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Relationships among carcass shape, tissue composition, primal cuts and meat quality traits in lambs: A PLS path modeling approach

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ABSTRACT

This study aimed to understand the relations among measures of carcass shape, of carcass tissue characterization, and of commercial cuts of hair sheep lambs in order to assess the ability of images obtained through video image analysis (VIA) to consistently describe meat quality. Information on 67 cold carcasses were submitted to the partial least squares path modeling (PLS-PM) method regarding the manifest variables (MV) that made up the latent variables (LV) of carcass shape (SHAPE), meat quality (QUALI_MEAT), carcass tissue composition (TISSUE_CARCASS), and commercial cut composition (TISSUE_ PRIMALCUTS). Three models that differed according to SHAPE characteristics were evaluated. Model VIA1, with MVs of total projection of carcass and regions, was considered the suitable validated model and was able to predict meat quality characteristics only for the aspects of cooking loss and shear force. It enables establishing categories for carcass classification that directly determine meat juiciness and tenderness from the latent variables considered from carcass shape and description of tissue carcass and primal cuts.

1. Introduction

Predicting meat quality characteristics based on video image analysis (VIA) of carcasses has been the target of studies in recent years, using measurements from images as predictive variables. Some studies link such information to the current carcass grading systems (Einarsson et al., 2014), with the aim of understanding the usefulness of digital measurements to assess meat quality. The use of technologies and tools as the VIA (Video Image Analysis) become quicker and more accurate alternatives in predicting the composition and quality of carcass and meat (Craigie et al., 2013; Hopkins et al., 2004).

The VIA has been consolidated as a tool to evaluate many quantitative and qualitative features of the carcass, for unite predicates as objectivity, doesn't be invasive neither destructive, which allows a precise evaluation of the carcass without interfering with the production flow (Craigie et al., 2013). However, the results are conflicting and sometimes exalt the direct implication of finishing, conformation, and marbling scores on characteristics such as texture, color and consumer preference (Moore et al., 2010; Valous et al., 2016; Gagaoua et al., 2018) and at times do not even find a relation among these aspects (Bonny et al., 2016; Lorenzo et al., 2017). In the face of this inconsistency, relational studies on carcass and meat quality converge towards the use of more robust modeling techniques that explain the systemic relations among sets of characteristics.

This study is based on the theory that each set of quantitative and tissue characteristics of the carcass, primal cuts and meat quality can be treated as latent variables (LVs), which can be quantified and qualified, in order to clarify relationships between the variables within a set and between the sets themselves. Therefore, the analyses were conducted in the structural equation modeling (SEM) using PLS path modeling (PLS-PM), a popular methodology in biological studies (Corradi-Dell'Acqua et al., 2012; Nazari et al., 2015; Tahani et al., 2018), still little explored for assessments of carcass and meat parameters, due to the large number of variables studied and the possibility of analysis validation within same sample universe. Thus, this study aimed to apply PLS-PM to understand the relations among measures of carcass shape, of carcass tissue characterization and of primal cuts of hair sheep lambs in order to evaluate the ability of shape measures obtained through VIA to consistently describe meat quality.

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2. Materials and methods

The experimental procedures were approved by the Federal University of Pará's Committee of Ethics on Animal (CEUA/UFPA protocol n°. 97–2015) and animal care followed the guidelines of the National Council of Animal Experimentation Control (CONCEA, 2015).

2.1. Obtaining the carcasses

Information on 67 cold carcasses from castrated male hair sheep lambs between 8 and 11 months old from commercial herds in the state of Pará, Brazil was used. The animals were finished in confinement and had body weight at slaughter between 21 and 49 kg, which reflects the variability in slaughter criteria of these herds. The cold carcasses were obtained after 24 h of refrigeration at 4 °C and the cold carcass weight (CCW, kg) and cold carcass yield (CCY, %) were measured, accepted as Manifest Variables (MVs) that composed, together with the tissue composition of the whole carcass, the LV TISSUE_CARCASS, specified in 2.4.

2.2. Characterization of the carcass shape (SHAPE)

Considering that the primary objective of this study was to understand the relationships among carcass shape, tissue composition and meat quality, three different shape characterizations were evaluated, also admitted as Latent Variables (LVs): the first one that appreciates shape as a set of morphometric measurements, obtained *in loco* in the cold carcass, was designated SHAPE_MPH and; the other two, which considered shape as sets of metrics obtained, in the cold carcass images, by VIA, composed SHAPE_VIA1 and SHAPE_VIA2.

2.2.1. Obtaining morphometric measures and SHAPE_MPH composition

Further the comparative purpose, the cold carcass morphometric measurements were also performed aiming the VIA calibration. The measurements obtained (Fig. 1a) 11 measures of the dorsal view, 21 of the right-side view, and 7 of the right-side half carcass. Some measurements were based on several publications (Yáñez et al., 2004; Cezar and Souza, 2007; Cam et al., 2010), but most were conceived for this study. The whole of these measures made up the latent variable (LV) called SHAPE_MPH, totaling 39 manifest variables (MVs).

2.2.2. Obtaining carcass images VIA and composition of SHAPE_VIA1 and SHAPE_VIA2

The images were obtained using a digital camera with 16 M P resolution (Nikon PowerShot SX160 IS®) placed 2 m from the carcass support structure/studio and 1.5 m high. The cold carcasses were positioned longitudinally by the tarsal-metatarsal joints, so they could be photographed from the dorsal and side views.

The images were processed using the software ImageJ2 (Rueden et al., 2017). 15 projections were manually delimited based on a reference scale in centimeter (cm) in the image (30 cm) to generate one projection of the whole carcass outline in the dorsal view and one in the side view (Fig. 1b) besides 13 projections of regions of interest (Fig. 1c), being 7 in the dorsal and 6 in lateral view.

To each projection were obtained eight characters described as shape descriptors, according to Leibrandt and Le Pennec (2015): area (A, cm^2), perimeter (P, cm), length (L, cm), width (W, cm), aspect ratio (AR, non-dimensional parameter obtained from the ratio between the width and length of the selection), convexity (CON, non-dimensional parameter obtained from the ratio between the perimeter and the perimeter of the convex hull), solidity (SOL, non-dimensional parameter obtained from the ratio between the selection area and the area of the convex hull of the selection) and circularity (CIR, non-dimensional parameter obtained by the equation $4\pi \times [\text{area}/(\text{perimeter})^2]$, whose values range from 0, representing an extremely oblong shape, to 1, a perfectly round shape).

The descriptors set of all 15 projections, referring to the whole carcass and the regions, comprising 120 descriptors or MVs, composed LV SHAPE_VIA1. However, 12 of these descriptors were excluded in the pre-processing phase because they presented low variability, generally with an average of 1 and a standard deviation less than 0.001, being related to the commercial cuts delimitations: solidity (in the dorsal view - of the palette, right and left leg, in lateral view - of the rib) and convexity (in the dorsal view - of the palette, rib I, loin, croup, right leg and left leg, side view - of rib and loin). Thus, LV SHAPE_VIA1 was composed of this set of 108 descriptors (MVs).

Also, another set of descriptors obtained by VIA was evaluated, considering only the two projections of the whole carcass (dorsal and lateral view), constituting the LV SHAPE_VIA2, with 16 MVs.

2.3. Obtaining Tissue Composition and characterization of LVs from tissue composition of whole carcass (TISSUE_CARCASS) and of the commercial cuts (TISSUE_PRIMALCUTS)

The right-side cold carcass was divided into primal cuts (shoulder, leg, rib, and loin) according to Lage et al. (2014). The cuts were weighed (kg) and multiplied by two to obtain their whole carcass yields in percentages. All cuts were dissected according to Lima et al. (2017) to obtain the weights of muscle (M), bone (B), and fat (F) in kg and their yields in percentages. For each cut, the muscle:bone (M:B), fat:bone (F:B) and edible portion:bone (EP:B) ratios were obtained from (M + F)/B. The LV made up of the set of such information added with the weights and yields of the primal cuts was called TISSUE_PRIMALCUTS, totaling 32 MVs.

The same ratios were measure for whole carcass by extrapolating the sum of the weights of M, B and F of the cuts. The set of information on quantitative cold carcass characteristics (CCW and CCY), of total tissue composition and ratios among carcass tissues determined LV TISSUE_CARCASS with 12 MVs.

2.4. Obtaining Meat Quality Traits and characterization of LV from meat quality (QUALI_MEAT)

The muscle pH at 45 min (pH_0) and 24 h (pH_{24}) post-mortem were measured by inserting a glass electrode into the region of Longissimus lumborum muscle between 12th and 13th ribs, using a pH meter equipped with thermometer (Schott-Geräte GMBH, Germany; calibrated to 4 and 7). In the same region of the muscle, fresh ribeye slices were cut perpendicular into 2.5 cm thick sections to obtain the instrumental color evaluation 24 h post mortem in terms of lightness (L*), redness (a*) and yellowness (b*) by means of illuminant D65, viewing angle 8° and standard of the observer of 10°, according to specifications of CIE (2004) using a portable colorimeter (Hunter Lab), with an accessory of protection to the humidity; besides the colorimetric indexes of chromaticity $(a^{*2} + b^{*2})^{1/2}$ and the Hue hab = arctangent (b*/a*) (AMSA, 2012). A white tile was use to calibrate the instrument. The averages of six measurements taken per slice were use in the statistical analysis.

Cooking loss (%) was obtained in triplicate calculated by the percentage difference between weights before and after baked in a preheated oven at 180 °C until to internal temperature of 70 °C (AOAC, 1995). The shear- force (kgf/cm^2) was evaluated after cooking subsamples of 1.27 cm^2 diameter taken from the slices by a cylindrical aluminum mold cut parallel to the muscle fibers and analyzed in a texturometer (Texture Analyzer TA - XT2i), with Warner - Bratzler blade, as proposed by Wheeler et al. (1994), with a velocity of 60 mm / min and a distance of 30 mm. QUALI_MEAT was called the LV formed from the set of meat quality parameters, totaling 9 VMs.

