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The potential of non-invasive pre- and post-mortem carcass measurements to predict the contribution of carcass components to slaughter yield of guinea pigs

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ABSTRACT

Guinea pig meat consumption is increasing exponentially worldwide. The evaluation of the contribution of carcass components to carcass quality potentially can allow for the estimation of the value added to food animal origin and make research in guinea pigs more practicable. The aim of this study was to propose a methodology for modelling the contribution of different carcass components to the overall carcass quality of guinea pigs by using non-invasive pre- and post mortem carcass measurements. The selection of predictors was developed through correlation analysis and statistical significance; whereas the prediction models were based on Multiple Linear Regression. The prediction results showed higher accuracy in the prediction of carcass component contribution expressed in grams, compared to when expressed as a percentage of carcass quality components. The proposed prediction models can be useful for the guinea pig meat industry and research institutions by using non-invasive and time- and cost-efficient carcass component measuring techniques.

1. Introduction

The diversification of commercial meat production practices creates the opportunity for the meat of certain indigenous species to be used as valuable food sources (Hoffman & Cawthorn, 2013). For example, nutria (*Myocastor coypus*) meat consumption is common in South America, and its consumption is increasing in Europe, Russia, China and the southern states of the USA (Glogowski & Panas, 2009; Migdal et al., 2013; Tůmová et al., 2017). When the guinea pig (*Cavia porcellus*) is considered, Lammers, Carlson, Zdorkowski, and Honeyman (2009) reported an increase in consumption in Latin American countries such as Ecuador, Perú, Colombia, and Bolivia; as well in other Asiatic and African countries. The biological, ecological and economic benefits that can arise from guinea pig production warrants further attention by those working to alleviate global poverty and food insecurity (Lammers et al., 2009). Vincent, Speybroeck, Assidjo, Grongnet, and Thys (2011) reported that guinea pig producers are found on all levels of society, regardless of gender, age, religion, education level or community.

The prediction of the contribution of different carcass components to overall carcass quality will produce valuable information for ensuring the viability and sustainability of agribusinesses, and nutritional and marketing approaches, as well to optimize production systems or determine the suitability of new feeds.

A variety of internal or external carcass measurements, on live or slaughtered animals, have been used in the prediction of carcass composition as a simple method to assess the edible product quality without involving carcass damage. In an experiment based on pigs, Doeschl-Wilson et al. (2005) showed the relationship between the body size and shape measurements with regard to the carcass component composition. Diverse results have been observed in the prediction of the contribution of carcass components to lamb carcass quality. Thereby, Wolf, Jones, and Owen (2006), Carrasco, Ripoll, Panea, Álvarez-Rodríguez, and Joy (2009) and Lambe et al. (2009) demonstrated the primary importance of live weight and external carcass measurements as predictors of tissue weights and proportions in lambs. More related to guinea pig, studies on carcass components prediction of rabbits were performed by Blasco et al. (1984) and Hernandez et al. (1996). In both works, they analyzed the prediction ability of live weight and some external measurements in a model by simple regression on carcass component composition of rabbits.

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Studies on carcass and meat quality of guinea pig characteristics are limited. To the best of our knowledge no studies have been conducted on the models to estimate carcass quality from carcass components based on standard methods and procedures proposed by Sánchez-Macías, Castro, Rivero, Argüello, and Morales-de la Nuez (2016). Anye, Manjeli, and Ebangi (2010) implemented linear models with different combinations of body metric traits to predict live weights during the growing period of local guinea pigs in Cameroon, useful when lack weighing machines. Hong, Ediger, Raetz, and Djurickovic (1977), developed by the method of least squares two equations in which the guinea pig weight (W2/3 × 8.054, as the general formula for guinea pig) or weight and length of the body (W0.425 × L0.725 × 3.545) were used to calculate the body surface area (BSA), with not significant differences due to sex or age. However, the ability of measured carcass components to predict carcass quality can depend on the experimental conditions. For instance, Liu (1988) concluded that it is necessary to include in the general formula the K-value (a shape constant for a given species), but it should be different for calculating BSA of guinea pig for various ages and body weights. In another guinea pig study (Liu, 1989), K-value also varied as a function of time after viral infection, suggesting that it may be inappropriate to use the BSA formula without another suitable predictor. The body conformation of guinea pigs is relatively uniform, which discard the problems associated with a large conformations variety found in another species. Zelenák, Körmendy, and Vada-Kovács (2004), working with pigs, found significant and considerable differences between prediction equations for individual subgroups representing different crossbreeds and/or different fattening systems; although the overall equation obtained still provided sufficient bias in comparing with the separate sub-group equations.

The objective of this study was thus to use non-invasive carcass component measurement of fattened and discarded reproductive guinea pigs in vivo, at slaughter and after slaughter to predict the contribution of each carcass component to carcass quality.

