	1	0.966 ^{**}	- 0.863 ^{**}	0.816 ^{**}
BLT	0.647 [*]	0.000 ^{ns}	0.658 [*]	0.789 [*]	0.798 ^{**}	1	- 0.845 ^{**}	0.799 ^{**}
TLT	0.607 ^{**}	0.000 ^{ns}	- 0.080 ^{ns}	0.499 ^{ns}	0.662 [*]	0.365 ^{ns}	1	- 0.755 ^{**}
LFT	- 0.168 ^{ns}	0.320 ^{ns}	- 0.503 ^{ns}	- 0.291 ^{ns}	- 0.220 ^{ns}	- 0.303 ^{ns}	0.246 ^{ns}	1

Californian White Rabbit

BWT = Body weight, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STF = Shoulder to tail drop, BLT = Body length, TLT = Tail length, LFT = Length of front leg. * = $p < 0.05$ (Low significant), ** = $p < 0.01$ (High significant), ns = $p > 0.05$ (Non-significant).

Table 5. Phenotypic coefficients of correlations (r_p) of post-weaning traits between New Zealand White (NZW) and Californian White (CAL) rabbits at twenty-one (21) weeks.

New Zealand White Rabbits								
	BWT	ELT	NTS	HGT	STF	BLT	TLT	LFT
BWT	1	0.575 ^{ns}	- 0.802 ^{**}	0.820 ^{**}	0.596 ^{ns}	0.740 ^{**}	0.167 ^{ns}	0.790 ^{**}
ELT	0.666 [*]	1	0.748 ^{**}	0.789 ^{**}	0.705 [*]	0.761 ^{**}	- 0.228 ^{ns}	0.741 ^{**}
NTS	0.611 [*]	0.756 [*]	1	0.916 ^{**}	0.853 ^{**}	0.898 ^{**}	- 0.130 ^{ns}	0.903 ^{**}
HGT	- 0.190 ^{ns}	- 0.542 ^{ns}	- 0.598 ^{ns}	1	0.924 ^{**}	0.973 ^{**}	0.77 ^{ns}	0.925 ^{**}
STF	- 0.570 ^{ns}	- 0.734 [*]	- 0.832 ^{**}	0.488 ^{ns}	1	0.952 ^{**}	0.145 ^{ns}	0.876 ^{**}
BLT	0.185 ^{ns}	0.139 ^{ns}	0.061 ^{ns}	0.051 ^{ns}	0.00 ^{ns}	1	0.141 ^{ns}	0.944 ^{**}
TLT	0.488 ^{ns}	0.819 ^{**}	0.853 ^{**}	- 0.581 ^{ns}	- 0.656 ^{ns}	0.209 ^{ns}	1	0.193 ^{ns}
LFT	- 0.249 ^{ns}	- 0.267 ^{ns}	- 0.354 ^{ns}	0.211 ^{ns}	0.196 ^{ns}	0.432 ^{ns}	- 0.511 ^{ns}	1

Californian White Rabbit

BWT = Body weight, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STF = Shoulder to tail drop, BLT = Body length, TLT = Tail length, LFT = Length of front leg. * = $p < 0.05$ (Low significant), ** = $p < 0.01$ (High significant), ns = $p > 0.05$ (Non-significant).

traits. These results agreed with the report of Obasi *et al.* (2019), who also reported positive correlations in the body weights and linear body measurements of New Zealand White rabbits studied in week 13. This implies that an improvement in one phenotypic trait could lead to a simultaneous improvement in the other traits correlated with it. On the lower diagonal of Table 3, the phenotypic correlation coefficients expressed for CAL rabbits were mostly negative, non-significant ($p > 0.05$), with the exceptions of the relationships between BWT and HGT (0.795), BWT and BLT (0.697), which were lowly significant ($p < 0.05$). The negative and non-significant phenotypic correlations indicated that an improvement in one trait could lead to a reduction in the other.

From 17 and 21 weeks of age as shown in Tables 4 and 5 (upper diagonal) for NZW rabbits, there were most high, positive and significant ($p < 0.01$) phenotypic relationships in most of the phenotypic traits with the exceptions of the relationship existing between TLT and all other phenotypic

traits, excluding week 17 which had a low and negatively high significant ($p < 0.01$) relationship expressed between TLT and BWT (0.667), TLT and HGT (- 0.793), TLT and STF (- 0.863), TLT and BLT (- 0.845) respectively. Besides, positive and highly significant ($p < 0.001$) correlations were observed between body weight and body length for weeks 17 and 21. This implies that as body weight increases, body length also increases. Therefore, selection for an increase in body weight leads to an increase in body length. The results of this study were in agreement with the results of Okoro *et al.* (2010), who reported a positive and highly significant ($p < 0.001$) relationship between body weight and body length. The studies of Afolabi *et al.* (2012) and Akinsola *et al.* (2014) are also in agreement with the present study. On the lower diagonal of Tables 4 and 5 are phenotypic correlation coefficients of Californian White (CAL) rabbits for 17 and 21 weeks. Interestingly, most of the correlation coefficients expressed for Californian White (CAL) rabbits at 17 and 21

Table 6. Body weight prediction using linear model with single trait.