2.5. Statistical analyses

The minimum sample size estimation for use of structural equation

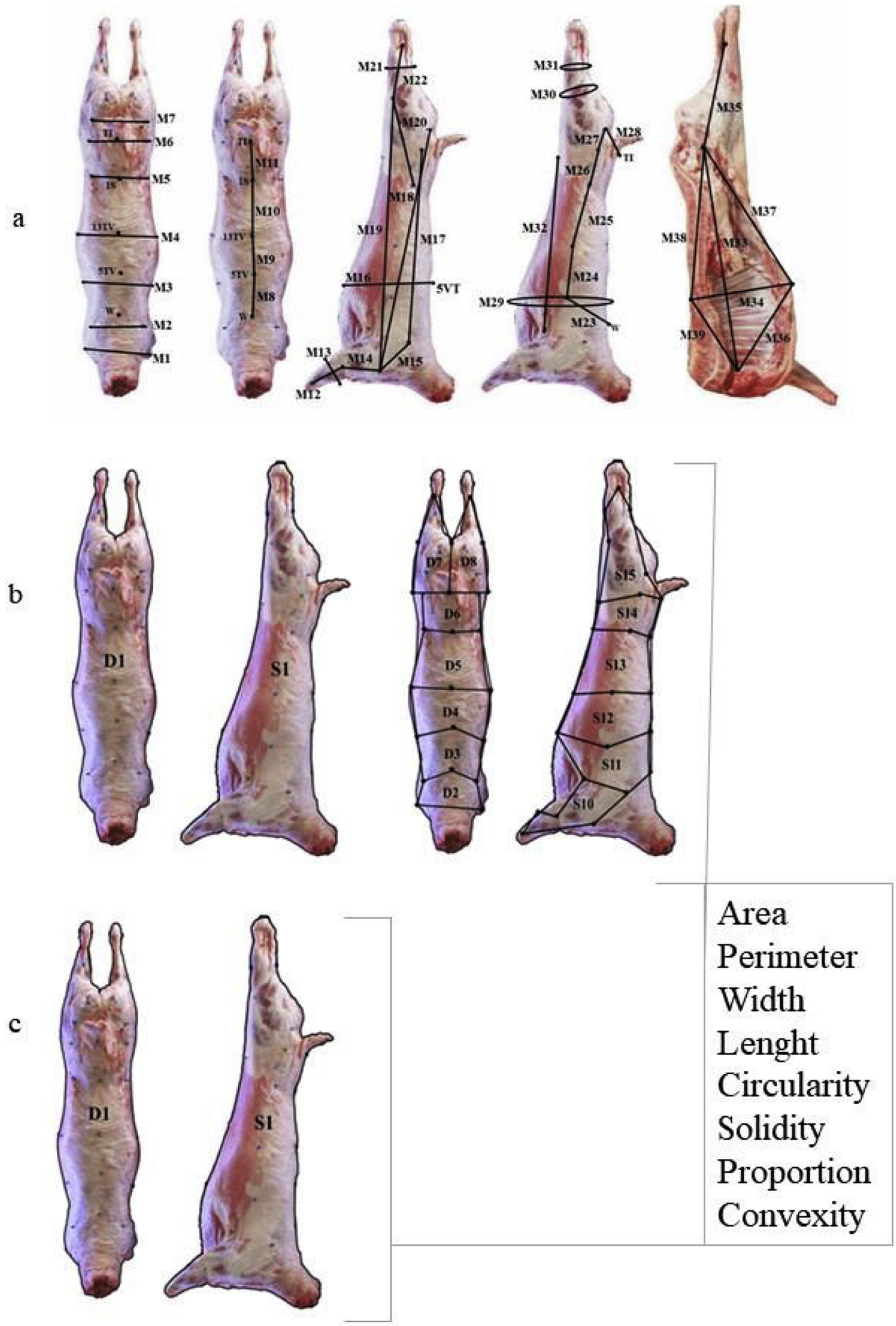

Fig. 1. Manifest variables of latent variable morphometric measures (a) obtained from the cold carcass of hair sheep lambs in the dorsal, side, and half-carcass views that composed the SHAPE_MPH; (b) regions obtained by VIA in the dorsal and side views for the interest region that composed the SHAPE_VIA 1 + the projections of the SHAPE_VIA1; (c) projections of the whole carcasses that composed the SHAPE_VIA 2 + the projections of the SHAPE_VIA2.

(a) Dorsal View 1: M1 = distance between shoulder blades; M2 = distance between shoulder spines; M3 = dorsal width; M4 = loin width; M5 = croup width; M6 = distance between the right ileum and the left ileum; M7 = distance between the right ischium and the left ischium; TI = tail insertion; 5TV = 5th thoracic vertebra; 13 T V = 13th thoracic vertebra; W = withers; 1S = 1st sacral.

(b) Dorsal View 2: M8 = distance between the withers and the 5th thoracic vertebra; M9 = distance between the 5th thoracic vertebra and the 13th thoracic vertebra; M10 = distance between the 13th thoracic vertebrae and 1st sacral vertebra; M11 = distance between the 1st sacral vertebra and the tail insertion.

Side View 1: M12 = forearm length; M13 = forearm width; M14 = arm length; M15 = scapula length; M16 = chest depth; M17 = distance between shoulder blade and ileum; M18 = distance between shoulder blade and ischium; M19 = distance between shoulder blade and femorotibial joint; M20 = thigh length; M21 = leg width; M22 = leg length. **Side View 2:** M23 = distance between the withers and the 5th rib; M24 = distance between the 5th rib and 13th rib; M25 = distance between the 13th rib and the coxal tuberosity; M26 = distance between the coxal tuberosity and the ileum; M27 = distance between the ileum and the ischium; M28 = distance between the ischium and the tail insert; M29 = chest perimeter, M30 = thigh perimeter; M31 = leg perimeter; M32 = distance from the lower line of the carcass.

Half-Carcass View: M33 = internal carcass length; M34 = inner carcass depth; M35 = internal leg length; M36 = distance between the 1st rib and the end of the womb; M37 = distance between the end of the womb and the pubic bone; M38 = distance between the pubic bone and the tip of the dorsum; M39 = extreme distance from the back to the 1st rib.

(b) Selections referring to the projections of the carcasses and of the regions obtained by ImageJ in the dorsal and side views for the entire carcass and the interest regions that composed the SHAPE_VIA 1.

Dorsal View 1: D1 = projection of the entire carcass in the dorsal view.

Dorsal View 2: D2 = dorsal shoulder; D3 = dorsal rib I; D4 = dorsal rib II; D5 = dorsal loin; D6 = dorsal croup - leg; D7 = dorsal right leg; D8 = dorsal left leg.

Side View 1: S1 = projection of the entire carcass in the side view.

Side View 2: S2 = side shoulder; S3 = side rib I; S4 = side rib II; S5 = side loin; S6 = side croup - leg; S7 = side leg.

(c) Selections referring to the projections of the carcasses obtained by ImageJ in the dorsal and side views that composed the SHAPE_VIA 2.

Dorsal View 1: D1 = projection of the entire carcass in the dorsal view.

Side View 1: S1 = projection of the entire carcass in the side view.

modeling in PLS-PM was done using G*POWER 3.1.7 software (Faul et al., 2009) considering such as moderate effect size (0.15) and test power (1-β) = 0.80 (Faul et al., 2007), resulting in the value of 20 samples. Thus, the sample size of the study exceeds more than three times the size necessary for the technique employed to be adequate and validated.

All MVs were standardized by Z-test. First, a multiblock component method, called Regularized Generalized Canonical Correlation Analysis

Table 1
Sequence of criterion for validation of the measurement and structural models in the structural equations modeling (SEM).

Indicator	Purpose	Criterion	Reference
Evaluation of Measurement Models			
AVE (Average Variance Extracted)	Convergent Validity	AVE > 0.50	Chin et al. (2010)
Composite reliability (Rho-DG)	Model reliability	Rho-DG: 0.6 – 0.70 (satisfactory in exploratory research); > 0.7 (satisfactory in more advanced stages of research)	Hair et al. (2011)
HTMT (Heterotrait-monotrait ratio of correlations)	Discriminant validity	HTMT < 1	Garson (2016)
Student- t test	Evaluation of the significance of correlations and regressions.	t ≥1.96 (α = 0.05)	Hair et al. (2011)
Evaluation of the structural model			
R^2	Evaluates the portion of the variance of the endogenous variables, which is explained by the structural model.	R^2 = 0.25 (weak) R^2 = 0.50 (moderate) R^2 > 0.75 (substantial)	Hair et al. (2011)
Effect size (f^2 - cross validated comunality; q^2 - cross validated redundance).	Evaluates how much each latent variable is "useful" for model adjustment.	f^2 or q^2 = 0.02 (small) f^2 or q^2 = 0.15 (medium) f^2 or q^2 = 0.35 (large)	Hair et al. (2011)
Predictive Validity or Stone-Geisser indicator (Q^2-Redundance).	Evaluates the accuracy of the adjusted model.	Q^2 > 0	Chin et al. (2010)
Path Coefficient (Path-β, for standardized data).	Evaluation of causal relationships.	t ≥ 1.96 (α = 5 %)	Hair et al. (2011)

(RGCCA) (Tenenhaus and Tenenhaus, 2011), was applied to obtain relevant information between and within LVs (blocks) and to reduce their dimensionality. The LVs considered were SHAPE (exogenous), TISSUE_CARCASS, TISSUE_PRIMALCUTS and QUALI_MEAT (endogenous LVs), considering pre-defined causality relations among blocks.

Three theoretical models were evaluated, differentiated by the carcass SHAPE LV employed: Model MPH, which considered SHAPE_MPH; Model VIA1 (SHAPE_VIA1); and Model VIA2 (SHAPE_VIA2). Each model is seen as a set of one measurement model (outer model), which elucidates relations among LVs and MVs, and one structural model (inner model), which specifies the relations among LVs.

For the needed linear combinations of the LVs estimation, the PLS-PM algorithm concentrates on the weights calculation (Weights), by means an iterative procedure related to the definition of the inner and outer relations, that are obtained based on the measurement and structural models specification. These are arbitrary initial weights that start the algorithm, in order to calculate an outside approximation of the latent variables, that is in order to approximate the LVs as linear combinations of their MVs. In practice terms it means that the inner relations among LVs are considered in order to calculate the inside approximations, named weighting schemes. With these approaches, the algorithm follows the calculation of new weights considering now how the MVs are related to their LVs, which determine the regression coefficients nature that will be used as new weights for an external approximation, in a process that iteratively proceeds until weights convergence (Hair, 2014). Thus, in this study was adopted a centroid weighting scheme of calculation for the inner estimation and the reflective model (‘mode a’) was chosen for all LVs. In mode a, the indicators are considered manifestations of the LV (effect indicators), where relations go from these LVs to the MVs and the indicators are more reliable when they are highly interrelated (Hair et al., 2006). Mode a, implies simple linear regressions, thus establishing simple regressions coefficients.

The criterion used for exclusion of variables was the Average Variance Explained (AVE): in LVs with AVE < 0.5, the sequential elimination of MVs with lower outer loadings values was performed until the minimum AVE of 0.5 was reached (Chin, 2010). Additionally, this minimum AVE was sought for the inner and outer models: a minimum outer loading value was established for all MVs, which was redefined until the criterion was reached, achieving the final outer loading value less than 0.6 in absolute value. AVE of at least 0.5 indicates sufficient converging validity, which suggests the LV is able to explain, more than half of the variance of its MVs (Chin et al., 2010). The package RGCCA (Tenenhaus and Guillemot, 2017) in R version 3.5.0 software (R Core Team, 2018) was used for these analyses.