2. Materials and methods

2.1. Animals and carcass measurements

2.1.1. Animals selection and slaughter procedure

The project was approved by the Universidad Nacional de Chimborazo, which included a statement that the approval by a bioethical committee was not required, since no other procedures were applied than the normal slaughters procedures.

Forty Andean breed guinea pigs (10 male and 10 female of 3 month-old fattened animals, and 10 male and 10 female of 12 month-old reproductive animals) were randomly selected from the experimental flock maintained at the Universidad Nacional de Chimborazo. The animals were fasted for a period of 12–14 h overnight (Vicent Kouakou et al., 2013), and then were slaughtered according to the procedures described by Sánchez-Macías et al. (2016). Live weight (LWS) of all animals was recorded just before slaughter. Empty body weight (EBW) was calculated as the LWS minus the sum of urine in the bladder and tract gastrointestinal content.

The carcasses were weighted approximately 15 min after slaughter in order to obtain the hot carcass weight (HCW) and weighted again after chilling at 4 °C for 24 h to obtain the cold carcass weight (CCW). Hot carcass yield (HCY) and dressing percentage (DCY) were calculated as HCW or CCW divided by LWS (×100), respectively. Also, net (after chilling) carcass yield (NCY) was calculated as CCW divided by EBW (×100).

2.1.2. Linear carcass conformation measurements

Carcass dimensions were measured according to the procedures detailed in the study of Sánchez-Macías et al. (2016). The following measurements were recorded for carcasses suspended in a gamble with a constant width:

- Internal carcass length (L): a straight line from the cranial edge of the manubrium of the sternum to the cranial edge of the pubic bone, measured internally in the left carcass.
- External Carcass Length (ECL): distance from the atlas vertebra to the distal part of os ischia.
- External hind limb length (F1): Distance from the tarsal-metatarsal joint surface to cranial edge of the pubic bone, measured externally in the left carcass.
- Internal hind limb length (F2): Distance from the tarsal-metatarsal joint surface to cranial edge of the pubic bone, measured internally in the left carcass.
- Width of the buttocks (G): Maximal length between both greater trochanters of the femur.
- Width of the thorax (ThW): The greatest width of the chest of the carcass at the level of the caudal edge of the scapula.
- Lumbar circumference (LC): Carcass circumference around the buttocks at the level of the maximum width of the greater trochanters.
- Thorax circumference (ThC): The circumference measured between the spinous process of the eighth thoracic vertebra and the xiphoid cartilage of sternum, just behind the elbow.

2.1.3. Carcass tissue dissection and composition

After the above mentioned linear measurements were recorded, carcasses were halved through the center of the vertebral column, and peri-renal fat (PF) was dissected free and weighed using a precision balance (PS 2100.R2, Radwag, Poland). Both carcass halves were divided into four cuts according to Sánchez-Macías et al. (2016) (Fig. 1), and each cut was weighed, packed in polyethylene bags and frozen at −20 °C for subsequent dissection.

Carcass cuts were thawed overnight at 4 °C, and thawing losses were calculated. After each cut was completely thawed, the respective tissue types were dissected free and grouped into muscle (M), subcutaneous fat (SF), inter-muscular fat (IF), bone (B), skin (Sk) and remainders (Rm, major blood vessels, ligaments, tendons, and thick connective tissue sheets associated with muscles). Total fat (TF) was calculated as the sum of subcutaneous and intermuscular fat deposits. No valuable or edible tissue was calculated as the sum of bone and remainders weights (B + Rm). Also, muscle and muscles + thawing losses weight (M + L, as the sum of M and thawing loss) was calculated. Tissue weights were summed across all individual carcass cuts to obtain the total weight of

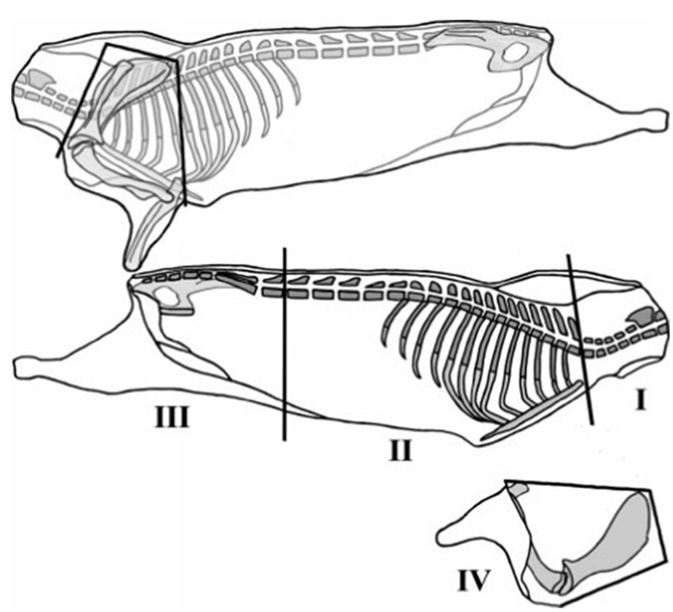

Fig. 1. Scheme for jointing the left half guinea pig carcass into 4 anatomical regions: I, Neck; II, Ribs; III, Long leg; and IV, Shoulder (Sánchez-Macías et al., 2016).

each tissue in carcass, and their percentages were calculated as the weight of each component divided by CCW.

