Canonical correlation analysis to identify the relationship of *in vivo* body measurements of rabbit (*Oryctolagus cuniculus* L.) with the carcass

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ABSTRACT

Objective: to determine the interrelations between morphological characteristics in live rabbits and carcasses, mainly loin and legs which are pieces of greater economic value in the carcass.

Design/ Methodology/ Approach: this study used the methodology of multivariate Canonical Correlation Analysis (CCA). Information was used from 139 rabbits of the New Zealand and California breeds, male and female, weaned at 35 days of age and carried in a fattening process up to 73 days. Morphological measurements were taken before and after slaughter to integrate a morphological traits database, which was divided into two subsets. First, Set X with the variables to be estimated (dependent) included those characteristics of the carcass before being chilled, *i.e.* non-chilled carcass weight (PCC), carcass loin weight (PLC), carcass leg weight (PPC), carcass loin width (ALC), carcass loin length (LLC), carcass leg length (LPC). The second, Set Y the predictor variables (independent) included the live measurements of body parts, live weight (PV), loin width (AL), loin length (LL), leg circumference (PP) and leg length (LP). No differences ($p>0.05$) were found between races or sexes, so database was analyzed in a general way.

Results: CCA results showed a strong association between the morphological characteristics measured in the live animal and those measured in the butchered carcass (CANAL, rc=0.85), which proved the CCA as relevant. Live weight (PV) and leg circumference (PP) were the factors most related to the important characteristics of the carcass (loin and legs).

Limitations/ Implications of the study: breeding stock selection is traditionally based on the visual evaluation of phenotypic characteristics, which is considered as subjective, thus limiting genetic progress. The proposal in this study was to consider an indirect selection, evaluating characteristics of the live animal that highly correlate with the characteristics of greater economic value of the carcass.

Findings/ Conclusions: indirect selection in rabbits can be an effective strategy to select future breeders, since animals above the average are obtained in the farm.

Keywords: canonical correlation analysis, rabbits, body measurements.

INTRODUCTION

Rabbit production in Mexico is concentrated in small farms located in rural and suburban areas around cities. These production units seek to obtain rabbit meat, a food of high nutritional value, low in fat and cholesterol (Villanueva-Díaz *et al.*, 2023), which can contribute to improve the diet of Mexican families. However, despite its benefits, the consumption of rabbit meat in Mexico is low, since it is limited to certain segments of the population; who eat it on special occasions, also as an exotic dish offered to national tourism on weekends.

There are around 10 000 rabbit production units in Mexico, with an annual *per capita* consumption of only 100 grams (SADER-SENASICA, 2019). This situation is partly due to the limited incorporation of rabbit meat into Mexican gastronomy, because it is perceived as an exotic product. Rabbit production in Mexico is semi-intensive, using breeds such as New Zealand, California and Chinchilla. Breeding stock selection is traditionally based on the visual evaluation of phenotypic characteristics, which can be subjective and limit genetic progress (Trocino *et al.*, 2019). Ideally, indirect selection should be considered, in order to evaluate characteristics of live animals that correlate with those of the carcass, such as yield of legs, thighs, and loin, which are pieces highly valued by consumers (Blasco *et al.*, 2018).

This practice implies the killing of the animal, which requires optimization for its initial application. Canonical correlation analysis (CCA) is a multivariate statistical technique that allows the identification and quantification of the relationships between two sets of variables. The CCA reduces the dimensionality of the data and makes it easier to interpret results. Previous research has shown that CCA is a powerful tool to identify relations between two homogeneous groups of variables in a dataset, based on pairs of linear combinations of these groups and the estimation of the variability of the data (Montes-Vergara *et al.*, 2020).

The procedure consists of dividing the set of variables into two subsets, the first consisting of p variables, denoted by the matrix X, of order (n, p); and the second by the q explanatory variables denoted as matrix Y, of order (n, q). The objective of the CCA is to analyze relations between multiple variables in order to find two linear functions. One of the X-variables, $V_1 = b_1X_1 + b_2X_2 + ... + b_LX_L$ and another of the Y-variables, $W_1 = a_1Y_1 + a_2Y_2 + ... + a_kY_k$ in such a way that the correlation between W and V is maximum. These linear combinations of functions (V, W) are called canonical variables, and the correlations between the corresponding pairs of canonical variables are called canonical correlations.

