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# Development of prediction equations to estimate carcass tissue composition in growing New Zealand White rabbits by shoulder and neck dissection

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**ABSTRACT.** The objective of this study was to determine the tissue composition of the carcass of growing New Zealand White rabbits based on the shoulder and neck traits (weight, meat and bone weights). Live weight and characteristics of dissected meat and bone tissues (neck, breast, rib, loin, shoulder, and leg) of 80 rabbits were recorded. Total carcass tissue weights (carcass fat weight, carcass meat weight – CMW, and carcass bone weight – CBW) were calculated and correlation and regression analyses were implemented. Shoulder, neck, shoulder meat, bone and neck meat were correlated ($P < 0.0001$ and $< 0.001$) with CMW and CBW. In conclusion, cut weights and tissue content of the shoulder and neck provided good predictions for total meat and bone weights of growing New Zealand White rabbits.

## Introduction

In livestock farming, the rabbit (*Oryctolagus cuniculus*) shows desirable traits such as high fertility, small area required, reduced competition for plant raw materials with humans and other livestock, as well as efficient feed conversion (Dalle Zotte, 2014; Sikiru et al., 2020). In addition, its meat has a high protein value (20–24%), cholesterol of 35–50 mg/100 g meat, it is rich in vitamin $B_{12}$ (8–12 mg/100 g meat) and minerals (1.2–1.3 g/100 g meat) (Cardinali et al., 2015; Martínez-Alvaro et al., 2018; Cesari et al., 2018; Dalle Zotte and Cullere, 2019; North et al., 2019). Moreover, rabbit production systems demonstrate food sustainability (economic, environmental, nutritional and social) in various regions of the world (Dalle Zotte, 2014; Cesari et al., 2018; Sikiru et al., 2020).

In the last decade, Mexico produced approximately 18 thousand tons of rabbit meat, ranking ninth in the global production (SENASICA, 2021). Rabbit rearing is based on New Zealand and California meat breeds (Ortiz-Hernández and Rubio-Lozano, 2001; Bautista et al., 2015). Rabbit meat is traditionally marketed whole or as half carcasses (without head and organs), fresh or frozen. Although there is no age preference or specific slaughter weight in the international or domestic market, it must exceed 1 kg carcass for its commercialization (Bautista et al., 2015; Dimitrova et al., 2015; Jaramillo-Villanueva et al., 2015).

In recent decades, there has been a notable demand for commercial rabbit cuts for sale in supermarkets and restaurants (Zeferino et al., 2013; Dalle Zotte, 2014; Martínez-Alvaro et al., 2018). Although Mexico uses the European commercial division into pieces, they may vary in terms of presentation. However, due to the growth of the domestic market, it is necessary to generate information on the carcass tissue composition to provide valuable information that would increase the profitability of the rabbit production system (Jaramillo-Villanueva et al., 2015; North et al., 2017).

Commercial rabbits are evaluated for carcass performance and carcass tissue composition (fat, meat, and bone) using dissection techniques (Deltoro and Lopez, 1985). Although this procedure is standardized, it involves a considerable number of people to separate tissues from the whole carcass, specific instruments, long-term training, and high economic costs. For this reason, a series of studies have emerged showing that certain cuts, such as leg and loin, could be used to estimate carcass tissue composition. However, these cuts have limitations due to the noticeable consumer sensory preferences (Dalle Zotte, 2014; Dalle Zotte and Cullere, 2019) and higher nutritional quality (Unah et al., 2012; Dalle Zotte, 2014). In this regard, few studies have evaluated cuts of lower commercial value, such as the shoulder and neck, for predicting carcass tissue composition in rabbits (Blasco et al., 1984; Hernández et al., 1996). Therefore, the objective of this study was to predict carcass traits and tissue composition through dissection of the shoulder and neck in growing New Zealand White rabbits.

## Material and methods

The study was conducted in accordance with the guidelines and regulations for ethical animal experimentation of the Instituto Tecnológico de Conkal (ID Project ITC: MX-ITC-002521) and NOM-033-SAG/ZOO-2014, Official Mexican Standard for killing domestic and wild animals.

The animals included in the present study were managed in accordance with the guidelines and regulations for ethical animal experimentation of the Instituto Tecnológico de Conkal (ID Project ITC: MX-ITC-002521).