2.2. Statistical analysis

2.2.1. Variable analysis

The Pearson correlation was introduced as a measure of the strength of the relationship between the carcass components and the non-invasive pre- and post-mortem carcass measurements. The relationship was assessed for its significance as well as its strength. The variable analysis was based on rank correlation and the significance test. The correlation matrix contains the pairwise linear correlation coefficient between each pair of predictors (1). The predictors are organized in a $N \times p$ matrix, with N samples and p predictors, consequently the correlation matrix is a $p \times p$ matrix. The significance test (2) was applied to accept or reject a null hypothesis of the existence of a relationship in the pairwise linear correlation.

The Pearson correlation coefficient was computed using the following formula:

$$R_i = \frac{\sum_{j=1}^{N} (x_{j,i} - \bar{x}_i)(x_{j,i+1} - \bar{x}_{i+1})}{\sqrt{\sum_{j=1}^{N} (x_{j,i} - \bar{x}_i)^2 \sum_{j=1}^{N} (x_{j,i+1} - \bar{x}_{i+1})^2}} \tag{1}$$

where i is the number of pairwise combinations.

The significance test of the correlation was computed using the formula:

$$t_i = R_i \sqrt{\frac{N-2}{1-R_i^2}} \tag{2}$$

2.2.2. Carcass tissue composition prediction

A multiple linear regression approach was used to model the relationship between the predictor variables selected previously and the response variables by fitting the resultant linear equations. The best predictors were selected from the results that were obtained in previous section. Parsimonious models (3) were implemented by means of the best correlation avoiding redundant predictors (for example HCW and CCW). For this reason, some predictors were rejected although they were correlated with the resultant variables.

The model for one response variable is defined as follows

$$\hat{y}_i = \beta_0 + \sum_{j=1}^{p} \beta_j x_{ji} + \epsilon, \tag{3}$$

where $\hat{y}_i$ es the ith estimated response variable, β_0 is the intercept, β_j is the jth estimated parameter, and x_{ji} is the jth predictor selected from the observed values, and ϵ is the deviation of the model.

The Least Mean Square (LMS) method was used to compute the estimated parameters. In the least-squares model, the best-fitting line for the observed data is calculated by minimizing the sum of the squares of the vertical deviations from each data point to the line (4). The criteria used by LMS is defined using the following formula:

$$min \sum (y_i - \hat{y}_i)^2, \tag{4}$$

where y_i is the observed response value (independent variable) in the ith observation, and $\hat{y}_i$ is the corresponding estimated response value.

The parameters $\beta_j$are estimated trougth the matrix algebra application; therefore, in matrix form it is expressed as follows

$$\beta = x^{+} y \tag{5}$$

where β is the parameters matrix, $x^{+}$is the Penrose pseudo-inverse matrix, and y is the observed predictor.

The data sample was split in two groups, training with the measurements of 24 animals (60%), and validation with the measurements of the remaining 16 (40%). More precise information on the relationships between carcass composition and non-invasive pre- and post-mortem carcass measurements is provided by the analysis performed on the basis of regression equations.

2.2.3. Prediction efficiency criteria

The prediction accuracy is evaluated using the metrics Root Mean Squared Error (RMSE; Eq. (6)) and Coefficient of Determination R^2 Eq. (7). The RMSE represents the sample standard deviation of the differences between the predicted values and the observed values; whereas R^2 represents the fraction of the total variance around the mean that is explained by the linear relation between the observed and the estimated value.

$$\mathrm{RMSE} = \sqrt{\frac{1}{Nv} \sum_{k=1}^{N_v} (y_k - \hat{y}_k)^2}, \tag{6}$$

$$\mathrm{R}^2 = 1 - \frac{\sum_{k=1}^{N_v} (\varepsilon_k - \bar{\varepsilon})^2}{\sum_{k=1}^{N_v} (y_k - \bar{y})^2}, \tag{7}$$

where N_v is the validation sample size, y_k is the kth observed value $\hat{y}_k$ is the predicted value, $\bar{y}$ is the mean observed value, ε_k is the kth residual value computed between the observed and the predicted value, $\bar{\varepsilon}$ is the mean residual.

3. Results and discussion

3.1. Descriptive statistics of carcass measurements and tissue composition

The means, standard deviations, and ranges for weights, yields, peri-renal fat deposits and linear measurements of guinea pigs are presented in Table 1. It was observed that the LWS ranged from 944 to 2137 g, with a variation of 27.59%, including fattened and reproductive animals, as well males and females.