Studies that apply CCA in rabbit farming are scarce. This multivariate technique has proven to be highly effective because it surpasses conventional univariate approaches, allowing deeper and more precise analyses of the relationships between sets of variables (Atac & Altincekic, 2023). Therefore, the objective was to use the CCA technique to identify the interrelation between morphological characteristics of 73-day-old live rabbits and some carcass measurements, in order to determine which characteristics can be used as criteria for indirect selection of superior breeding stock.

MATERIALS AND METHODS

This research was implemented at the Experimental Rabbit Farm of Colegio de Postgraduados, Campus Montecillo, Texcoco, State of Mexico, in accordance with the regulations for the use and care of animals destined for research at Colegio de Postgraduados. The information was obtained from measurements made in 139 rabbits (78 of New Zealand breed, and 61 of California breed, 51% males and 49% females); 35 days-old (weaning) to 73 days-old (fattening), with an average initial weight of 754.5 g, and 2115 g at the end. Measurements were considered in live rabbits that included live weight (PV), loin width (AL), loin length (LL), leg circumference (PP), and leg length (LP). One day later, those animals were desensitized, slaughtered, and the parts cut from the dressed carcass were measured as, non-chilled carcass weight (PCC), carcass loin weight (PLC), carcass leg weight (PPC), carcass loin width (ALC), carcass loin length (LLC), carcass leg length (LPC).

Canonical Correlation Analysis (CCA)

The CCA was applied to know the relationship between two sets of variables. The first group of prediction or comparison variables, constituted by "p" (V=CANAL), denoted by the X-matrix of order (139 observations * 6 variables), which are non-chilled carcass weight (PCC), carcass loin weight (PLC), carcass leg weight (PPC), carcass loin width (ALC), carcass loin length (CLL), and carcass leg length (LPC).

The second set of "q" criteria variables (W=ANIMAL), denoted by the Y-matrix, of order (139 observations * 5 variables) which are, live weight (PV), loin width (AL), loin length (LL), leg circumference (PP) and leg length (LP), seeking to maximize the correlation between both canonical variables (V and W). Likewise, in linear combinations $V_i = a_1X_1 + a_2X_2 + ... + a_kX_k = X_{ai}$ and $W_1 = b_1Y_1 + b_2Y_2 + ... + b_LY_L = Y_{bi}$. The *ai* and *bi* are standardized canonical coefficients that can be used to determine which variables are redundant and to interpret the canonical variables. These coefficients indicate the relative importance of the set of variables measured in the carcass, and determine the value of the set of variables of the animal. On the other hand, coefficients can be unstable due to the presence of multicollinearity in the data (Mihalik *et al.*, 2022). For this reason, canonical weighing (canonical loadings) provided the importance of each canonical variable.

The correlations between Vq and Wp are called canonical correlations. The square root of canonical correlations (canonical roots or eigenvalues) represent the amount of variance in a canonical variable caused by another canonical variable. To know the canonical coefficients (b1, b2, b3, ... b6 & a1, a2, a3, ... a5), which maximize linear combinations the CCA was implemented, in which the following set of hypotheses was tested:

$$H_0 = p1 = p2 = p3 = p4 = p5 = 0$$

$$H_a = p1 = p2 = p3 = p4 = p5 \neq 0$$

In order to do this, the Wilks' Lambda statistic was used, which showed that under the null hypothesis (H0) the sets Vq and Wp were not linearly related. That is, in the case of this research, the set of variables measured in the carcass and the set measured in live animals were not linearly related.

$\Lambda m = \prod_{i=1}^{m} (1 - \lambda i)$ Wilk's Lambda equation;

where, Λm: canonical correlation coefficient; λi: quadratic canonical correlation; m: number of canonical correlations.

The significance of the canonical correlation coefficient can be tested using the Chi-square test shown below:

$$\chi^2 = -\left(N - 1\left(\frac{Kx + Ky + 1}{2}\right)\right) Ln\Lambda m$$

where, N: number of cases; Λm: canonical correlation coefficient; Kx: number of variables in set X; Ky: number of variables in the set Y.

The sets of V and W of canonical variables were estimated

$$CANAL = V = ZxBx \qquad ANIMAL = W = ZyBy$$

where Zx and Zy are standardized values and Bx, By are canonical coefficients.