With the reduced models, the modeling of structural equations (SEM) began aiming to promote the validation of theoretical models applying the PLS-PM technique, which enables measuring the interrelations among LVs and MVs, establishing predictive equations for both that can be validated in the same sampling universe from a sequential evaluation of some model fitting criteria (Henseler, 2010). As a soft-modeling-technique, PLS-PM does not require any distributional assumptions on the data and can tolerate small sample sizes. In PLS-PM an iterative sequence of ordinary least squares (OLS) regressions is used to obtain estimating partial model relationships which maximize the explained variance of the endogenous LVs and allows the estimation of structural equations. Moreover, through the PLS-PM technique is possible to obtain and estimate the LVs scores as exact linear combinations of their associated manifest variables (MVs) and treats them as error free substitutes for the manifest variables (Tenenhaus et al., 2005; Monecke and Leisch, 2012). The validation of PLS-PM results considered seven procedures in two steps (Table 1): 1st - validation of the outer model and 2nd - validation of the inner model. The plspm package in R version 3.5.0 (R Core Team, 2018) and SmartPLS 3.2.7 (Ringle et al., 2015) were used for models validations, also employed to obtain the suitable model’s path diagram.

Complementarily, the coefficients of variation were also estimated by the bootstrapping technique to identify whether the model is robust (Hair et al., 2006), with the choice of generating 500 random samples with 1000 replicates for the estimation. For the accomplishment of *t*-test and bootstrapping, a 95 % confidence interval was used.

Finally, in order to verify the applicability of using LVs scores obtained from theoretical model selected, latent class cluster analysis method, was performed in XLSTAT 2017 (XLSTAT. XLSTAT, 2017). LVs scores and all MVs were submitted to ANOVA considering the effect of cluster the sample belongs and to Tukey’s multiple comparisons test, considering effect at $p < 0.05$.

3. Results

In the theoretical models established after MV reductions through RGCCA (Fig. 2), ten, twenty-one, and two variables remained in

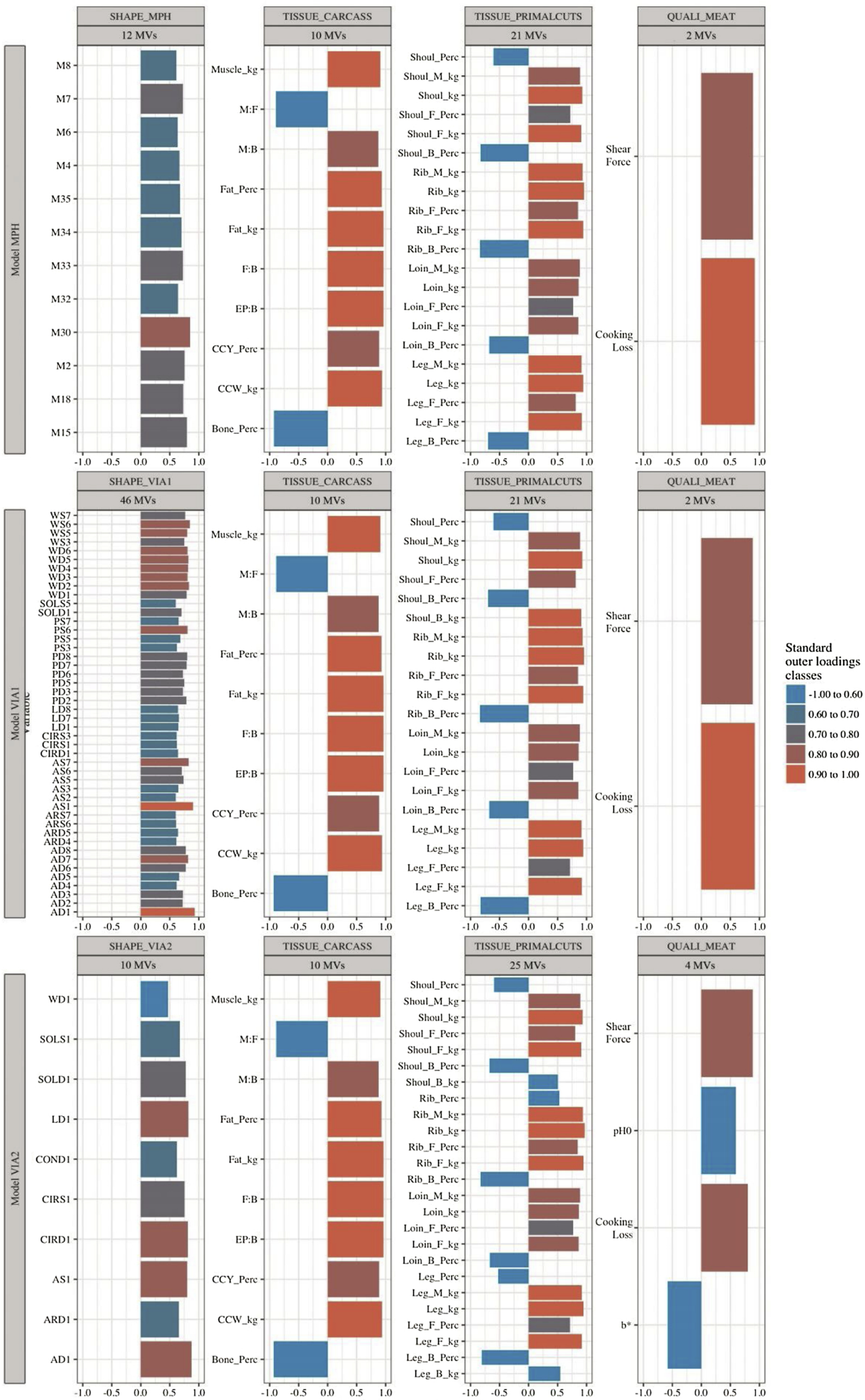

Fig. 2. Number of manifest variables and theirs outer loading values for each latent variable in models MPH, VIA1 and VIA2 reduced by RGCCA.

SHAPE_MPH: M2 = distance between shoulder spines; M4 = loin width; M6 = distance between the right ileum and the left ileum; M7 = distance between the right ischium and the left ischium. **Dorsal View 2:** M8 = distance between the withers and the 5th thoracic vertebra; M15 = scapula length; M18 = distance between shoulder blade and ischium. **Side View 2:** M30 = thigh perimeter; M32 = distance from the lower line of the carcass. **Half-Carcass View:** M33 = internal carcass length; M34 = inner carcass depth; M35 = internal leg length.

SHAPE_VIA1: AD1 = carcass dorsal area; WD1 = carcass dorsal width; LD1 = carcass dorsal length; CIRD1 = carcass dorsal circularity; SOLD1 = carcass dorsal solidity; AD2 = shoulder dorsal area; PD2 = shoulder dorsal perimeter; WD2 = shoulder dorsal width; AD3 = rib I dorsal area; PD3 = rib I dorsal perimeter; WD3 = rib I dorsal width; AD4 = rib II dorsal area; WD4 = rib II dorsal width; ARD4 = rib II dorsal aspect ratio; AD5 = loin dorsal area; PD5 = loin dorsal perimeter; WD5 = loin dorsal width; ARD5 = loin dorsal aspect ratio; AD6 = croup dorsal area; PD6 = croup dorsal perimeter; WD6 = croup dorsal width; AD7 = right leg dorsal area; PD7 = right leg dorsal perimeter; LD7 = right leg dorsal length; AD8 = left leg dorsal area; PD8 = left leg dorsal perimeter; LD8 = left leg dorsal length; AS1 = carcass side area; CIRS1 = carcass side circularity; AS2 = shoulder side area; AS3 = rib side area; PS3 = rib side perimeter; WS3 = rib sidel width; CIRS3 = rib side circularity; AS5 = loin side area; PS5 = loin side perimeter; WS5 = loin side width; SOLS5 = loin side solidity; AS6 = croup side area; PS6 = croup side perimeter; WS6 = croup side width; ARS6 = croup side aspect radio; AS7 = leg side area; PS7 = leg side perimeter; WS7 = leg side width; ARS7 = leg side aspect radio.

SHAPE_VIA2: AD1 = carcass dorsal area; WD1 = carcass dorsal width; SOLD1 = carcass dorsal solidity; SOLS1 = carcass side solidity; WD1 = carcass dorsal width; COND1 = carcass dorsal convexity; CIRS1 = carcass side circularity; CIRD1 = carcass dorsal circularity; AS1 = carcass side area; ARD1 = carcass dorsal aspect ratio.

TISSUE_CARCASS: F:B = fat bone ratio; F_kg = fat weight; F_Perc = fat percentage; EP:B = edible portion; CCY = cold carcass yield; M:F = muscle fat ratio; B_Perc = bone percentage; M_kg = muscle weight; M:B = muscle bone ratio; CCW_kg = cold carcass weight.

TISSUE_PRIMALCUTS: Shoul_Perc = shoulder percentage; Loin_B_Perc = loin bone percentage; Leg_M_kg = leg muscle weight; Loin_F_Perc = loin fat percentage; Shoul_kg = shoulder weight; Rib_kg = rib weight; Leg_kg = leg weight; Loin_kg = loin weight; Shoul_M_kg = shoulder muscle weight; Shoul_B_kg = shoulder bone weight; Leg_F_kg = leg fat weight; Loin_M_kg = loin muscle weight; Rib_M_kg = rib muscle weight; Rib_F_kg = rib fat weight; Leg_B_Perc = leg bone percentage; Leg_F_Perc = leg fat percentage; Loin_F_Perc = loin fat.

QUALI_MEAT: CL = cooking loss; pH_0 = pH 45 min *post mortem*; b* = yellowness.

Table 2
Goodness-of-fit of the measurement model of convergent validity (AVE) and composite reliability (Rho-DG) of the latent variables in the models MPH, VIA1 and VIA2.

Latent variables	AVE			Rho-DG		
	MPH	VIA1	VIA2	MPH	VIA1	VIA2
SHAPE	0.51 (12)	0.54 (46)	0.54 (11)	0.90 (12)	0.98 (46)	0.91 (11)
TISSUE_CARCASS	0.86 (10)	0.86 (10)	0.86 (10)	0.95 (10)	0.95 (10)	0.96 (10)
TISSUE_PRIMALCUTS	0.72 (21)	0.72 (21)	0.65 (25)	0.94 (21)	0.94 (21)	0.94 (25)
QUALI_MEAT	0.83 (2)	0.88 (2)	0.52 (4)	0.90 (2)	0.90 (2)	0.61 (4)
OUTER MODEL	0.70	0.63	0.63			
INNER MODEL	0.66	0.71	0.71			

The values in parentheses refer to the number of MVs.