For the carcass characteristics, it was observed that the HCW varied from 486 to 1304 g, while CCW ranged from 461 to 1251 g, with a variation of 30% for both parameters. A lower variation was observed for carcass yields (5.85–6.96%). The greater variation was observed for the weights of peri-renal fat, registering > 61%. Silva et al. (2009), working with rabbits between 70 and 90 days of age, found a variation of 23.6% for LWS, while CCW had a variation of 27.6%, very similar to our data. On the other hand, Piles, Blasco, and Pla (2000), working with rabbits from different generations, found variation for CCW and CCW of 14 and 15.83%, respectively, while the variation for peri-renal fat deposits of these animals was 36.52%. Bautista-Díaz et al. (2017) working with ewes, found a variation of 20% for LWS, while HCW and CCW had a variation of approximately 26%. In lambs, Díaz et al. (2004) registered a variation for CCW of 15.58%.

The variation of the linear measurements ranged from 9.35 to 14.11% in this study with guinea pigs. Díaz et al. (2004) working with lambs, the variation for these parameters ranged from 4.26 to 13–35%, highly similar to our study, while Silva et al. (2009) observed a variation of 16.7% for dorsal lengths in rabbit carcasses.

The means, standard deviations and ranges for the respective carcass components of guinea pig carcasses are shown in Table 2. The highest weight and proportion mean value was observed for muscle; while the lowest values were found for Rm and IF. For SF, IF, and TF in carcasses, the greater variations were registered: from 56.29 to 67.71 when expressed in grams, and 44.86 to 58.54% when expressed in percentage. Also, other authors found in rabbit carcasses the higher variation for fat deposits, both in grams or percentage, ranging from 23.3 to 40.4% (Piles et al., 2000; Silva et al., 2009). In case of lambs, Bautista-Díaz et al. (2017) and Díaz et al. (2004) found variations for total fat in ewe and lamb carcasses ranging from 24 to 66%. In our study, the high variation in fatness of guinea pig carcasses, similar to lambs, could be due to guinea pigs have higher subcutaneous and localized fat deposits in neck, inguinal region than rabbits.

The percentage of M + L in carcass registered a variation of 60.21%.

Table 1
Means, standard deviations (SD), ranges (Min = minimum; Max = maximum) and coefficient of variation (CV) for weights, yields, peri-renal fat and linear measurements of female (F) or male (M), fattening (3-mo) or discarded (12-mo) guinea pigs.

Item[a]	Mean (± SD)	Min	Max	CV (%)	Mean of the different groups			
					3mo-M	3mo-F	12mo-M	12mo-F
Live weight at slaughter, g	1335.38 (368.40)	944.00	2137.20	27.59	993.20	1054.68	1610.60	1683.04
Hot carcass weight, g	737.08 (221.80)	486.00	1304.00	30.09	512.80	594.24	907.60	933.66
Cold carcass weight, g	702.49 (215.10)	461.00	1251.40	30.62	488.10	559.83	868.90	893.14
Hot carcass percentage, %	54.95 (3.73)	47.44	64.94	6.78	51.67	56.31	56.28	55.53
Cold carcass percentage, %	52.30 (3.64)	45.70	62.32	6.96	49.17	53.07	53.84	53.13
Net carcass yield, %	56.57 (3.31)	49.70	65.96	5.85	53.33	56.94	57.66	58.33
Peri-renal fat, g	5.58 (3.41)	0.75	12.32	61.11	2.13	5.98	8.50	5.05
Internal carcass length, cm	21.27 (1.99)	18.20	25.40	9.35	20.05	19.05	22.66	23.11
External carcass length, cm	26.82 (2.90)	22.00	34.00	10.81	24.53	24.44	29.61	28.69
External hind limb length, cm	10.15 (1.26)	7.50	13.30	12.38	9.77	8.99	11.60	10.25
Internal hind limb length, cm	8.84 (0.99)	7.00	10.90	11.24	8.44	8.51	9.59	8.80
Width of the buttocks, cm	5.80 (0.84)	4.50	7.80	14.11	6.48	4.83	5.73	6.14
Lumbar circumference, cm	20.40 (2.76)	16.40	29.00	13.51	18.06	18.93	21.46	23.14
Thorax circumference, cm	22.09 (2.55)	18.60	28.50	11.54	19.56	20.46	23.89	24.44
Width of the thorax, cm	7.11 (0.84)	5.40	9.40	11.88	7.27	6.83	7.34	6.98

[a] LWS: live weight at sacrifice; HCW: hot carcass weight; HCY: hot carcass yield; CCY: cold carcass yield; PF: peri-renal fat; L: Internal carcass length; ECL: External Carcass Length; F1: External hind limb length; G: Width of the buttocks; ThW: Width of the thorax; ThC: Thorax circumference.

The other tissues range from 30.70 to 33.42% when expressed in grams, while they ranged from 10 to 17.06% when expressed in percentage in carcass. Silva et al. (2009) found a variation of the weight of muscle and bones of 31 and 24%, respectively, and a variation of the percentage of the same tissue of 3 and 11%, respectively. On the other hand, Bautista-Díaz et al. (2017) found a variation of the weight of muscle and bones in ewe carcasses of 18.9 and 11.9%, respectively.