The correlation matrix between variables was calculated using the weighted matrix and correlation coefficient.

$$Ax = RxxBx \qquad Ay = RyyBy$$

$$Pv_{xc} = \sum_{i=1}^{Kx} \frac{a^2 ixc}{kx} \qquad Pw_{yc} = \sum_{i=1}^{Ky} \frac{a^2 iyc}{ky}$$

where Pv: the proportion of the variance obtained from a set of variables through a canonical variable of the set, a^2: the square of the correlation and the number of variables in the set, and rd: $redundancy = \left[PV\left(r^2 c\right)\right]$.

Statistical analyses

Descriptive statistics were obtained for all the variables measured using PROC MEANS (SAS Institute Inc., 2013). An analysis of variance was performed using a fixed-effect model and two classification criteria with interaction to know the influence of race and sex on the criteria variables. Non-significant differences ($p > 0.05$) were found between them, so a single dataset was considered.

The PROC CANCORR procedure was applied to know the relationship between the sets of variables V and W, in this study they represent the association between morphological characteristics of the carcasses and the live animals. Large canonical correlations do not always mean that there is a high correlation between the two sets because the CCA does not maximize the amount of variance due to one or more variables in one set for the other set of variables (Badii & Castillo, 2007). Therefore, it is suggested to calculate the redundancy measures for each canonical correlation in order to determine how much of the variance in one set of variables is attributed to the other set.

RESULTS AND DISCUSSION

The descriptive statistics of the morphological and carcass characteristics are presented in Table 1, to provide information for each morphological variable such as, average PV 2115.21g ± 229.21, an average PCC 1185 g ± 165.26 and a carcass yield 56.12% ± 5.73. Carcass yield values were similar to previous studies (Montes-Vergara *et al.*, 2020; Luis-Chincoya *et al.*, 2021). The economically important measurements of the non-chilled carcass PLC (258 g), PPC (349 g) and PCC were notable. These measures varied greatly (12% to 19%). Regarding the measurements in the live animal, those presented a minor variation, similar and homogeneous among them.

Pearson correlations between morphological characteristics of rabbits

Table 2 presents the correlations between the original variables. Regarding the correlations evaluated with variables in the live ANIMAL, those relevant were, PV that was correlated with loin width (AL, r=0.34) and loin length (LL, r=0.38); leg circumference (PP, r=0.31) and leg length (LP, r=0.46). While loin length (LL) was correlated with leg circumference (PP, r=0.48) and leg length (LP, r=0.60).

That is, to the extent that a rabbit has greater measurements in legs and loin, its live weight is greater. This coincides with what was reported by Montes-Vergara *et al.* (2020), where the weight of the non-chilled carcass increased as the measurements in the live animal were greater. In this way, body measurements in the live animal can be a way to predict the weight of the carcass, because both characteristics are closely related. In other zootechnical species (cattle), it is reported that live weight has a high correlation with height

Table 1. Descriptive statistics of the two sets of rabbit variables at the end of fattening.

Carcass	X Variables (Mean±SD)	CV (%)	Animal	Y Variables (Mean±SD)	CV (%)
PCC	1185.3±165.2	13.9	PV	2115.21±229.21	10.8
PLC	258.3±49.1	19	AL	60.14±6.55	10.9
PPC	349.8±41.7	11.9	LL	18.20±2.32	12.7
ALC	56.1±5.4	9.7	PP	13.78±1.87	13.6
LLC	15.3±1.4	9.5	LP	10.13±1.07	10.6
LPC	9.2±0.9	10.4			
PCC	1185.3±165.2	13.9	PV	2115.21±229.21	10.8

SD, standard deviation; CV, coefficient of variation, PCC, non-chilled carcass weight; PLC, carcass loin weight; PPC, carcass leg weight; ALC, carcass loin width; LLC, carcass loin length; LPC, carcass leg length; PV, live weight; AL, loin width; LL, loin length; PP, leg circumference; LP, leg length.

Table 2. Correlation matrix between morphological characteristics in rabbits, measured alive (ANIMAL) or in carcass cuts (CARCASS).