Traits	NZW	R ²	CAL	R ²
ELT	- 3.820 + 0.416 ELT	0.879	- 2.103 + 0.312 ELT	0.834
NTS	- 3.291 + 0.378 NTS	0.891	- 2.152 + 0.308 NTS	0.829
HGT	- 2.041 + 0.109 HGT	0.772	- 3.199 + 0.189 HGT	0.819
STF	- 2.126 + 0.139 STF	0.867	- 3.319 + 0.189 STF	0.772
BLT	- 2.769 + 0.141 BLT	0.949	- 1.916 + 0.129 BLT	0.590
TLT	- 0.534 + 0.216 TLT	0.760	- 0.130 + 0.169 TLT	0.835
FLT	- 2.319 + 0.303 FLT	0.913	- 1.347 + 0.227 FLT	0.809

BWT = Body weight, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STF = Shoulder to tail drop, BL = Body length, TLT = Tail length, FLT = Flank length, R² = Coefficient of determination, NZW = New Zealand White, CAL = Californian White rabbit.

weeks (Tables 4 and 5) were mostly non-significant ($p > 0.05$), with the exceptions of low positive significant ($p < 0.05$) correlation coefficients obtained between BWT and BLT (0.647), TLT and STF (0.662) and high positive significant ($p < 0.01$) correlation coefficients for BLT and STF (0.798) and HGT (0.847) at 17 weeks of age. Also there was high positive significant ($p < 0.01$) correlation coefficients for TLT and ELT (0.819), TLT and NTS (0.853), and high negative significant ($p < 0.01$) correlation coefficients for STF and NTS (- 0.832) as well as low positive significant ($p < 0.05$) correlation coefficients for NTS and ELT (0.756), and low negative significant ($p < 0.05$) correlation coefficients for STF and NTS (- 0.734) in Californian White (CAL) rabbits. The presence of very low and non-significant ($p > 0.05$) correlation coefficients implies that an increase in any trait could lead to a decrease in the corresponding traits. Therefore, selection for an increase in one trait leads to a decrease in corresponding traits. Some authors in the literature also reported negative correlations among some phenotypic measurements. Okoro *et al.* (2010) and Sam *et al.* (2020) all reported negative and non-significant ($p > 0.05$) correlation among some phenotypic traits.

The results in Table 6 present the regression equations and coefficients of determination (R²) for body weight and other linear body measurements/phenotypic traits in NZW and CAL rabbits, estimated using a linear model. The regression estimates of traits and coefficient of determination (R²) for the simple linear model with one trait (BLT), (BW = - 2.769 + 0.141 BLT) showed that body length (BLT) was the best predictor of body weight for NZW rabbits, as it expressed 94.9% of the variation. Similarly, the regression estimates of traits and coefficient of determination (R²) for the simple linear model with one trait (TLT) and with one trait (ELT), (BW = - 0.130 + 0.169 TLT) and (BW = - 2.103 + 0.312 ELT) showed that TLT and ELT were the best predictors in CAL rabbits as they expressed 83.5% and 83.4% of the (R²) variations, respectively. However, the simple linear regression estimates of traits and coefficients of determination (R²) obtained from any single trait were high, ranging from 76% with TLT to 94.9% with BLT for NZW and from 59% with BLT to 83.5% with TLT for CAL rabbits. The R² values

obtained in this study for the linear model were similar to those reported by de Oliveira Paula *et al.* (2020), who developed a linear regression model to estimate ear length in New Zealand White rabbits using body length, chest length, and height as predictors. The model in this study showed a slightly lower R² value than the 0.92 reported by de Oliveira Paula *et al.* (2020). Also, the R² value obtained in this study was lower than the R² value (0.92) reported by Smith (2022). The lower R² value indicates that the variability in body weight of CAL rabbits can be explained by 52.7%-84.8% of the variation in other linear phenotypic traits. The differences between the R² values obtained in this study and those reported by earlier researchers may be attributable to differences in the species used. The present study was also consistent with the findings of Mallam *et al.* (2018) regarding the estimation of body weight. The coefficient of determination (R²) is the percentage of variations in the value of the dependent variable that variations in the value of the independent variable can explain. The magnitude of the coefficient of determination for each body measurement in rabbits, obtained in this study, corroborated the findings of Csóka *et al.* (2022) that body weight can be readily predicted from any given body measurement using linear regression.