3.2. Correlation coefficients between carcass measurements and carcass tissue composition

Pearson correlation coefficients between carcass tissues (weight and percentage) vs. carcass measurements are presented in Tables 3 and 4, respectively. The LWS, HCW, and CCW parameters were positive and highly correlated to all tissues weights studied and were lowly correlated with percentage contribution of the respective carcass components. Live weight and cold carcass weight have been demonstrated to be powerful estimators for muscle and bone amounts in rabbit carcass (Blasco et al., 1984; Hernández et al., 1996; Silva et al., 2009), as well in light lamb carcasses (Carrasco et al., 2009). Moreover, Carrasco et al. (2009) found positive (percentage of fat) or negative (percentage of muscle and bone) significantly correlation with HCW or CCW, reflecting the tissue growth pattern described for lambs (Kempster, Croston, & Jones, 1987).

Peri-renal fat deposit was highly and positively correlated with TF in guinea pig carcasses but only when expressed in grams (63–70%). This parameter is usually measured by visual assessment, in other species according to a scale, as well it is a good predictor of carcass fatness of rabbits (Varewyck & Bouquet, 1982). In the case of guinea pig carcasses, Ara, Jiménez, Huamán, Carcelén, and Díaz (2012) described a 1 to 5 rating system for body condition scores, well correlated with body mass index (87%), total fat (83%), dorso-cervical caudal fat (86%) and peri-renal fat (83%). In the present study, we do not used this rating system with the objective to be more precise in the predictions.

The L, ECL, LC and ThC parameters were also highly and positively correlated with all tissue compositions weights, but not very well

Table 2
Means, standard deviations (SD), ranges (Min = minimum; Max = maximum) and coefficient of variation (CV) for carcass components weights and percentages of female (F) or male (M), fattening (3-mo) or discarded (12-mo) guinea pig carcasses.

Item	Mean ± SD	Min	Max	CV (%)	Mean of the different groups			
					3-M	3-F	12-M	12-F
Carcass composition, g								
Subcutaneous fat	46.2 (26.8)	4.2	125.0	57.96	22.60	49.17	48.13	65.19
Intermuscular fat	17.5 (11.9)	2.7	51.0	67.71	6.22	18.81	20.42	24.82
Total fat	63.8 (35.9)	6.8	147.3	56.29	28.58	67.98	68.56	90.01
Muscle	323.5 (99.2)	147.4	545.7	30.70	233.11	245.84	420.06	395.14
Muscle + thawing loss	341.2 (106.5)	153.0	572.4	31.26	239.64	259.02	448.63	417.53
Bone	124.7 (41.1)	88.6	255.1	32.96	98.14	87.82	156.16	156.51
Skin	140.5 (46.9)	85.9	261.6	33.42	99.25	111.30	164.05	187.46
Remainders	12.7 (7.1)	3.0	29.7	55.98	10.09	8.24	12.73	19.91
Bone + remainders	137.4 (45.8)	85.8	284.8	33.37	108.23	96.06	168.90	176.42
Carcass composition, %								
Subcutaneous fat	6.4 (3.0)	0.6	14.3	46.90	4.57	8.70	5.33	7.10
Intermuscular fat	2.4 (1.4)	0.4	7.8	58.54	1.27	3.27	2.25	2.87
Total fat	8.8 (3.9)	0.9	18.2	44.86	5.85	11.97	7.58	9.97
Muscle	46.2 (4.6)	30.4	53.4	10.00	47.72	48.45	44.06	44.52
Muscle + thawing loss	48.7 (5.1)	31.5	60.2	60.21	49.07	46.46	51.93	47.08
Bone	17.9 (2.9)	12.3	26.7	16.60	20.13	15.79	18.19	17.47
Skin	20.0 (2.2)	15.1	26.0	10.73	20.36	19.96	18.84	20.85
Remainder	1.8 (0.8)	0.3	5.2	46.67	2.08	1.49	1.45	2.20
Bone + remainders	19.7 (3.3)	13.1	30.3	17.06	22.21	17.29	19.64	19.67

Table 3
Pearson's correlations between carcass component composition (in grams) and objective carcass measurements of guinea pigs.