### Experimental site and animals

The experiment was carried out at the Agricultural and Livestock Production and Research Unit of the Instituto Tecnológico de Conkal, Yucatán, México, located at 21°05′N and 89°32′W, 8 meters above sea level. The experimental site has an average annual temperature of 26 °C and an annual rainfall of 1000 mm, and is considered a sub-humid tropical region (García, 1981).

Eighty New Zealand White (NZW) growing rabbits (40 females and 40 males) were used in the trial. The animals were housed in individual raised-slatted floor cages (45 × 30 × 40 cm) with photoperiod and natural ventilation. Feed and water were supplied *ad libitum*. A commercial diet (Provi rabbits®, Mérida, México) containing 88% dry matter, 17% crude protein, 11% crude fibre, 2% fat, and 11% ash was offered.

### Pre and post-mortem measurements

Before slaughter, the rabbits were fasted for 12 h and weighed using a 10-kg electronic scale (BAPO-10, Rhino Maquinaria, Atizapán de Zaragoza, Mexico) to determine live weight (LW). Sixteen animals (8 females and 8 males) were slaughtered over five periods. The animals were selected at different ages and mean body weights: 14 weeks = 1861 ± 263 g; 17 weeks = 2243 ± 152 g; 20 weeks = 2487 ± 209 g; 24 weeks = 2759 ± 390 g and 28 weeks = 2939 ± 366 g.

The animals were slaughtered in a humane manner in accordance with the current regulations for the slaughter and dressing of domestic animals (NOM-033-SAG/ZOO-2014). Subsequently, the skin, head, tail, legs, thorax (oesophagus, trachea, lungs, thymus, and heart) and abdominal organs (gastrointestinal tract, liver, kidneys, spleen, and urinary bladder) were separated; then, hot carcass weight (HCW) was determined. Hot carcass yield (HCY) was calculated by dividing HCW by LW and multiplying by 100.

Subsequently, the carcass was chilled at 3 °C for 24 h, cold carcass weight (CCW) was obtained, and the carcass was divided along the dorsal midline into two halves and weighed. Dissectible fat was obtained from different areas: perirenal fat, dorsal-scapular fat from the superficial layers that cover the areas of the scapula and *Longissimus thoracic*, and inguinal-hypodermic layers of the external inguinal area and lower part of the abdominal wall. These were weighed and used to determine the total carcass fat (CFW). The left half-carcass was divided into five commercial cuts according to Shahin (2001) as follows: 1) neck (N): from the atlas vertebra to the last cervical vertebra; 2) chest and ribs (C-R): from the joint between the last thoracic vertebra and the first lumbar vertebra; 3) loin (L): lumbar vertebrae and abdominal wall; 4) shoulder (S): from the insertion muscles in the thoracic trunk region and 5) hind leg (H-L): including the sacrum (coxal) bone. The weight of each cut was determined and the main tissues (muscle and bone) were separated, weighed individually, and finally added to obtain the total weight of the left carcass tissues. The left carcass tissue weight was adjusted to the weight of the whole carcass (CFW, CMW – carcass meat weight, and CBW – carcass bone weight).

### Data analyses

For statistical analysis and internal model validation, the data were read in the Python environment as follows: descriptive statistics were obtained using the description function of the "pandas" package (McKinney, 2021). The relationship between carcass traits and carcass measurements was determined by linear equations using the "lmfit" package (Newville et al., 2021). Models and their residuals were plotted using the "matplotlib" package (Hunter, 2021). Goodness-of-fit of regression models was evaluated using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), coefficient of determination ($R^2$), mean square error (MSE), and root MSE (RMSE). The last three parameters were obtained using the "scikit-learn" package (Pedregosa et al., 2021).

The predictive capacity of the three models was assessed using k-fold cross-validation (k = 10). This approach involved randomly dividing a set of observation values into non-overlapping k-folds of approximately the same size. The first fold was treated as a validation set, and the model fitted the remaining k-1 folds (training data). The ability of the fitted model to predict the actual observed value was evaluated using MSE, $R^2$, mean absolute error (MAE) and root mean squared prediction error (RMSPE). Lower values of root RMSPE and MAE indicated a better fit. The k-fold cross-validation was performed using the "scikit-learn" package (Pedregosa et al., 2021), which allowed the comparison of many multivariate calibration models.