TISSUE_CARCASS, TISSUE_PRIMALCUTS, and QUALI_MEAT, respectively, in the models MPH and VIA1 with the same MVs; and ten, twenty-five, and four variables in TISSUE_CARCASS, TISSUE_PRIMALCUTS, and QUALI_MEAT, respectively, for model VIA2.

Only bone weight and muscle yield were removed from LV TISSUE_CARCASS. In TISSUE_PRIMALCUTS, in models MPH and VIA1, weights of individual cuts and of muscle and fat, in addition to yields of bone and fat in the leg and loin, remained. In model VIA2, shoulder fat weight, leg bone weight, and the yields of rib and leg bone also remained.

The most significant reduction was obtained in QUALI_MEAT in models MPH and VIA1, in which only cooking loss and shear force remained. In SHAPE_VIA2, pH_0 and b* also remained.

In MPH model (SHAPE_MPH), MVs remained of dorsal view that express primarily distances and widths between shoulder spines (M2), loin width (M4), distance between the right ileum and the left ileum (M6) and distance between the right ischium and the left ischium (M7); two measures of carcass length (M8 and M32) and thigh perimeter measure (M30), which are recurrently mentioned since they are notably correlated with tissue deposition (Grandis et al., 2016; Sena et al., 2016). From the half-carcass view, measures length (M33 and M35) and depth (M34) were selected.

SHAPE_VIA1 had permanence of areas (AD1, AD2, AD3, AD4, AD5, AD6, AD7, AD8, AS1, AS2, AS3, AS5, AS6 and AS7), perimeters (PD2, PD3, PD5, PD6, PD7, PD8, PS3, PS5, PS6 and PS7) and widths (WD1, WD2, WD3, WD4, WD5, WD6, WS3, WS5, WS6 and WS7) of the projections. Some edge descriptors of the regions (circularity, convexity and solidity) were removed, possibly due to the projection nature of primal cuts regions delimited in the image. In SHAPE_VIA2, these descriptors remained since, for the total projection of the carcass at hand, all descriptors expressed adequate values for the characterization of muscle profiles; the perimeters were excluded.

The three models were submitted to PLS-PM analysis with an assessment of the measuring models initially by convergent validity and composite reliability criteria (Table 2).

Since the models were reduced based on the AVE criterion, they already had convergent validity. High AVE values were obtained for TISSUE_CARCASS (0.86 in all three models) and QUALI_MEAT (0.83 and 0.88 in MPH and VIA1, respectively), which indicates these LVs represent a significant portion of the total values of their MVs and, therefore, become consistent effect indicators in the models. The AVE value for QUALI_MEAT in model VIA2 was not high (0.52).

The composite reliability criterion, identified by the value of Dillon-Goldstein's Rho (Rho-DG), was found in all three models, which indicates reliability of all responses and no sample bias (Ringle et al., 2014). In the three models, the LVs reached values above 0.90, beyond the threshold (0.70) established as satisfactory value in more advanced stages of research (Hair et al., 2011), except for QUALI_MEAT in SHAPE_VIA2 (0.61).

The discriminant validity, assessed by the heterotrait-monotrait ratio of correlations (HTMT) method was reached by all models, which indicates the LVs are independent from each other (Hair et al., 2011). Moreover, loading values of the MVs and of correlations between MVs and their respective LVs in all three models were significant according to *t*-test, thus ensuring the totality of the requirements for proper evaluation of the measurement model.

Then, comes the analysis of the structural model initiated with the assessment of Pearson coefficients of determination (R^2) (Table 3), which estimate the portion of the variance in the endogenous variables explained by structural model and indicate the quality of the fitted model. Substantial R^2 values ($>$ 0.75) (Hair et al., 2011) were obtained for the most LVs in all models studied, which indicates a large portion of the variance of endogenous LVs could be captured by exogenous ones. Thus, since the PLS-PM technique generates measurements for LVs of the theoretical models, called scores in this study, it was noted that the scores of TISSUE_CARCASS, TISSUE_PRIMALCUTS and QUALI_MEAT could be obtained based on predictive equations generated sequentially from the shape characteristics score (only exogenous LV).

The values obtained for QUALI_MEAT (0.77, 0.82 and 0.78 in the MPH, VIA1 and VIA2 models, respectively) stand out, suggesting that highly precise scores can be obtain for this LV using carcass shape information.

Next, the redundancy or predictive validity (Q^2) criteria and commonality or effect size (F^2) were assessed (Table 4). Q^2 and F^2 were positive, which shows the LVs were properly estimated (Jayabal and Ramanathan, 2014). The lowest Q^2 values were obtained for TISSUE_PRIMALCUTS (0.37) and QUALI_MEAT (0.35) in the SHAPE_VIA2 model. Higher Q^2 values are related to the predictive power of the model, or accuracy of the fitted model and of their LV scores (Chin et al., 2010). F^2 values were higher than 0.35, which indicates great influence of the LVs considered to fit the model.

Table 3
Goodness-of-fit of the structural model: predictive equation for the latent variables in the models MPH, VIA1 and VIA2.

	Latent variables	Equation	R^2	Pr > F	R^2 Bootstrap
MPH model	TISSUE_CARCASS	0.82*SHAPE_MPH	0.69	0.01	0.69
	TISSUE_PRIMALCUTS	0.30*SHAPE_MPH + 0.61*TISSUE_CARCASS	0.77	0.01	0.78
	QUALI_MEAT	0.11*SHAPE_MPH-0.41*TISSUE_CARCASS-0.58*TISSUE_PRIMALCUTS	0.77	0.01	0.77
VIA1 model	TISSUE_CARCASS	0.88*SHAPE_VIA1	0.78	0.01	0.78
	TISSUE_PRIMALCUTS	0.31*SHAPE_VIA1 + 0.56*TISSUE_CARCASS	0.73	0.01	0.73
	QUALI_MEAT	0.12*SHAPE_VIA1-0.56*TISSUE_CARCASS-0.49*TISSUE_PRIMALCUTS	0.82	0.01	0.82
VIA2 model	TISSUE _CARCASS	0.86*SHAPE_VIA2	0.74	0.01	0.75
	TISSUE_PRIMALCUTS	0.17*SHAPE_VIA2 + 0.69*TISSUE_CARCASS	0.73	0.01	0.73
	QUALI_MEAT	0.12*SHAPE_VIA2 -0.47*TISSUE_CARCASS-0.5*TISSUE_PRIMALCUTS	0.78	0.01	0.79

R^2 - Pearson coefficient of determination of the predictive equation of each LV. R^2 Bootstrap - Pearson coefficient of determination of the predictive equation of each LV obtained by Bootstrap.

Table 4
Goodness-of-fit of the structural model: commonalities, cross validated commonality, redundancies and cross validated redundancy of the latent variation, path coefficients (beta) and *t*-test of the causal relations among the latent variables in the models MPH, VIA1 and VIA2.

Latent variables	Commonality (F^2)			CV-commonality (f^2)			Redundancy (Q^2)			CV-redundancy (q^2)		
	MPH	VIA1	VIA2	MPH	VIA1	VIA2	MPH	VIA1	VIA2	MPH	VIA1	VIA2
SHAPE	0.51	0.53	0.50	0.51	0.42	0.34						
TISSUE_CARCASS	0.86	0.86	0.85	0.86	0.70	0.70	0.41	0.68	0.636	0.52	0.57	0.53
TISSUE_PRIMAL CUTS	0.72	0.72	0.65	0.72	0.58	0.52	0.44	0.53	0.472	0.54	0.43	0.37
QUALI_MEAT	0.81	0.82	0.522	0.82	0.36	0.23	0.59	0.68	0.407	0.67	0.59	0.35

Hypotheses	Causal relation	MPH				VIA1				VIA2			
		Beta	Std Error	t-value*	Supported	Beta	Std Error	t-value*	Supported	Beta	Std Error	t-value*	Supported
H1	SHAPE TISSUE_CARCASS	0.76	0.03	23.01	Yes	0.89	0.02	44.15	Yes	0.86	0.03	31.24	Yes
H2	SHAPE TISSUE_PRIMAL CUTS	0.28	0.10	2.82	Yes	0.37	0.13	2.59	Yes	0.13	0.12	1.09	No
H3	SHAPE QUALI_MEAT	−0.01	0.10	0.13	No	0.10	0.11	1.04	No	0.04	0.12	1.30	No
H4	TISSUE_CARCASS TISSUE_PRIMAL CUTS	0.63	0.10	6.03	Yes	0.52	0.14	3.83	Yes	0.73	0.13	5.70	Yes
H5	TISSUE_CARCASS QUALI_MEAT	−0.42	0.11	4.00	Yes	−0.54	0.12	4.56	Yes	−0.33	0.16	2.10	Yes
H6	TISSUE_PRIMAL CUTS QUALI_MEAT	−0.49	0.09	5.76	Yes	−0.49	0.08	5.96	Yes	−0.62	0.10	6.42	Yes

* $t \geq 1.96$ (α = 5 %).

After Q^2 and criteria were found, the *t*-test was applied to the path coefficients (beta), which assess the causality relation between LV pairs (Table 4). The betas of the SHAPE⇒QUALI_MEAT relation were not significant in all models. In VIA2, the SHAPE⇒TISSUE_PRIMALCUTS relation was also non-significant.

In order to validate the instruments (theoretical models), the criteria to assess goodness-of-fit must be found in full, including all betas being significant. The literature recommends that, if a beta is non-significant, the presence of the endogenous LV in the pair at hand in the model should be re-evaluated (Ringle et al., 2014), leading to a new theoretical model and further validation. Exceptions are admitted when the relative importance of these findings is taken into account (Frezatti et al., 2015).

The instrument implemented by VIA1 is considered to have better fits to the criteria assessed, thus only its study will be furthered using a path diagram (Fig. 3), which will visually summarize theoretical relations among variables and results of several structural regressions, yielding path coefficients (beta, for standardized data), R^2, correlations between MVs and the LV they belong to correlations among LVs and external weights (W).