Predictor	Carcass component amounts								
	Subcutaneous fat	Intermuscular fat	Total fat	Muscle	Muscle + thawing loss	Bone	Skin	Remainders	Bone + remainders
Carcass measurements									
Live weight at slaughter, g	0.62**	0.55**	0.65**	0.95**	0.92**	0.83**	0.94**	0.63**	0.84**
Hot carcass weight, g	0.69**	0.55**	0.70**	0.95**	0.95**	0.87**	0.94**	0.63**	0.88**
Cold carcass weight, g	0.69**	0.58**	0.70**	0.95**	0.94**	0.86**	0.94**	0.60**	0.87**
Hot carcass percentage, %	0.53**	0.26	0.48**	0.41**	0.46**	0.45**	0.40*	0.23	0.44**
Cold carcass percentage, %	0.57**	0.41**	0.55**	0.42**	0.47**	0.44**	0.41**	0.20	0.42**
Net carcass yield, %	0.53**	0.35	0.51**	0.47**	0.52**	0.53**	0.47**	0.22	0.51**
Peri-renal fat, g	0.63**	0.70**	0.70**	0.58**	0.54**	0.30	0.57**	0.25	0.31
Linear measurements									
Internal carcass length, cm	0.37*	0.36	0.40*	0.86**	0.84**	0.84**	0.76**	0.60**	0.85**
External carcass length, cm	0.42**	0.34	0.43**	0.88**	0.89**	0.86**	0.76**	0.51**	0.85**
External hind limb length, cm	0.08	0.02	0.07	0.62**	0.63**	0.72**	0.44**	0.27	0.68**
Internal hind limb length, cm	0.05	0.08	0.07	0.35	0.35	0.36	0.21	0.13	0.34
Width of the buttocks, cm	0.06	−0.09	0.02	0.21	0.18	0.39*	0.33	0.43**	0.42**
Lumbar circumference, cm	0.59**	0.51**	0.61**	0.78**	0.77**	0.64**	0.88**	0.54**	0.66**
Thorax circumference, cm	0.61**	0.56**	0.65**	0.92**	0.90**	0.75**	0.91**	0.55**	0.76**
Width of the thorax, cm	0.22	0.08	0.19	0.18	0.16	0.14	0.20	0.05	0.13

* $\rho < 0.02$.
** $\rho < 0.01$.

correlated with tissue composition in percentages. F1 (external hind leg length) was also well correlated but only with muscle, bone and skin tissues weights. A lower correlation is obtained between the proportional measurements and the predictors than the measurements in grams. The variables related with live weight, carcass weights and yields, and most of the linear measurements had no correlation statistically significant with respect to all proportional components in carcass.

3.3. Prediction of carcass component composition

Table 5 presents the regression equations to predict carcass component composition (grams and percentages), and the results of metrics RMSE and R^2, which advise the prediction accuracy.

The equations for assessment both, SF and TF, expressed in grams, in a carcass composition, contained the three variables LWS, HCW and PF. The prediction accuracies based on RMSE were 13.9 and 19.4 g, and based on R^2 were 70.3% and 74% for SF and TF, respectively. The equation for assessment IF, expressed in grams, contains only one variable (PF), and the prediction accuracy based on RMSE was 8.4 g, and based on R^2 was 60.7 Lower accuracy was obtained for the fat deposits percentages, where the correspondents R^2 were 55.9%, 55.7% and 42.5% for SF, TF and IF, respectively. Silva et al. (2009) also found that live weight of rabbits is a good predictor when using simple linear regression, with a prediction accuracy of 44.9% and only 0.04% for fat amount and fat percentage in carcass. Hernández et al. (1996) also used PF to predict fat weight and fat percentage of two synthetic rabbit breeds, reporting a R^2 of 77% and 69%, respectively.

The lower accuracy dynamic was observed for all carcass components expressed in percentages, as found by Díaz et al. (2004) in lamb carcasses, and Blasco et al. (1984) and Hernández et al. (1996) in rabbit carcasses. This finding agreed with Silva et al. (2009), who noted that conversion of weights to percentage removes most of the variation caused by the differences in LWS among animals, and hence makes the explanation of the variation in the percentage of each tissue more difficult.

Table 4
Pearson's correlations between carcass component composition (in percentages) and objective carcass measurements of guinea pigs.

Predictor	Carcass components in percentages								
	Subcutaneous fat	Intermuscular fat	Total fat	Muscle	Muscle + thawing loss	Bone	Skin	Remainders	Bone + remainders
Carcass measurements									
Live weight at slaughter, g	0.09	0.17	0.13	−0.03	−0.02	−0.16	0.06	0.06	−0.12
Hot carcass weight, g	0.12	0.20	0.16	−0.04	−0.03	−0.19	0.04	0.06	−0.15
Cold carcass weight, g	0.16	0.17	0.18	−0.08	−0.03	−0.15	0.01	0.04	−0.12
Hot carcass percentage, %	0.16	0.2	0.19	−0.1	−0.05	−0.17	−0.01	0.03	−0.14
Cold carcass percentage, %	0.37***	0.13	0.32**	−0.23	−0.08	−0.14	−0.18	−0.06	−0.14
Net carcass yield, %	0.25	0.01	0.20	−0.2	−0.03	−0.01	−0.12	−0.07	−0.02
Peri-renal fat, g	0.37***	0.29*	0.37***	−0.31*	−0.17	−0.23	−0.26	−0.12	−0.23
Linear measurements									
Internal carcass length, cm	0.25	0.20	0.25	−0.29*	−0.13	−0.12	−0.22	−0.14	−0.14
External carcass length, cm	0.44***	0.54***	0.53***	−0.14	−0.18	−0.57***	−0.04	−0.15	−0.54***
External hind limb length, cm	−0.16	−0.01	−0.13	0.12	0.11	0.1	−0.06	0.13	0.12
Internal hind limb length, cm	−0.09	−0.01	−0.07	0.1	0.19	0.05	−0.17	0.02	0.05
Width of the buttocks, cm	−0.29*	−0.29*	−0.33**	0.19	0.26	0.39***	−0.21	−0.03	0.26
Lumbar circumference, cm	−0.14	−0.07	−0.13	0.15	0.20	0.16	−0.21	−0.07	0.12
Thorax circumference, cm	−0.18	−0.33*	−0.25	−0.06	−0.15	0.43***	0.26	0.40***	0.48***
Width of the thorax, cm	0.15	0.19	0.18	−0.11	−0.09	−0.26	0.25	0.04	−0.22