## Results

### Carcass traits and tissue composition

Carcass traits and tissue composition of growing NZW rabbits are presented in Table 1. The average LW was 2.5 kg, while for HCW it was 1.4 kg (Figure 1). HCY was 58%, while CCW was approx. 1.4 kg. With regard to commercial cuts, neck weight (NW) had an average of 0.02 kg (Table 1) and consisted of 66.6% muscle (NM) and 33.4% bone (NB). Shoulder weight (SW) was 0.1 kg and contained 79.4% muscle and 19.6% bone. For carcass tissues, fat, muscle, and bone constituted 4.4%, 75.8%, and 19.8%, respectively.

**Table 1**. Descriptive statistics of the data set obtained from growing New Zealand White rabbits (n = 80)

| Abbreviation | Indices, g | Mean ± SD | Min | Max | CV, % | Skew | Kurtosis |
|---|---|---|---|---|---|---|---|
| NW | neck weight | 23.8 ± 8.7 | 8 | 49 | 36.5 | 0.67 | −0.04 |
| NM | neck meat | 15.7 ± 6.9 | 4 | 36 | 43.9 | 0.84 | 0.21 |
| NB | neck bone | 7.7 ± 3.6 | 1 | 21 | 46.7 | 0.80 | 0.86 |
| SW | shoulder weight | 97.2 ± 21.8 | 52 | 150 | 22.4 | 0.00 | −0.55 |
| SM | shoulder meat | 77.2 ± 18.7 | 38 | 131 | 24.2 | 0.17 | −0.08 |
| SB | shoulder bone | 19.1 ± 5.1 | 11 | 38 | 26.7 | 1.34 | 2.12 |
| CFW | carcass fat weight | 63.3 ± 32.4 | 14 | 166 | 51.2 | 1.16 | 1.42 |
| CMW | carcass meat weight | 1097 ± 267.7 | 542 | 1747 | 24.4 | 0.28 | −0.33 |
| CBW | carcass bone weight | 285.5 ± 62.2 | 148 | 434 | 21.7 | 0.25 | −0.57 |

Min – minimum, Max – maximum, SD – standard deviation, CV – coefficient of variation

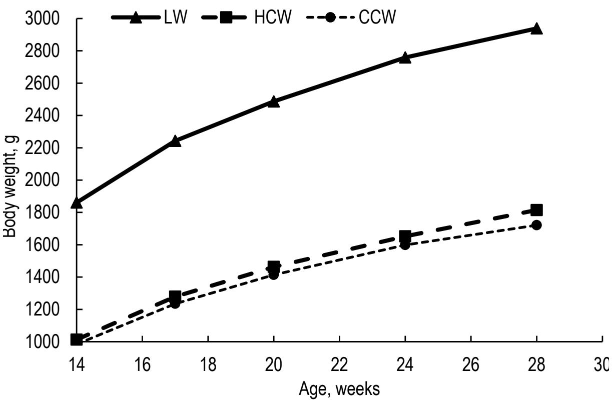


**Figure 1.** Slaughter intervals of growing New Zealand White rabbits LW – live weight, HCW – hot carcass weight, CCW – cold carcass weight

### Correlation coefficients

Except for the correlation of NB with CFW, correlations between neck and shoulder traits, and carcass tissue composition were positively and significantly correlated (Figure 2). Shoulder traits (SW, SM – shoulder meat, and SB – shoulder bone) were moderately to highly correlated with carcass tissues weights (> 0.48 and ≤ 0.92), while the r values for carcass tissues and the neck ranged from low to moderate (> 0.09 and ≤ 0.72).