Correlations between LVs assess how much the score of one LV influences the other. Since a LV reflects its MVs (effect indicator), the impact of changing a MV not only on the LV to which it belongs but also on the resulting LV, can be stated. Thus, SHAPE_VIA1 had high positive correlations with TISSUE_CARCASS (r = 0.88; P < 0.05) and TISSUE_PRIMALCUTS (r=0.81; P < 0.05), which shows the shape characteristics strongly impact carcass and cut tissue composition, as observed in many other studies (Rius-Vilarrasa et al., 2009; Kongsro et al., 2009; Jia et al., 2010). Huidobro et al. (2004) also stated that determining scores that assess carcass shape patterns enable determining their characteristics regarding yields and edible portions, pointing out the possibility of precise, non-destructive carcass evaluation. The most impactful MVs for SHAPE_VIA1 were those related to areas (total carcass area - dorsal (r = 0.93), side (r = 0.90) and leg side (r = 0.83)) and widths (croup (r = 0.84), shoulder (r = 0.83) and loin (r = 0.82)). The correlations between MVs and their LVs are in the Fig. 4.

High positive correlations were obtained between TISSUE_CARCASS and TISSUE_PRIMALCUTS (r = 0.84; P < 0.05), which shows that carcass and cut composition are closely related. High negative correlations were obtained between QUALI_MEAT and LVs TISSUE_PRIMALCUTS (r= −0.86; P < 0.05) and TISSUE_CARCASS (r= −0.87; P < 0.05), justified by the nature of the MVs meat quality, cooking loss and shear force, to which more negative values are desirable to determine juicier, more tender meat.

In TISSUE_CARCASS, all correlations obtained were above 0.80, making up a balanced LV. The most significant ones (r > 0.90) are related to the fat and muscle contents of the carcass, such as fat:bone ratio (r = 0.96), total fat weight (0.96), fat percentage (r = 0.93), total muscle weight (r = 0.91), carcass edible portion (r = 0.96), cold carcass weight (r = 0.94) and bone percentage (r= −0.93). In TISSUE_PRIMALCUTS, the MVs that stood out the most (r > 0.90) were associated with the rib (weights of the cut (r = 0.96), fat (r = 0.94), and muscle (r = 0.93)), leg (weights of the cut (r = 0.94), fat (r = 0.92) and muscle (r = 0.91)) and shoulder (weights of the cut (r = 0.93) and bone (r = 0.93)). The correlations found in QUALI_MEAT were 0.92 for cooking loss and 0.89 for shear force.

Aiming to further the understanding of scores of LVs generated by the instrument and to obtain patterns capable of providing practical carcass classification categories, latent clustering analysis was performed based on these scores. Thus, four clusters were formed.

Clusters 1 and 4 were the extreme groups, where: Cluster leanest (cluster 1; N = 19) had the highest values of SHAPE_VIA1, TISSUE_CARCASS and TISSUE_PRIMALCUTS scores and the lowest scores of QUALI_MEAT, whereas Cluster higher (cluster 4; N = 15) had the lowest scores of SHAPE_VIA1, TISSUE_CARCASS and TISSUE_PRIMALCUTS and the highest of QUALI_MEAT. Clusters lower (cluster 2; N = 17) and acceptable (cluster 3; N = 16) had intermediate LV scores. A statistical difference was found among the clusters for all LV scores (Table 5).

In order to establish LV score ranges based on the clusters formed, an amplitude defined by the mean value of each score in the cluster ± 1 standard deviation was define aiming to make cluster use more intelligible. In this way, ranges with few overlaps among them were established for QUALI_MEAT, unlike for other LVs, which suggests the clustering more efficiently grouped more similar carcasses in terms of meat quality, highlighting the usefulness of the methodology for the categorization of carcasses from this standpoint. Therefore, each cluster will be treated as a meat quality category (Fig. 5).

In addition, to promote more assertive characterization of the categories, the criterion by Rodas-González et al. (2009), which establishes a range for meat texture called sensorily acceptable by the consumer (< 4.90 kgf/cm^2) and the tenderness ranges defined by Cezar e Souza (2007), which define meat as tender (< 2.27 kgf/cm^2), medium

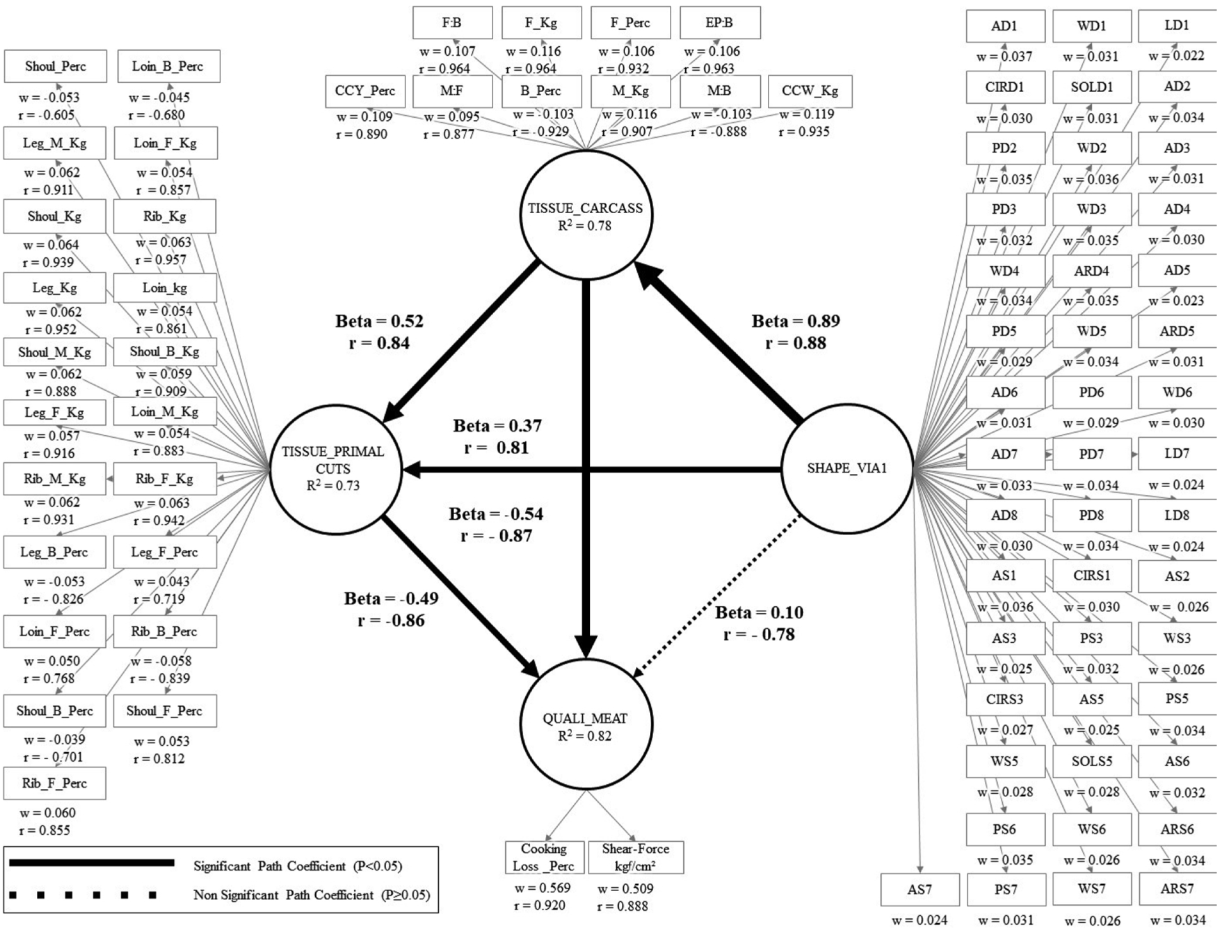

Fig. 3. Structural Model VIA1: path diagram with external weights (W), path coefficients (beta), correlation (r) and Pearson coefficients of determination (R^2).**SHAPE_VIA1**: AD1 = carcass dorsal area; WD1 = carcass dorsal width; LD1 = carcass dorsal length; CIRD1 = carcass dorsal circularity; SOLD1 = carcass dorsal solidity; AD2 = shoulder dorsal area; PD2 = shoulder dorsal perimeter; WD2 = shoulder dorsal width; AD3 = rib I dorsal area; PD3 = rib I dorsal perimeter; WD3 = rib I dorsal width; AD4 = rib II dorsal area; WD4 = rib II dorsal width; ARD4 = rib II dorsal aspect ratio; AD5 = loin dorsal area; PD5 = loin dorsal perimeter; WD5 = loin dorsal width; ARD5 = loin dorsal aspect ratio; AD6 = croup dorsal area; PD6 = croup dorsal perimeter; WD6 = croup dorsal width; AD7 = right leg dorsal area; PD7 = right leg dorsal perimeter; LD7 = right leg dorsal length; AD8 = left leg dorsal area; PD8 = left leg dorsal perimeter; LD8 = left leg dorsal length; AS1 = carcass side area; CIRS1 = carcass side circularity; AS2 = shoulder side area; AS3 = rib side area; PS3 = rib side perimeter; WS3 = rib sidel width; CIRS3 = rib side circularity; AS5 = loin side area; PS5 = loin side perimeter; WS5 = loin side width; SOLS5 = loin side solidity; AS6 = croup side area; PS6 = croup side perimeter; WS6 = croup side width; ARS6 = croup side aspect radio; AS7 = leg side area; PS7 = leg side perimeter; WS7 = leg side width; ARS7 = leg side aspect ratio.
TISSUE_CARCASS: F:B = fat bone ratio; F_kg = fat weight; F_Perc = fat percentage; EP:B = edible portion; CCY = cold carcass yield; M:F = muscle fat ratio; B_Perc = bone percentage; M_kg = muscle weight; M:B = muscle bone ratio; CCW_kg = cold carcass weight.
TISSUE_PRIMALCUTS: Shoul_Perc = shoulder percentage; Loin_B_Perc = loin bone percentage; Leg_M_kg = leg muscle weight; Loin_F_Perc = loin fat percentage; Shoul_kg = shoulder weight; Rib_kg = rib weight; Leg_kg = leg weight; Loin_kg = loin weight; Shoul_M_kg = shoulder muscle weight; Shoul_B_kg = shoulder bone weight; Leg_F_kg = leg fat weight; Loin_M_kg = loin muscle weight; Rib_M_kg = rib muscle weight; Rib_F_kg = rib fat weight; Leg_B_Perc = leg bone percentage; Leg_F_Perc = leg fat percentage; Loin_F_Perc = loin fat.

tender (2.28–3.63 kgf/cm^2), tough (3.64–5.44 kgf/cm^2), and extremely tough (> 5.44 kgf/cm^2), were applied. It was soon observed that Clusters 3 and 4 make up categories out of the acceptable range for consumers, resulting in extremely tough meats due to the means and deviations obtained for shear force: 7.27 ± 1.72 and 9.28 ± 2.64 kgf/cm^2, respectively. Thus, as categories, Cluster 3 will be called “Inferior Carcass - Out of the Quality Standard” and Cluster 4 will be called “Very Inferior Carcass - Out of the Quality Standard.”