* $\rho < 0.1$.
** $\rho < 0.05$.
*** $\rho < 0.02$.

Table 5
Equations to predict carcass tissue composition of guinea pigs in grams or percentage, RMSE (Root Mean Squared Error) and R^2 (determination coefficients).

Traits			
Carcass tissue, g	Prediction equation	RMSE, g	R^2, %
Subcutaneous fat	= −6.6 + (0.03 × LWS) + (0.1 × HCW) + (3.2 × PF)	13.9	70.3
Intermuscular fat	= 5.2 + (2 × PF)	8.4	60.7
Total fat	= −14.1 – (0.01 × LWS) + (0.08 × HCW) + (4.9 × PF)	19.4	74.0
Muscle	= −98 + (0.03 × LWS) + (0.31 × HCW) + (6.9 × ThC)	25.7	94.4
Muscle + thawing loss	= −56 + (0.4 × HCW) + (3.8 × ThC)	24.6	96.1
Bone	= −8.7 + (0.15 × HCW) + (5.6 × ECL) – (5.9 × ThC)	14.7	90.2
Skin	= −77.9 + (0.14 × HCW) + (5 × ThC)	11.4	94.7
Remainder	= 2.8 + (0.02 × HCW) – (0.27 × ThC)	4.1	68.9
Bone + remainders	= 14.6 + (0.19 × HCW) + (4.7 × ECL) – (6.5 × ThC)	16.8	90.1
Carcass tissue, %	Prediction equation	RMSE, %	R^2, %
Subcutaneous fat	= 5.3 + (0.19 × HCY) + (0.35 × PF) – (1.07 × F1)	2.2	55.9
Intermuscular fat	= 4.3 + (0.19 × PF) – (0.3 × F1)	1.2	42.5
Total fat	= 13.5 + (0.12 × CCY) + (0.58 × PF) – (1.36 × F1)	2.8	55.7
Muscle	= 50 – (0.24 × CCY) + (0.08 × F1)	3.5	34.1
Muscle + thawing loss	= 37.6 + (1.25 × F1) – (0.09 × ThC)	3.8	8.2
Bone	= 16.5 – (0.12 × CCY) + (1.4 × G)	1.7	51.2
Skin	= 22.5 – (0.12 × CCY) + (0.65 × G)	1.9	16.0
Remainder	= 1.3 + (0.025 × L)	0.5	3.9
Total fat	= 13.5 + (0.12 × CCY) + (0.58 × PF) – (1.36 × F1)	2.8	55.7
Bone + remainders	= 19.7 + (0.19 × HCW) – (0.18 × CCY) + (2.11 × G) – (0.34 × ThW)	2.0	51.4

Another significant guinea pig carcass component is muscle content, which may be determined based on measurements of LWS, HCW and ThC. The obtained accuracy was high, with a R^2 of 94.4%. In consequence, also M + L obtained high accuracy with a R^2 of 96.1%. Muscle composition in percentage obtained a R^2 of 34.1%. Other authors also used LWS for muscle amount prediction in rabbit carcass, with a R^2 ranging from 78 to 90.6% (Blasco et al., 1984; Hernandez et al., 1996; and Silva et al., 2009), whereas through CCW the accuracy was increased to R^2 ranging from 88 to 95%. These authors, also found that carcass muscle in percentage obtains lower accuracy, with these parameters.

Skin is a significant carcass compositional parameter, it may be determined with HCW and ThC. The prediction accuracy obtained by means of the regression equation was high, with a R^2 of 94.7%. For Skin composition in percentage, poor prediction results were obtained. As in introduction section was explained, guinea pig weight and length of the body have been used in some studies to predict BSA. In our study we evaluate the powerful of some carcass measurements to predict the skin weight, and ThC plays an important role together with hot carcass weight.