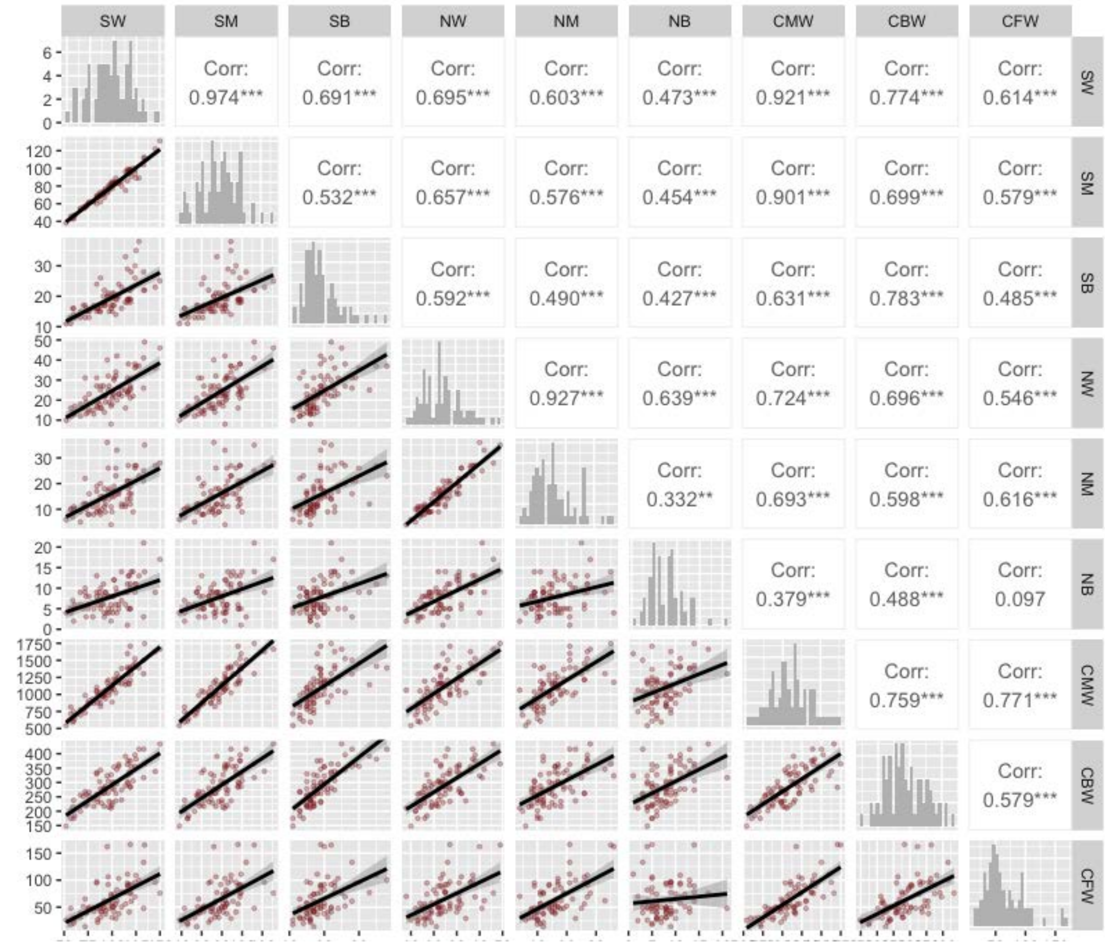


**Figure 2.** Graphical analysis of the input and output variables. Scatterplots, distributions, and correlation coefficients of carcass fat weight (CFW), carcass meat weight (CMW), carcass bone weight (CBW), shoulder weight (SW), shoulder meat (SM), shoulder bone (SB), neck weight (NW), neck meat (NM) and neck bone (NB). Correlations with superscript indicate: *** – $P < 0.0001$, ** – $P < 0.001$, * – $P < 0.05$, ns – non-significant

## Prediction equations

Using the stepwise process, six equations were developed using neck and shoulder characteristics to predict carcass tissue composition in growing NZW rabbits (Table 2, Figure 3). The coefficient of determination ($R^2$) ranged from 0.51 to 0.88, while the root mean square error (RMSE) was between 21 and 92 ($P$ = < 0.0001). The best equations for predicting CMW (Eq. 2) using SW, NW, and NM performed well in the internal validation (Table 3). Eq. 2 showed a high $R^2$ value and lower MAE value (Table 3). While Eq. 4 was the most optimal model

**Table 2.** Simple and multiple regression equations to predict carcass tissue composition of growing New Zealand White rabbits