Evidently, score values linked to these two categories are undesirable. Hence, QUALI_MEAT scores must be lower than 0.15 and are associated with SHAPE_VIA1 scores above −0.15, TISSUE_CARCASS scores above −0.11, and TISSUE_PRIMALCUTS scores of at least −0.24. These values characterize carcasses with at least 2960.32 cm^2 of total dorsal area, 3651.91 cm^2 of total side area, 525.59 cm^2 of leg side area, 25.76 cm of croup width, 22.05 cm of shoulder width, 26.36 cm of loin width, at least 15.42 kg CCW, 20.28 % total fat yield, fat:bone ratio of 1.07, 2.57 kg of shoulder weight, 5.17 kg of leg weight, 0.94 kg of loin weight, 5.87 kg of rib weight and cooking loss values below 42.70 %.

Analogously, Cluster 1 (3.01–4.29, average of 3.61 kgf/cm^2) was called “Superior Carcass,” implying that cluster that had the best indicators for cooking loss (< 32.65 %) and shear force. In this category, the scores are between 0.4–1.50 for SHAPE_VIA1, 0.6 and 1.44 for TISSUE_CARCASS, 0.73–1.51 for TISSUE_PRIMALCUTS and -1.37 to -1.07 for QUALI_MEAT.

4. Discussion

The three theoretical models proposed were able to recognize the existence of relations between carcass shape and meat quality from the standpoint of texture and juiciness, which makes them not appropriate to characterize quality based on color or pH. Furthemore, shape features are were less associeted with color in particular, because it has hues that makes hard these associations in this specific methodology to

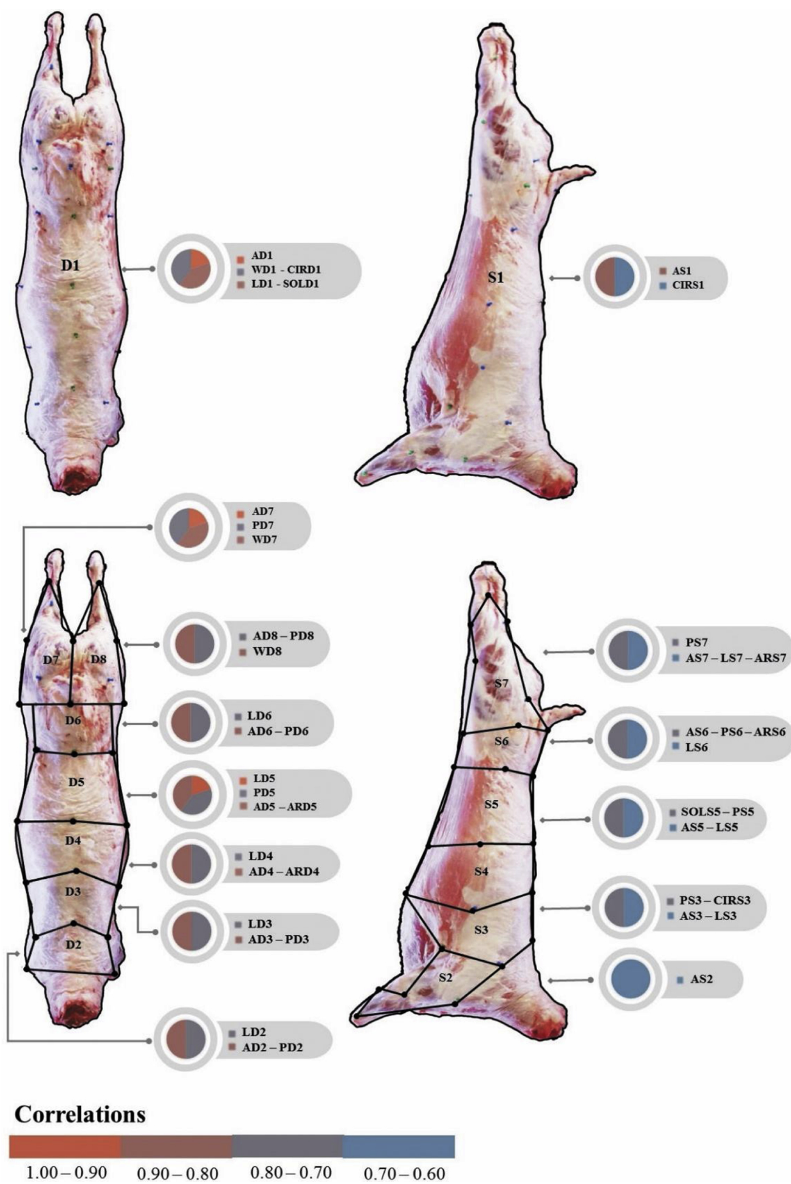

Fig. 4. Correlations among manifest variables (MVs) and their latent variable (LV) SHAPE for each carcass projection of hair sheep lambs in LV SHAPE_VIA 1: (a) whole carcass in dorsal and side views; (b) carcass regions in dorsal and side view.

a) **Dorsal View 1:** D1 = projection of the entire carcass in the dorsal view. **Side View 1:** S1 = projection of the entire carcass in the side view.

(b) **Dorsal View 2:** D2 = dorsal shoulder; D3 = dorsal rib I; D4 = dorsal rib II; D5 = dorsal loin; D6 = dorsal croup - leg; D7 = dorsal right leg; D8 = dorsal left leg. **Side View 2:** S2 = side shoulder; S3 = side rib I; S4 = side rib II; S5 = side loin; S6 = side croup - leg; S7 = side leg.

SHAPE_VIA1: AD1 = carcass dorsal area; WD1 = carcass dorsal width; LD1 = carcass dorsal length; CIRD1 = carcass dorsal circularity; SOLD1 = carcass dorsal solidity; AD2 = shoulder dorsal area; PD2 = shoulder dorsal perimeter; WD2 = shoulder dorsal width; AD3 = rib I dorsal area; PD3 = rib I dorsal perimeter; WD3 = rib I dorsal width; AD4 = rib II dorsal area; WD4 = rib II dorsal width; ARD4 = rib II dorsal aspect ratio; AD5 = loin dorsal area; PD5 = loin dorsal perimeter; WD5 = loin dorsal width; ARD5 = loin dorsal aspect ratio; AD6 = croup dorsal area; PD6 = croup dorsal perimeter; WD6 = croup dorsal width; AD7 = right leg dorsal area; PD7 = right leg dorsal perimeter; LD7 = right leg dorsal length; AD8 = left leg dorsal area; PD8 = left leg dorsal perimeter; LD8 = left leg dorsal length; AS1 = carcass side area; CIRS1 = carcass side circularity; AS2 = shoulder side area; AS3 = rib side area; PS3 = rib side perimeter; WS3 = rib sidel width; CIRS3 = rib side circularity; AS5 = loin side area; PS5 = loin side perimeter; WS5 = loin side width; SOLS5 = loin side solidity; AS6 = croup side area; PS6 = croup side perimeter; WS6 = croup side width; ARS6 = croup side aspect radio; AS7 = leg side area; PS7 = leg side perimeter; WS7 = leg side width; ARS7 = leg side aspect ratio.

get color parameters, as the necessity of muscle exposure for the colorimetrics analysis and time of evaluation. Thus, interferences associated with pre-slaughter conditions, oxygenation, and oxidation (Gao et al., 2014) may be more determinant on pH and color than factors related to carcass shape itself. Parameters like texture and juiciness are associated with the fat content, the structures, and the composition of skeletal muscles in the carcass (Nishimura, 2010) they may be more closely related to carcass shape.

The QUALI_MEAT score is a representative measure of a pool of meat quality characteristics: cooking loss and shear force when the MPH and VIA models are considered and cooking loss, shear force, pH_0 and b* for VIA2.

The equations obtained for QUALI_MEAT indicate greater influence of the scores of tissue characteristics of the carcass (TISSUE_CARCASS) and cuts (TISSUE_PRIMALCUTS) than of shape scores, yielding negative coefficient values. Consequently, more negative the QUALI_MEAT score, the better meat quality and the higher scores of these two LVs, which imply better tissue compositions.

VIA1 yielded higher R^2 values for TISSUE_CARCASS (0.78) and QUALI_MEAT (0.82), being the model with the best fits. Video Image Analysis (models VIA1 and VIA2) yielded better goodness-of-fit regarding R^2 than the carcass morphometry evaluation (MPH) except to estimate TISSUE_PRIMALCUTS scores. That highlights the benefits of capturing more faces of a shape, such as two-dimensional measurements and edge descriptors, besides the possibility of automated processing at the industrial level. That corroborated other studies (Hopkins et al., 2004; Ngo et al., 2016) that showed the efficiency of VIA as a good predictor of carcass characteristics. For instance, when VIA variables were included in the predictive model, Pabiou et al. (2011) found better estimates of cut weight and carcass tissue composition of bovines and Lorenzo et al. (2017) obtained better predictive results for tissue yield and composition of equine carcasses.

Besides the conceptual and biological importance for all models, QUALI_MEAT also had adequate values according to individual criteria (AVE, Rho-DG, Q^2, F^2), even showing high R^2 values in all three models, which guarantees its indispensability. Similar situations are sometimes identified as the result of data multicollinearity, but the theoretical importance of the LV was always decisive for its permanence in the model (Pabiou et al., 2011; Ringle et al., 2014).

Weight is an extremely important indicator as it denotes the regression coefficient of the MV in simple regression of the LV under the MV, which implies the effective prediction of all indicator characteristics of a model from LV scores. Objectively, the value of a MV can be obtained from the score of the LV it belongs to, e.g., the standardized values of cooking loss and shear force can be predicted from the QUALI_MEAT score. In this sense, this research, besides allowing for the individual prediction of carcass and meat characteristics from VIA information, primarily proposes a score for each pool of characteristics (LVs).

It is, therefore, understood that carcasses that provide superior meat quality regarding juiciness and tenderness are those of broad area both in the dorsal and side views, wider in all dorsal thirds, and with larger leg area (side) that are visually identified as massive carcasses (SOLD1: r = 0.70) and round or rounded (CIRD1: r = 0.64). These characteristics mainly influence fat distribution in the carcass and muscle content and lead to heavier carcasses with greater edible portion as they have lower bone yield. For the industry, a more interesting carcass is produced, with heavier cuts, particularly leg, shoulder and rib, which also

Table 5
Means, standard deviations and amplitude values of manifest variables, latent variable scores and typification scores* for the clusters established by latent variables scores of model VIA1.