	PV	AL	LL	PP	LP	PCC	PLC	PPC	ALC	LLC	LPC
Animal											
PV	1.00	0.34	0.38	0.31	0.46	0.70	0.45	0.77	0.38	0.41	0.37
AL		1.00	0.11	0.36	−0.08	0.34	0.41	0.24	0.12	0.28	0.26
LL			1.00	0.48	0.60	0.34	−0.11	0.23	−0.09	0.28	0.25
PP				1.00	0.28	0.20	0.21	0.34	0.03	0.28	0.18
LP					1.00	0.32	−0.21	0.37	0.23	0.11	0.30
Carcass											
PCC						1.00	0.63	0.65	0.29	0.45	0.29
PLC							1.00	0.40	0.16	0.43	0.18
PPC								1.00	0.39	0.32	0.34
ALC									1.00	−0.02	0.04
LLC										1.00	0.43
LPC											1.00

PV, live weight; AL, loin width; LL, loin length; PP, leg circumference; LP, leg length; PCC, non-chilled carcass weight; PLC, carcass loin weight; PPC, carcass leg weight; ALC, carcass loin width; LLC, carcass loin length; LPC, carcass leg length.

at withers, and rump length, both measurements approximate well the size of the animal (Lakew *et al.*, 2017; Ozen *et al.*, 2021; Atac & Altincekic, 2023; Macena *et al.*, 2024).

Among the carcass variables (CANAL) correlations, the non-chilled carcass weight (PCC) was positive correlated with all the variables of cuts from the dressed carcass, mainly with the carcass loin weight ($r=0.63$), carcass leg weight ($r=0.65$) and carcass loin length ($r=0.45$). This means that the PCC is determined by the economically important characteristics of the carcass (PLC, PPC and LLC), without the need of considering other characteristics of little or null economic importance. This coincides with what was reported by Adamu *et al.* (2016), who mentioned that breed genetic component has an influence on non-chilled carcass weight.

Correlations between canonical variables

Although the characteristics measured in the live animal are important indicators of the measurements made in the carcass, it is difficult to interpret the simultaneous contribution of the variables included in each set to the relationship between them. To explain more clearly the interrelations between the carcass variables and those in the live animal, five canonical correlations were estimated to explain the correlations between the studied sets. Because the number of canonical correlations to be interpreted corresponds to the minimum number of characteristics within the periods evaluated in the live rabbit (ANIMAL) and in those of the carcass (CANAL) (Table 3).

The likelihood ratio test (Lr) showed that the first three canonical coefficients were significant (0.851, 0.562 and 0.414, $p<0.01$), *i.e.* the hypothesis of equality among canonical coefficients ($p<0.0001$) is rejected, which was corroborated by the tests of Wilks', Pillai,

Table 3. Pairs of canonical correlations between two sets of variables (Vi, Wi), eigenvalues, likelihood ratio, and probabilities.

Canonical	CC	ACC	CC^2	DF	Ev	Lr	Pr>F
1) W_1V_1	0.851	0.841	0.724	30	2.633	0.144	<0.0001
2) W_2V_2	0.562	0.525	0.315	20	0.461	0.525	<0.0001
3) W_3V_3	0.414	0.383	0.171	12	0.207	0.766	<0.0005
4) W_4V_4	0.266	0.248	0.070	6	0.071	0.924	0.1145
5) W_5V_5	0.069	0.028	0.005	2	0.005	0.995	0.7310

CC, canonical correlation; ACC, adjusted canonical correlation; CC2, canonical correlation squared; Df, degrees of freedom; Ev, eigenvalues; Lr, likelihood ratio; Pr>F, probability in relation to F.

Hotelling and Roy. This coincides with what was reported by Adamu *et al.* (2016). The first canonical correlation is the one that showed the highest correlation coefficient of the five analyzed, 0.851 (CC^2=0.72) and correlated the variable measured in the carcass (CANAL, V_1) with the canonical live variable (ANIMAL, W_1). The adjusted canonical correlation presented similar information. The other canonical correlations were lower; therefore, only the first canonical variable was considered, which is consistent with other studies (Lakew *et al.*, 2017; Kim *et al.*, 2018; Atac & Altincekic, 2023), that also considered the first canonical variable.

Based on the proposed hypotheses,

$$H_0 = p1 = p2 = p3 = p4 = p5 = 0$$

$$H_a = p1 = p2 = p3 = p4 = p5 \neq 0\,;$$

in which null hypotheses (H_0) is rejected.

In Table 4 we present the standardized canonical coefficients associated with the first pair of canonical variables. Those coefficients are of great importance because the original variables were not measured in the same units. Thus, standardized coefficients should be interpreted instead of the non-standardized coefficients. The correlations given by the matrices of canonical structure should also be examined. This table shows the effects of the carcass set (CANAL) on the variables included in it (Table 4). Therefore, the canonical variants (W_1 and V_1) represent the optimal linear combinations of the dependent and independent variables, which can be defined using the standardized canonical coefficients.