Tables 7 and 8 summarise the results of regression analysis from New Zealand White and Californian White rabbits. Ear length (Table 7) accounted for 83.6% of differences in body weights in New Zealand White rabbits, but when NTS was added to ELT, these accounted for 86.6% of differences in body weight. The model becomes more accurate as additional variables are included. The prediction model, which includes all body traits, may be suitable for predicting body weight in New Zealand White rabbits in the study.

The regression models for the prediction of body weight using individual phenotypic traits measurement for Californian White rabbits are shown in Table 8. Ear length accounted for 52.7% of the differences observed in body weight in Californian White. The precision of the mathematical equation increased to 75.5% when NTS was included in the model. Precision of the mathematical equation was 82.9% when HGT was included in the model. Each of these phenotypic traits (ELT, NTS, HGT, STF,

Table 7. Body weight prediction in New Zealand White with multiple traits.

Traits	New Zealand White	R ² (%)	S. E.
ELT	- 3.824 + 0.415 ELT	83.6	0.268
NTS	- 3.377 + 0.082 ELT + 0.301 NTS	86.7	0.243
HGT	- 3.114 + 0.32 ELT + 0.154 NTS + 0.096 HGT	95.2	0.147
STT	- 3.218 + 0.037 ELT + 0.154 NTS + 0.054 HGT + 0.035 STT	95.5	0.143
BLT	- 3.211 + 0.041 ELT + 0.150 NTS + 0.052 HGT + 0.032 STT + 0.004 BLT	95.5	0.143
TLT	- 2.654 - 0.009 ELT + 0.102 NTS + 0.47 HGT + 0.0465 STT + 0.004 BLT + 0.048 TLT	96.0	0.134
FLT	- 2.453 + 0.050 ELT + 0.080 NTS + 0.047 HGT + 0.0375 STT + 0.002 BLT + 0.043 TLT + 0.076 FLT	96.4	0.130

R² = Coefficient of determination, S.E = Standard Error, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STT = Shoulder to tail drop, BLT = Body length, TLT = Tail length, FLT = Flank length.

Table 8. Body weight prediction in Californian White with multiple traits.

Traits	Californian White	R ² (%)	S. E.
ELT	- 0.578 + 0.182 ELT	52.7	0.305
NTS	- 2.310 + 0.038 ELT + 0.280 NTS	75.5	0.220
HGT	- 3.032 + 0.022 ELT + 0.152 NTS + 0.097 HGT	82.9	0.186
STT	- 3.280 + 0.011 ELT + 0.157 NTS + 0.072 HGT + 0.036 STT	83.6	0.183
BLT	- 3.50 + 0.007 ELT + 0.152 NTS + 0.070 HGT + 0.032 STT + 0.015 BLT	83.9	0.183
TLT	- 3.428 + 0.011 ELT + 0.144 NTS + 0.067 HGT + 0.032 STT + 0.018 BLT + 0.006 TLT	84.1	0.183
FLT	- 2.983 + 0.007 ELT + 0.111 NTS + 0.063 HGT + 0.018 STT + 0.008 BLT + 0.016 TLT + 0.052 FLT	84.8	0.181

R² = Coefficient of determination, S.E = Standard Error, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STT = Shoulder to tail drop, BLT = Body length, TLT = Tail length, FLT = Flank length.

BLT, TLT and FLT) is a good predictor of body weight, although the extent of improvement differed in New Zealand White and Californian White rabbits. The addition of more phenotypic trait measurements to ELT improved the precision of the predictive model (R²) in the research. This is in agreement with the report of Eshimutu *et al.* (2023), who reported that measurements such as body length (BLT), heart girth (HGT), and ear length (ELT) can be used to accurately estimate the body weight of rabbits. Ayyat *et al.* (2024) also supported the results in Tables 7 and 8. The authors pointed out that phenotypic traits can be used for accurate prediction of body weight of rabbits by analysing a larger sample size of rabbits and including phenotypic traits such as tail length (TLT) and flank length (FLT) to develop a predictive model. The results shown in Tables 7 and 8 were in line with the report of Sam *et al.* (2020), who showed that body weight can be predicted using phenotypic traits/measurements, but the highest R² obtained in Table 6 was lower than 95% and 84%, respectively, obtained for New Zealand White and Californian White. The results in Tables 7 and 8 supported the study by Mallam *et al.* (2018), who reported that body length (BLT), shoulder to tail drop (STF), ear length (TLT) and flank length (FLT) were significantly ($p < 0.01$) related to body weight. Using morphometric traits to predict body weight can provide accurate estimates of body weight in rabbits, which is crucial for monitoring growth and development in rabbit farming.