LATENT VARIABLES SCORES

Latent variable	Cluster 1	MIN-MAX	2	MIN-MAX	3	MIN-MAX	4	MIN-MAX
SHAPE_VIA1	0.95 ± 0.55 a	−0.17/2.07	0.46 ± 0.61 b	−0.61/1.37	−0.36 ± 0.35 c	−0.92/0.0.33	−1.28 ± 0.56 d	−2.65/-0.33
TISSUE_CARCASS	1.02 ± 0.42 a	0.09/1.67	0.42 ± 0.53 b	−0.66/1.32	−0.33 ± 0.26 c	−0.91/0.0.08	−1.35 ± 0.26d	−2.73/-0.60
TISSUE_PRIMALCUTS	1.12 ± 0.39 a	0.51/1.91	0.30 ± 0.54 b	−0.91/1.32	−0.35 ± 0.19 c	−0.69/0.03	−1.33 ± 0.47 d	−2.60/-0.73
QUALI_MEAT	−1.22 ± 0.15 d	−1.65/1.00	−0.21 ± 0.36 c	−0.06/1.1.35	0.48 ± 0.31 b	−0.74/0.48	1.22 ± 0.67 a	−0.06/2.57

QUALI_MEAT

Manifest Variable	Cluster 1	MIN-MAX	2	MIN-MAX	3	MIN-MAX	4	MIN-MAX
Cooking loss, %	30.84 ± 1.81 c	26.32/34.54	40.46 ± 2.24 b	37.74/44.18	43.81 ± 3.36 b	40.80/55.00	48.45 ± 6.82 a	35.56/61.11
Shear force, kgf/cm^2	3.61 ± 0.64 c	2.40/4.87	4.90 ± 1.45 c	2.97/9.28	7.27 ± 1.72 b	4.35/10.28	9.28 ± 2.64 a	5.28/14.42

TISSUE_CARCASS

Manifest Variable	Cluster 1	MIN-MAX	2	MIN-MAX	3	MIN-MAX	4	MIN-MAX
Cold carcass weight, kg	20.36 ± 1.98 a	16.47/24.05	17.66 ± 2.24 b	14.28/21.75	14.46 ± 0.99 c	12.78/15.86	11.04 ± 1.65 d	6.93/12.97
Cold carcass yield, %	52.83 ± 2.38 a	48.16/57.87	49.23 ± 2.90 b	43.65/53.54	47.71 ± 1.60 b	44.86/50.29	43.04 ± 3.27 c	33.24/46.76
Muscle, kg	10.40 ± 1.14 a	8.82/13.16	9.23 ± 1.11 b	7.33/10.84	7.90 ± 0.72 c	6.73/9.15	5.85 ± 1.03 d	3.53/7.46
Fat, kg	5.21 ± 0.83 a	3.54/6.80	4.10 ± 0.88 b	2.48/5.55	2.55 ± 0.33 c	1.97/2.97	2.55 ± 0.46 c	0.64/2.29
Fat, %	26.89 ± 3.01 a	21.59/31.13	23.69 ± 3.41 b	17.31/29.70	18.31 ± 2.24 c	13.60/21.79	14.73 ± 3.53 d	9.33/20.88
Bone, %	16.45 ± 1.50 c	14.63/19.69	17.64 ± 2.51 b c	14.66/24.30	19.47 ± 1.97 b	16.54/23.03	24.77 ± 3.48 a	19.86/32.94
Muscle:Fat	2.03 ± 0.29 c	1.66/2.63	2.32 ± 0.41 c	1.76/3.38	3.14 ± 0.44 b	2.49/3.82	3.92 ± 0.99 a	2.52/552
Muscle:Bone	3.29 ± 0.30 a	2.73/3.76	3.09 ± 0.39 ab	2.11/3.78	2.94 ± 0.35 b	2.32/3.35	2.25 ± 0.37 c	1.56/2.91
Fat:Bone	1.66 ± 0.28 a	1.17/2.13	1.38 ± 0.31 b	0.80/2.03	0.95 ± 0.15 c	0.61/1.22	0.62 ± 0.21 d	0.28/0.98
Edible portion:Bone	4.95 ± 0.53 a	3.94 / 5.75	4.47 ± 0.65 a	2.91/5.59	3.89 ± 0.44 b	2.94/4.46	2.87 ± 0.55 c	1.85/3.85

TISSUE_PRIMALCUTS

	Manifest Variable	Cluster 1	MIN-MAX	2	MIN-MAX	3	MIN-MAX	4	MIN-MAX
Shoulder	Shoulder, kg	3.28 ± 0.31 a	2.81/4.03	2.87 ± 0.30 b	2.28/3.26	2.47 ± 0.25 c	2.09/3.03	1.99 ± 0.28 d	1.39/2.43
	Muscle, kg	1.94 ± 0.24 a	1.62/2.43	1.69 ± 0.5 b	1.28/2.02	1.51 ± 0.17 b	1.19/1.74	1.14 ± 0.19 c	0.80/1.47
	Bone, kg	0.65 ± 0.13 a	0.42/0.89	0.48 ± 0.15 b	0.26/0.84	0.31 ± 0.06 c	0.22/0.44	0.21 ± 0.07 d	0.06/0.34
	Shoulder, %	16.21 ± 1.04 c	13.97/18.29	16.91 ± 1.16 bc	15.31/19.36	17.34 ± 1.10 b	15.92/20.36	18.89 ± 3.18 a	16.98/21.89
	Bone, %	19.36 ± 1.85 b	16.76/22.67	21.54 ± 3.65 b	16.76/22.67	21.45 ± 2.24 b	16.83/252.64	25.18 ± 3.07 a	13.51/30.94
	Fat, %	19.75 ± 3.56 a	12/24.56	16.57 ± 4.07 b	12/24.56	12.67 ± 2.03 c	10.26/16.59	10.34 ± 6.32 c	4.32/14.85
Leg	Leg, kg	6.16 ± 0.67 a	5.11/7.59	5.36 ± 0.19 b	4.20/6.29	4.67 ± 0.39 c	4.07/5.22	3.71 ± 0.55 d	2.39/4.29
	Muscle, kg	3.95 ± 0.46 a	3.26/4.97	3.41 ± 0.36 b	2.67/3.97	3.14 ± 0.34 b	2.37/3.52	2.27 ± 0.41 c	1.33/2.88
	Fat, kg	1.00 ± 0.17 a	0.72/1.33	0.80 ± 0.20 b	0.39/1.22	0.56 ± 0.11 c	0.42/0.79	0.39 ± 0.11 d	0.18/0.62
	Bone, %	16.14 ± 1.35 b	13.18/19.06	16.84 ± 2.34 b	13.17/21.19	17.82 ± 1.76 b	15.22/22.30	22.44 ± 2.79 a	19.35/31.38
	Fat, %	16.24 ± 2.10 a	13.19/20.23	14.78 ± 3.29 a	7.47/20.46	11.98 ± 2.13 b	8.74/16.29	10.59 ± 4.30 b	4.99/15.16
Loin	Loin, kg	1.25 ± 0.15 a	0.95/1.49	1.09 ± 0.15 b	0.77/1.45	0.91 ± 0.15 c	0.64/1.23	0.73 ± 0.14 d	0.53/1.01
	Muscle, kg	0.72 ± 0.09 a	0.53/0.90	0.59 ± 0.14 b	0.20/0.75	0.52 ± 0.082 b	0.37/0.65	0.37 ± 0.09 c	0.19/0.55
	Fat, kg	0.29 ± 0.07 a	0.17/0.45	0.22 ± 0.07 b	0.13/0.37	0.15 ± 0.054 c	0.07/0.26	0.09 ± 0.04 d	0.05/0.20
	Bone, %	15.84 ± 2.96 b	9.47/21.19	19.33 ± 4.50 b	13.79/29.41	19.74 ± 7.72 b	10.00/37.18	27.36 ± 3.59 a	16.98/41.82
	Fat, %	23.28 ± 3.78 a	16.10/30.20	19.51 ± 4.07 b	14.91/28.46	16.70 ± 4.44 b	8.64/27.66	12.35 ± c	7.58/22.73
Rib	Rib, kg	7.48 ± 0.89 a	6.06/9.39	6.07 ± 0.20 b	3.76/7.69	5.03 ± 0.48 c	4.08/6.01	3.60 ± 0.68 d	1.95/4.43
	Muscle, kg	3.21 ± 0.44 a	2.42/4.42	2.67 ± 0.38 b	1.84/3.33	2.28 ± 0.29 c	1.69/2.78	1.72 ± 0.31 d	0.97/2.18
	Fat, kg	3.04 ± 0.50 a	2.02/4.32	2.03 ± 0.55 b	1.00/3.12	1.35 ± 0.28 c	0.73/1.68	0.82 ± 0.43 d	0.18 / 1.23
	Bone, %	14.63 ± 1.84 c	11.70/19.14	17.13 ± 3.44 b	12.40/26.07	19.46 ± 4.32 b	14.36/30.48	25.51 ± 4.67 a	17.73/33.85
	Fat, %	40.53 ± 3.62 a	33.33/46.01	33.00 ± 4.81 b	24.67/40.74	6.99 ± 5.35 c	13.91/32.35	22.40 ± c	9.23/31.38

(continued on next page)

Table 5 (*continued*)