Bone, Remainders, and B + Rm are the less significant components of carcasses; their content may be determined based on HCW, ECL and ThC parameters, and their prediction accuracy were 90.2%, 68.9% and 90.1%, respectively. Blasco et al. (1984) also used carcass measurements to include them in equations for prediction of bone amount of rabbit carcass. The authors reported a maximum R^2 of 78%, lower than in our study.

The HCW parameter was included in all the equations to predict carcass component amounts in guinea pig, except for intermuscular fat deposit prediction equation. In this work we have found that Thorax circumference (ThC) contributes greatly in regression models for most of the tissues amount prediction, except fat deposits. As found in other works in rabbits, live weight, carcass weight and external measurements are good predictors and are often included in prediction models (Blasco et al., 1984; Hernandez et al., 1996; Silva et al., 2009).

The peri-renal fat predictor was included in all the equations to predict fat deposits, which indicates that this variable can be a very good subjective indicator of carcass fatness. Previous studies conducted in ewes have shown that body weight and body condition score are good estimators of body energy reserves, especially as fat reserves (Caldeira & Portugal, 2007; Chay-Canul, Ayala-Burgos, Kú-Vera, Magãna-Monforte, & Tedeschi, 2011; Kenyon, Maloney, & Blache, 2014). Morais et al. (2016) reported that to predict the lamb carcass fat content and muscle content, body weight is a very good variable, concluding that it is an easily variable obtained in the field, at a low cost. Bautista-Díaz et al. (2017) found that biometric measurements can be used to predict carcass tissue composition (in weights) of Pelibuey ewes with different body compositions. They recommended not using the models for animal from different sex or physiological conditions. In that case, they used 4-year-old, non-pregnant and non-lactating ewes with a mean body weight of 41 kg and the five body condition scores. In our study we included both sexes in the models, as well fattened or discarded reproductive guinea pigs, with a very good accuracy.

The equations that were obtained to predict the carcass tissue composition of guinea pigs in percentage, hot or cold carcass yields were widely used as predictors. They were involved in the estimation of subcutaneous fat, muscle, bone, skin, and total fat in carcass. Again, in this case, the peri-renal fat was a good predictor for all deposits recorded in this study, as well F1 (external hind limb length) is presented in the equations for carcass fatness. The variable G (width of the buttocks) was used in the estimation of bone and skin.

Dissection is an invasive, expensive, and labor-intensive method, which makes it impracticable at most research institutions. In Peru and Ecuador, researchers are working in the characterization of existing and new synthetic breeds of guinea pigs. There is a need to focus on methods which can display carcass components composition directly without using dissection. The actual classification of guinea pig carcasses according to the Peruvian Technical Norm (NTP 201.058, Indecopi, 2006) can lead some messy confusion related to fatness and guinea pig carcass conformation, and Ecuador is interested in implementing a technical standard norm on guinea pig meat.

It is essential to find strategies to evaluate carcass quality both with industrial and researching purposes on a large scale without using dissection methods. Methods must be easy to apply by producers, slaughterhouses, and researchers, but mainly non-expensive. An advantage of external carcass measurements is their low cost, but their limitation is associated with the accuracy of measures (Fernandes, Tedeschi, Paulino, & Paiva, 2010; Fonseca et al., 2016). It is necessary further research to analyze the ability of producers and researchers on measuring, as well the precision and repeatability of their measures.

It is necessary to develop tradition prediction studies before analyzing the possibility of using imaging methods (ultrasound, computer tomography, magnetic resonance imaging, dual energy X-ray absorptiometry) or compare with learning machine algorithms which can be more sophisticated than simple linear formulas.

4. Conclusions

Nine parsimonious models were implemented by means of the best predictors (1 to 3 variables) selected from the correlation analysis of 17 non-invasive, cost-efficient measurements of different guinea pig carcass components.

Hot carcass weight is a good predictor for guinea pig carcass components expressed in grams; whereas the cold carcass yield is a good predictor for the composition in percentages but not in grams. Metrics measurements can be used to predict carcass components. Thorax circumference is important in the prediction of muscle, bone, skin, and remainders weights, whereas thorax width is important only for non-valuable carcass component. High efficiency was found in the prediction of carcass components composition in grams. However, with the same predictors, the prediction of carcass composition in percentage reaches low efficiency.

Prediction models presented in this study have a very good accuracy to estimate the weights of the different carcass components of guinea pig carcasses, as well fatness in carcass in percentage. For the rest of the tissues estimations in percentage, the models must be improved, or simply it can be calculated using the tissues weights and hot carcass weight.

All the variables were obtained using non-invasive and easy body or carcass measuring techniques, which were efficient in terms of cost and time. It has been established that non-invasive techniques for predicting carcass composition in animals in vivo are preferred over techniques involving the destruction of the carcass (Scholz, Bünger, Kongsro, Baulain, & Mitchell, 2015). To improve the efficiency of the prediction of guinea pig carcass component composition, our research group is currently developing artificial intelligence methods to improve the accuracy in the estimation of guinea pig carcass components composition.

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