These estimated coefficients can be interpreted by the following equations, in which only the significant coefficients ($p<0.05$) were included.

$$V_1 = \text{CANAL1} = 0.26\text{PCC} + 0.23\ \text{PLC} + 0.56\text{PPC} + 0.13\text{ALC} + 0.08\text{LLC} + 0.05\ \text{LPC}$$

$$W_1 = \text{ANIMAL1} = 1.01\ \text{PV} + 0.03\ \text{AL} - 0.23\ \text{LL} + 0.24\ \text{PP} - 0.10\text{LP}$$

The first canonical variable, for the carcass (CANAL) variables (V1, V2, V3, V4, V5) shown in Table 4, is a standardized difference with more emphasis on PPC (rc=0.56)

Table 4. Interrelations between standardized canonical coefficients.

X−variables Set						
CARCASS	**PCC**	**PLC**	**PPC**	**ALC**	**LLC**	**LPC**
V1	0.26	0.23	0.56	0.13	0.08	0.05
V2	0.23	−1.1	0.32	0.11	0.17	0.30
V3	−0.50	0.32	0.02	0.81	−0.55	0.25
V4	0.03	0.21	0−.79	0.22	0.16	0.91
V5	−1.35	0.52	0.97	−0.39	0.04	−0.23
Y−variables Set						
ANIMAL	**PV**	**AL**	**LL**	**PP**	**LP**	
W1	1.01	0.03	−0.23	0.24	−0.10	
W2	−0.21	−0.09	0.32	−0.21	0.90	
W3	−0.02	0.18	−1.13	−0.24	0.85	
W4	−0.48	0.43	0.27	−0.48	0.33	
W5	−0.51	0.09	−0.51	1.06	0.39	

PCC, non-chilled carcass weight; PLC, carcass loin weight; PPC, carcass leg weight; ALC, carcass loin width; LLC, carcass loin length; LPC, carcass leg length; PV, live weight; AL, loin width; LL, loin length; PP, leg circumference; LP, leg length.

with PCC (rc=0.26) and PLC (rc=0.23). The coefficients for LLC and LPC were very small and close to zero. Whereas, for the first canonical variable, live variables (ANIMAL) showed a high correlation in live weight and leg circumference, with some negative signs for (−0.03) loin length and leg length (−0.10), but with higher weightings for live weight (PV, rc=1.01) and leg circumference (PP, rc=0.24). Higher coefficients are represented in Figure 1.

According to the equations, the correlations between PPC and PCC and the first canonical variable are positive, which means that as the values of PV and PP increase, also PCC, PLC and PPC increase in the carcass. Variables with the highest canonical weighting contribute to a greater extent to the multivariate relationship between morphological characteristics measured at the end of fattening in the live rabbit. Those will have an impact on the economically important cuts of the dressed carcass.

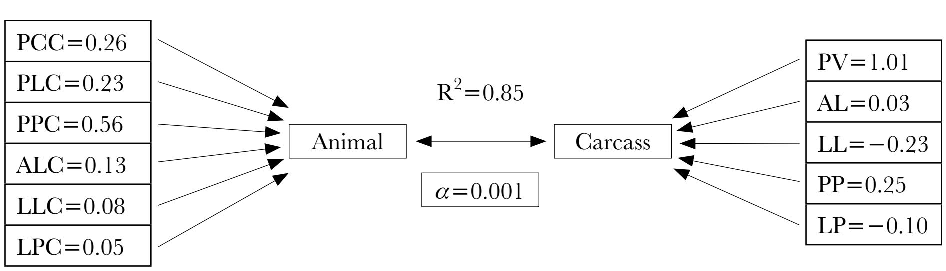

Figure 1. Maximum canonical correlation and standardized canonical coefficients: interrelation between characteristics of the animal and their effects on the carcass. PCC, non-chilled carcass weight; PLC, carcass loin weight; PPC, carcass leg weight; ALC, carcass loin width; LLC, carcass loin length; LPC, carcass leg length; PV, live weight; AL, loin width; LL, loin length; PP, leg circumference; LP, leg length.