The results in Table 9 show the regression equation and coefficients of determination (R²) relating body weight and other linear body measurements/phenotypic traits for the NZW and CAL rabbits using a quadratic model. The results of regression estimates of traits and coefficients of determination (R²) confirmed the earlier results using a simple linear model, that TLT and ELT were outstanding for CAL with 83.5% and 83.4% of variations, respectively. However, the quadratic regression estimates of traits and coefficient of determination (R²) obtained from any single trait were high, ranging from 78.5% with TLT to 95.2% with BLT for the NZW and 75.8% with BLT to 85% with NTS for the CAL rabbits. The values of R² of each variable added in quadratic form to the regression equations showed that estimating body weights using a single body measurement in quadratic form was a suitable criterion for predicting body weight with only single body traits. The results of this study confirmed that the body weight of rabbits can be predicted with confidence from most of the body traits/measurements. The application of the quadratic regression model had yielded higher values for the coefficient of determination (R²) than when the simple linear model was applied for NZW and CAL. All traits measured maintained their order of prediction magnitude in the quadratic regression model, as observed or shown by a high R². The study found that the quadratic model provided a better fit to the data, with a higher coefficient of determination (R² = 0.952) for NZW and (R² = 0.850) for

Table 9. Body weight prediction using quadratic model with single trait.

Traits	NZW	R ²	CAL	R ²
ELT	- 1.569 + 0.57 ELT + 0.014 ELT ²	0.881	- 2.269 + 0.342 ELT + 0.001 ELT ²	0.834
NTS	- 2.385 + 0.232 NTS + 0.006 NTS ²	0.892	- 2.264 + 0.479 NTS + 0.034 NTS ²	0.850
HGT	- 1.979 + 0.188 HGT + 0.007 HGT ²	0.847	- 3.861 + 0.243 HGT + 0.001 HGT ²	0.819
STF	- 4.157 + 0.297 STF + 0.003 STF ²	0.873	- 0.491 + 0.042 STF + 0.005 STF ²	0.775
BLT	- 4.031 + 0.263 BLT + 0.002 BLT ²	0.952	- 12.720 + 0.945 BLT + 0.015 BLT ²	0.758
TLT	- 2.012 + 0.548 TLT + 0.017 TLT ²	0.785	- 0.566 + 0.267 TLT + 0.005 TLT ²	0.842
FLT	- 0.373 + 0.017 FLT + 0.013 FLT ²	0.919	- 0.931 + 0.173 FLT + 0.017 FLT ²	0.821

BWT = Body weight, ELT = Ear length, NTS = Nose length, HGT = Heart girth, STF = Shoulder to tail drop, BL = Body length, TLT = Tail length, FLT = Flank length, R² = Coefficient of determination, NZW = New Zealand White, CAL = Californian White rabbit.

CAL compared to linear models. This suggested that the quadratic regression model captured the non-linear relationship between phenotypic traits and body weight more accurately in rabbits (de Oliveira Paula *et al.*, 2020).

Similarly, Udeh (2013) used a quadratic regression model to estimate body weight in rabbits from body length and height. The quadratic model demonstrated a strong predictive ability, indicating a robust estimation of body weight considering the non-linear relationship between the phenotypic traits and body weight in rabbits. Quadratic regression models have been increasingly used in animal breeding and genetics to estimate body weights and other traits in rabbits. The New Zealand White and Californian White rabbit breeds are two popular breeds widely kept as pets and used in scientific research. This research focused on phenotypic correlations and the use of linear and quadratic regression models to estimate body weight in these two breeds.

Conclusion

The results of this study revealed that phenotypic correlations among phenotypic traits for NZW rabbits showed mostly high, positive and negative significant ($p < 0.01$) values for 9, 13, 17 and 21 weeks of age, with a few low, positive, significant ($p < 0.05$) values and non-significant ($p > 0.05$) values. CAL rabbit, on the other hand, expressed mostly non-significant ($p > 0.05$) both positive and negative low values, with the exceptions of high, positive significant ($p < 0.01$) correlation coefficients between STF and HGT, between BLT and SFT for week 17, between STF and NTS, between TLT and ELT, and between TLT and NTS for week 21 of age. Prediction of body weight in rabbits using simple and quadratic analyses can be more accurately achieved by applying BLT (NZW) and TLT (CAL), and BLT (NZW) and NTS (CAL), respectively. This suggests that rabbit body weight can be predicted from phenotypic traits with high accuracy, thereby supporting the development, improvement, selection, and marketing of rabbits.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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