| No. | Equation | $R^2$ | RMSE | AIC | BIC | *P*-value |
|---|---|---|---|---|---|---|
| 1 | CMW = 23.16 (± 48.53$^{ns}$) + 9.70 (± 0.60***) × SW + 8.26 (± 1.89***) × NM | 0.88 | 92.67 | 971.58 | 981.16 | <0.0001 |
| 2 | CMW = 21.90 (± 47.60$^{ns}$) + 10.31 (± 0.66***) × SW − 7.15 (± 3.54*) × NW +15.42 (± 4.0***) × NM | 0.88 | 90.31 | 969.41 | 981.38 | <0.0001 |
| 3 | CBW = 51.94 (± 17.04*) + 1.30 (± 0.25***) × SM + 6.92 (± 0.84***) × SB | 0.72 | 32.46 | 801.67 | 811.25 | <0.0001 |
| 4 | CBW = 58.06 (± 16.72***) + 0.99 (± 0.26***) × SM + 6.10 (± 0.89***) × SB +1.42 (± 0.58***) × NW | 0.73 | 44.53 | 797.71 | 809.68 | <0.0001 |
| 5 | CFW = −19.60 (± 11.66*) + 0.74 (± 0.15***) × SW + 1.88 (± 0.45***) × NM − 2.41 (± 0.78**) × NB | 0.51 | 22.12 | 741.56 | 753.53 | <0.0001 |
| 6 | CFW = −22.21 (± 11.91*) + 0.64 (± 0.18***) × SW + 0.73 (± 0.69) × SB +1.82 (± 0.45***) × NM − 2.54 (± 0.79**) × NB | 0.51 | 21.96 | 742.37 | 756.74 | <0.0001 |

CFW – carcass fat weight, CMW – carcass meat weight, CBW – carcass bone weight, SW – shoulder weight, SM – shoulder meat, SB – shoulder bone, NW – neck weight, NM – neck meat, NB – neck bone, $R^2$ – coefficient of determination, RMSE – root mean square error, AIC – Akaike Information Criterion, BIC – Bayesian Information Criterion; values within parentheses are the standard error of parameter estimates; ns – non-significant, * – $P < 0.05$, ** – $P < 0.001$, *** – $P < 0.0001$

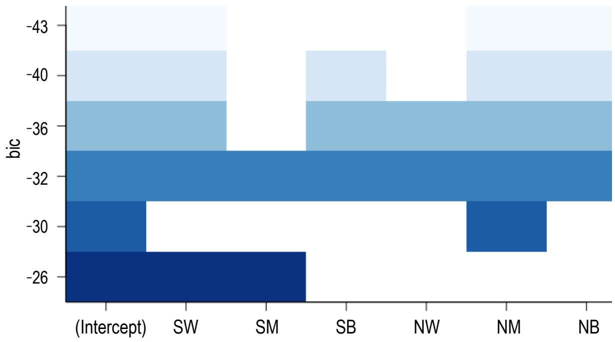


**Figure 3.** Graphical representation of a stepwise process for selecting the best models to estimate carcass fat weight of growing New Zealand White rabbits (n = 80)

tissues continue to enlarge, resulting in higher carcass weight (North et al., 2017). It should be noted that previous studies considered head weight in HCW and CCW as an indicator of carcass yield.

Information is scarce with respect to neck and tissue composition of NZW rabbits, but a previous study have reported higher values (96 g neck weight) in the Soviet Chinchilla breed (Banerjee, 2011). Shoulder weight ranged from 50 to 150 g, similarly to other studies involving medium size breeds (Blasco et al., 1984; Michalik et al., 2006). Likewise, meat values ranged from 38 to 130 g, and bone weight varied from 10 to 38 g, which was in line with the results of Blasco et al. (1984) and Michalik et al. (2006). In recent times, studies have followed the regulations of the World Association for Rabbit Sciences that recommend the neck, rib, and shoulder as primary cuts (Dalle Zotte and Cullere, 2019). This is due to the limited availability of dissection protocols for commercial cuts (Sánchez-Macías et al., 2018; North et al., 2019).

**Table 3.** Evaluation of proposed models using k-fold cross-validation

| ID | Predictors | RMSPE | $R^2$ | MAE | RMSPE (SD) | $R^2$ (SD) | MAE (SD) |
|---|---|---|---|---|---|---|---|
| Carcass meat weight | | | | | | | |
| 1 | SW, NM | 91.89 | 0.88 | 78.78 | 27.58 | 0.052 | 19.78 |
| 2 | SW, NW, NM | 93.29 | 0.90 | 71.32 | 31.32 | 0.057 | 26.98 |
| Carcass bone weight | | | | | | | |
| 3 | SM, SB | 32.78 | 0.73 | 27.50 | 7.12 | 0.15 | 6.55 |
| 4 | SM, SB, NW | 32.81 | 0.73 | 27.28 | 7.83 | 0.13 | 7.12 |
| Carcass fat weight | | | | | | | |
| 5 | SW, NM, NB | 23.63 | 0.52 | 19.59 | 10.08 | 0.20 | 7.01 |
| 6 | SW, SB, NM, NB | 23.04 | 0.54 | 19.36 | 8.44 | 0.20 | 5.79 |

SW – shoulder weight, SM – shoulder meat, SB – shoulder bone, NW – neck weight, NM – neck meat, NB – neck bone, $R^2$ – coefficient of determination, MAE – mean absolute error, RMSPE – root meansquared prediction error, SD – standard deviation

to predict CBW, as it showed lower RMSPE, MAE values and included SM, SB, and NW as predictors. For CFW prediction, Eq. 6 was the most effective because it provided lower RMSPE and MAE values, and a high $R^2$ value.