In rabbit selection processes, if the PCC of a rabbit is to be predicted with the information of PV and PP, then rabbits with higher PV and PP will produce animals with a higher weight at slaughter age and consequently a higher weight of the cuts from the non-chilled carcass. This information is important to support indirect selection programs, when there are no productive records. The measurement of specific parts of the animal body can help to predict productive behavior, contributing with information for the selection of superior animals. Our results are similar to those reported by Mokoena y Tyasi (2021).

The weightings for carcass characteristics showed that the live weight (PV) of the animal has more influence than other characteristics in the construction of the canonical variable W1. The weightings for the carcass set (CANAL) are mainly influenced by carcass leg weight (PPC), non-chilled carcass weight (PCC) and carcass loin weight (PLC) to form the canonical variable V1 (Table 5).

The weightings of each set of canonical variables in the generation of interrelations (Table 6) for carcass variables (CANAL) are constituted by the non-chilled carcass weight (PCC), where legs weight (PPC) and loin weight (PLC) are outstanding in the canonical variable (V1), these constitute the pieces of highest economic value in the rabbit carcass. While the set of variables W1 is constituted by the live weight (PV) and the leg circumference (PP).

It was found that the canonical variables W1 and V1 presented the proportions of explained variance 66% and 51% respectively, of the total variation in the morphological characteristics measured in rabbits. Their respective values from the redundancy analysis were 31% and 21%.

Table 5. Canonical weightings of the original variables with their opposite canonical variables.

X-variables Set						
CARCASS	**PCC**	**PLC**	**PPC**	**ALC**	**LLC**	**LPC**
V1	0.85	0.66	0.90	0.42	0.49	0.40
V2	−0.07	−0.71	0.26	0.14	0.02	0.36
V3	−0.23	−0.05	0.04	0.75	−0.54	−0.03
V4	0.05	0.21	−0.24	−0.01	0.77	0.07
V5	−0.43	0.03	0.23	−0.31	0.27	−0.60
Y-variables Set						
ANIMAL	**PV**	**AL**	**LL**	**PP**	**LP**	
W1	0.94	0.51	0.23	0.27	−0.80	
W2	−0.23	0.79	0.08	0.29	0.04	
W3	0.18	−0.04	0.38	−0.14	0.94	
W4	−0.06	0.11	−1.09	−0.17	0.94	
W5	−0.15	−0.31	−0.60	1.13	0.16	

PCC, non-chilled carcass weight; PLC, carcass loin weight; PPC, carcass leg weight; ALC, carcass loin width; LLC, carcass loin length; LPC, carcass leg length; PV, live weight; AL, loin width; LL, loin length; PP, leg circumference; LP, leg length.

Table 6. Canonical correlations between carcass characteristics (Carcass) and canonical variables of live rabbits (Animal).

X-variables Set						
CARCASS	**PCC**	**PLC**	**PPC**	**ALC**	**LLC**	**LPC**
V1	0.73	0.56	0.76	0.39	0.42	0.35
V2	−0.04	−0.40	−0.16	0.08	0.01	0.20
V3	−0.10	−0.02	0.11	0.04	−0.23	−0.01
V4	0.01	0.06	0.01	0.30	0.11	0.20
V5	−0.04	0.01	0.05	−0.01	0.01	0.02
Y-variables Set						
ANIMAL	**PV**	**AL**	**LL**	**PP**	**LP**	
W1	0.82	0.37	0.18	0.39	0.25	
W2	0.13	−0.16	0.35	0.05	0.52	
W3	−0.02	−0.03	−0.29	−0.17	0.06	
W4	0.01	0.22	0.05	0.01	0.01	
W5	−0.01	0.01	0.01	0.06	0.01	

PCC, non-chilled carcass weight; PLC, carcass loin weight; PPC, carcass leg weight; ALC, carcass loin width; LLC, carcass loin length; LPC, carcass leg length; PV, live weight; AL, loin width; LL, loin length; PP, leg circumference; LP, leg length.

CONCLUSIONS

This study made it possible to establish the relation of morphological characteristics measured in live rabbits to those measured in dressed carcass cuts. Live weight of rabbits and leg circumference were the factors that most influenced the economically important characteristics of the carcass (loin and legs).

These results are of great importance for breeding stock selection programs, with the aim of improving carcass weight indirectly. Therefore, they can be criteria for rabbit producers when selecting outstanding breeders. The efficiency of indirect selection, based on characteristics in live rabbits, can be an effective strategy for early selection of breeding stock with better weights of carcass, loin and legs.

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