## Discussion

In this study, LW ranged from 1.4 to 3.5 kg, which was similar to information obtained in NZB animals, aged 10 to 21 weeks (Deltoro and Lopez, 1985; Ortiz-Hernández and Rubio-Lozano, 2001; Bautista et al., 2015; Cardinali et al., 2015; Dimitrova et al., 2015; Cesari et al., 2018), and raised in temperate climates. With regard to HCW and CCW, they ranged from 0.7 to 2.2 kg, which was consistent with the results reported by North et al. (2019), Cesari et al. (2018), Michalik et al. (2006) and Dalle Zotte and Paci (2014). Hot carcass yield was similar to that reported by several authors (Ortiz-Hernández and Rubio-Lozano, 2001; Gouda, 2008; Cardinali et al., 2015; Cesari et al., 2018; North et al., 2019). As animals' age at slaughter increases, organ growth tends to stabilize and carcass tissues continue to enlarge, resulting in higher carcass weight (North et al., 2017).

Regarding tissue proportions, CF and CM contents ranged from 2 to 7.7 and 78 to 81.5%, respectively, which was in agreement with the previous studies carried out in the same breed (Ortiz-Hernández and Rubio-Lozano, 2001; Shahin, 2001; Gouda, 2008). These noticeable changes in lipid accumulation have been shown to be associated with age, genetic improvements, environmental temperature, and sexual maturity (Deltoro and Lopez, 1985; Martínez-Alvaro et al., 2018; Cesari et al., 2018). Animals have been found to have higher muscle content at young age, and lower muscle growth rates after reaching adult or maturity weight (Deltoro and Lopez, 1985; North et al., 2017). Finally, CBW ranged from 21.3 to 20.2%, and was higher compared to previous studies (Deltoro and Lopez, 1985).

### Correlation coefficients

Correlations between shoulder traits (SW, SM, and SB) and carcass tissue composition (CFW, CMW, and CBW) were consistent with findings of Shahin (2001) in NZW and Michalik et al. (2006), who introduced these features to predict tissue content in the French Lop rabbit. With regard to neck correlations, they varied for NM and NB traits, as reported previously (Shahin, 2001). In general, the shoulder was the section whose tissue composition correlated best with carcass contents, and was suggested as a suitable predictor to generate predictive equations.

### Prediction equations

The equations generated to estimate the CFW had lower $R^2$ values (from 0.52 to 0.54). This could be caused by a low accumulation of body fat by rabbits, which generally have tissues that exhibits asymptotic growth as they approach adulthood (Shahin, 2001; North et al., 2017). When predicting carcass meat content using SM, the result was similar to that reported by Deltoro and López (1985) who obtained the $R^2$ value equal to 0.96 in NZW crosses, and Hernández et al. (1996) who obtained an $R^2 = 0.90$ in hybrid lines. However, other authors (Blasco et al., 1984) selected SW or SM as a predictor of CMW and reported an $R^2$ of 0.67 and 0.71 in the California rabbit breed. Moreover, the estimation of CBW in our study was consistent with the results of Blasco et al. (1984) who reported the $R^2$ vaule of 0.65 using SW. However, when SB was applied as a predictor in an allometric growth study, an $R^2 \geq 0.90$ was obtained (Deltoro and López, 1985). In summary, shoulder and neck traits used as predictors of carcass tissue composition in growing NZW rabbits yielded equations with good predictive values.

## Conclusions

Among the evaluated cuts, shoulder traits (SW, SM, and SB) were well correlated with carcass tissue composition (> 0.48 and ≤ 0.92). The combination of commercial cuts with those of lower economic value, such as the shoulder and neck, can be used to predict, with high accuracy ($R^2 = 0.73$ and $\leq 0.90$), carcass tissue composition (meat and bone) in growing NZW rabbits.

## Conflict of interest

The Authors declare that there is no conflict of interest.

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