SHAPE_VIA1									
Projection	Cluster								
	Manifest variable	1	MIN-MAX	2	MIN-MAX	3	MIN-MAX	4	MIN-MAX
D1	AD1, cm^2	3536.95 ± 238.08 a	3199.29/4002.79	3271.32 ± 311.0 b	2835.95/4032.78	3048.26 ± 191.46 b	2745.35/3383.76	2780.72 ± 216.85 c	2314.93/3096.93
	WD1, cm	32.04 ± 2.47 a	29.46/39.81	29.98 ± 1.98 b	26.86/33.78	29.22 ± 1.90 b	25.97/32.57	27.38 ± 1.74 c	24.57/30.60
	LD1, cm	162.94 ± 5.22 a	153.14/172.70	161.04 ± 8.33 a b	149.65/178.35	156.48 ± 6.51 b c	144.95/166.92	153.35 ± 6.37 c	143.49/168.57
	CIRD1	0.24 ± 0.02 a	0.21/0.28	0.23 ± 0.02 a	0.18/0.26	0.22 ± 0.017 a	0.19/0.26	0.20 ± 0.02 b	0.17/0.24
	SOLD1	0.83 ± 0.01 a	0.79/0.86	0.83 ± 0.02 a	0.78/0.85	0.82 ± 0.01 a	0.80/0.84	0.79 ± 0.02 b	0.73/0.83
D2	AD2, cm^2	337.76 ± 29.06 a	276.59/388.10	297.68 ± 45.26 b	228.94/405.26	278.35 ± 34.76 b	188.89/332.52	240.01 ± 30.87 c	171.73/294.11
	PD2, cm	74.71 ± 2.76 a	69.08/79.84	71.21 ± 4.92 ab	64.55/81.84	68.24 ± 3.99 b	58.21/75.53	63.15 ± 4.66 c	52.08/70.56
	WD2, cm	24.50 ± 0.99 a	23.24/26.54	24.05 ± 2.00 a	21.02/27.94	22.08 ± 1.66 b	18.73/25.78	19.48 ± 1.90 c	17.14/24.70
D3	AD3, cm^2	286.40 ± 57.55 a	176.70/412.20	287.33 ± 59.45 a	160.77/403.96	224.76 ± 45.36 b	155.93/320.32	167.75 ± 40.37 c	109.24/253.78
	PD3, cm	70.88 ± 6.71 a	61.51/85.31	71.31 ± 6.56 a	55.82/83.88	64.21 ± 5.46 b	55.05/77.52	56.16 ± 5.68 c	47.54/68.16
	WD3, cm	24.32 ± 1.35 a	21.52/26.79	23.97 ± 1.79 ab	20.57/27.56	22.83 ± 1.20 b	20.95/25.21	20.54 ± 1.45 c	17.97/23.30
D4	AD4, cm^2	681.99 ± 84.41 a	550.59/835.71	586.95 ± 70.39 b	486.38/745.52	559.25 ± 60.70 b	411.42/650.85	547.71 ± 57.78 b	384.96/650.42
	WD4, cm	31.19 ± 2.21 a	27.81/36.70	28.89 ± 2.64 b	23.94/33.65	27.53 ± 2.08 b	24.00/31.87	27.53 ± 1.95 b	22.41/30.22
	ARD4	1.08 ± 0.09 a	0.96/1.31	1.09 ± 0.15 a	0.75/1.38	1.03 ± 0.11 a	0.87/1.28	0.89 ± 0.074 b	0.77/1.05
D5	AD5, cm^2	501.53 ± 68.51 a	395.54/644.07	456.82 ± 63.52 a	375.56/608.98	437.59 ± 45.33 b	366.90/541.78	409.47 ± 41.16 b	331.70/469.23
	PD5, cm	93.45 ± 6.18 a	83.81/106.34	89.00 ± 6.58 a b	80.73/103.76	87.18 ± 4.94 b	79.15/97.01	81.58 ± 4.39 c	75.14/92.49
	WD5, cm	30.93 ± 2.25 a	27.68/36.70	28.81 ± 2.45 b	23.94/32.89	27.48 ± 2.03 b c	24.13/313.62	25.50 ± 1.95 c	22.29/30.22
	ARD5	1.41 ± 0.13 a	1.12/1.65	1.39 ± 0.14 a	1.17/1.70	1.30 ± 0.09 a	1.16/1.44	1.17 ± 0.15 b	0.86/1.43
D6	AD6, cm^2	356.68 ± 33.07 a	296.96/439.53	359.19 ± 43.12 a	283.91/429.27	331.77 ± 41.19 a	278.22/413.55	272.94 ± 28.30 b	227.52/320.07
	PD6, cm	78.36 ± 3.10 a	72.71/85.73	77.62 ± 4.19 a	72.76/86.03	75.60 ± 3.00 a	70.62/81.45	69.70 ± 4.03 b	61.99/74.25
	WD6, cm	24.96 ± 2.78 a	15.49/28.06	25.12 ± 1.46 a	22.67/27.81	22.34 ± 2.76 b	13.27/24.51	20.30 ± 2.54 b	12.70/23.11
D7	AD7, cm^2	379.55 ± 58.68 a	257.02/468.02	352.12 ± 33.95 a	300.83/425.13	312.44 ± 23.58 b	277.75/350.00	284.98 ± 32.82 b	192.93/326.02
	PD7, cm	95.87 ± 9.78 a	77.95/109.38	86.30 ± 6.52 b	79.47/103.64	80.56 ± 4.50 b c	72.11/88.98	77.85 ± 4.12 c	70.73/84.64
	LD7, cm	39.81 ± 7.98 a	12.57/47.05	36.04 ± 3.43 a b	31.62/45.40	33.52 ± 2.55 b	28.44/38.48	32.46 ± 2.04 b	29.21/36.32
D8	AD8, cm^2	369.96 ± 65.51 a	273.35 / 510.58	348.23 ± 53.00 a b	284.02/468.50	303.92 ± 24.33 bc	254.49/333.32	281.20 ± 35.58 c	190.50/333.33
	PD8, cm	281.20 ± 9.28 c	80.44 / 106.27	86.26 ± 7.56 b	76.80/106.77	80.09 ± 4.4 b c	72.17/87.77	77.15 ± 4.11 c	69.61/83.31
	LD8, cm	39.90 ± 7.96 a	12.57 / 46.29	35.91 ± 3.74 ab	31.37/46.10	33.46 ± 2.32 b	29.97/38.35	32.56 ± 2.01 b	29.84/35.68
S1	AS1, cm^2	4063.07 ± 267.23 a	3540.82 / 4494.46	3926.46 ± 274.55 a	3584.02/4603.09	3566.80 ± 206.25 b	3255.45/3888.96	3312.05 ± 270.49 c	2861.35/3875.35
	CIRS1	0.29 ± 0.02 a	0.26/0.32	0.28 ± 0.02 ab	0.22/0.32	0.27 ± 0.021 bc	0.23/0.31	0.25 ± 0.017 c	0.22/0.28
S2	AS2, cm^2	604.03 ± 207.85 a	291.51/906.50	575.23 ± 162.21 a	339.77/856.57	527.31 ± 159.45 a	209.40/779.06	308.29 ± 97.1 b	213.88/489.17
S3	AS3, cm^2	112.49 ± 11.44 a	99.13/131.69	111.84 ± 10.63 a	96.32/131.51	110.59 ± 13.05 a	86.19/128.09	92.04 ± 8.03 b	81.61/108.00
	PS3, cm	38.96 ± 1.61 a	36.06 / 42.29	37.48 ± 1.67 a	35.17/41.52	35.73 ± 1.84 b	32.70/37.84	35.02 ± 1.82 b	32.51/38.60
	WS3, cm	0.60 ± 0.11 a	0.39/0.75	0.58 ± 0.07 a	0.45/0.71	0.54 ± 0.06 a	0.37/0.62	0.46 ± 0.07 b	0.37/0.58
	CIRS3	1.34 ± 0.15 a	1.16/1.68	1.32 ± 0.16 a	1.03/1.66	1.25 ± 0.073 a	1.13/1.38	1.33 ± 0.19 a	0.94/1.68
S5	AS5, cm^2	518.10 ± 73.28 a	372.41/683.45	474.16 ± 64.71 a b	379.02/590.29	445.78 ± 37.76 b	375.61/527.84	402.01 ± 43.82 c	341.28/473.13
	PS5, cm	93.05 ± 6.32 a	80.05/108.31	89.46 ± 5.46 ab	81.34/100.66	86.30 ± 3.53 bc	79.47/92.94	84.18 ± 4.38 c	76.67/91.06
	WS5, cm	29.37 ± 1.64 a	26.29/34.03	28.73 ± 1.74 a	26.54/33.65	26.60 ± 1.34 b	23.56/28.44	25.47 ± 1.12 b	22.92/27.37
	SOLS5	0.99 ± 0.01 a	0.98/1.00	0.99 ± 0.02 a	0.94/1.00	0.99 ± 0.01 a	0.97/1.00	0.96 ± 0.03 b	0.88/1.00

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Table 5 (*continued*)

SHAPE_VIA1

Projection	Cluster								
	Manifest variable	1	MIN-MAX	2	MIN-MAX	3	MIN-MAX	4	MIN-MAX
S6	AS6, cm^2	382.48 ± 56.85 a b	283.71/ 529.85	393.51 ± 57.71 a	324.05/ 518.75	341.16 ± 41.83 bc	262.39/ 428.88	295.40 ± 28.41 c	234.54/ 341.70
	PS6, cm	81.72 ± 5.44 a	69.14/90.47	82.38 ± 6.11 a	73.45/ 92.96	75.96 ± 4.85 b	67.13/ 85.75	70.31 ± 3.74 c	61.18/ 76.14
	WS6, cm	28.23 ± 2.18 a	22.86/31.43	28.21 ± 2.45 a	24.76/ 32.76	24.80 ± 2.02 b	21.33/ 28.31	22.98 ± 1.61 b	19.05/ 26.03
	ARS6	1.60 ± 0.17 a	1.18/1.94	1.57 ± 0.13 a	1.33/1.88	1.40 ± 0.11 b	1.22/1.63	1.41 ± 0.15 b	1.00/1.59
S7	AS7, cm^2	623.90 ± 87.68 a	429.28 / 795.45	589.27 ± 63.68 a	495.29/ 732.71	513.68 ± 45.41 b	445.99/ 585.89	463.58 ± 59.27 b	365.70/ 540.84
	PS7, cm	121.26 ± 10.00 a	97.23 / 135.13	122.01 ± 5.07 a	111.24/ 128.90	116.07 ± 4.24 a	109.51/ 121.30	111.94 ± 5.79 b	103.97/ 125.07
	WS7, cm	24.71 ± 2.97 a	20 / 29.71	25.58 ± 1.95 a	22.73/ 29.59	22.32 ± 1.80 b	19.30/ 25.21	20.71 ± 1.78 b	16.89/ 23.43
	ARS7	0.53 ± 0.05 ab	0.43 / 0.60	0.55 ± 0.05 a	0.46/0.67	0.49 ± 0.05 bc	0.42/0.60	0.47 ± 0.052 c	0.38/0.55

TYPIFICATION*

Variable	Cluster							
	1	MIN-MAX	2	MIN-MAX	3	MIN-MAX	4	MIN-MAX
Conformation score	2.42 ± 0.69 a	1.00 / 4.00	2.41 ± 0.87 a	1.00/4.00	1.93 ± 0.80 a	1.00/3.00	1.31 ± 2.64 b	1.00/3.00
Fatness score	2.74 ± 0.65 a	2.00 / 4.00	2.18 ± 0.72 ab	1.00/4.00	2.07 ± 0.59 b	1.00/3.00	1.38 ± 0.60 c	1.00/3.00

SHAPE_VIA1: CE 1 = carcass dorsal area; WD1 = carcass dorsal width; LD1 = carcass dorsal length;CIRD1 = carcass dorsal circularity; SOLD1 = carcass dorsal solidity; CE 2 = shoulder dorsal area; PD2 = shoulder dorsal perimeter; WD2 = shoulder dorsal width; CE 3 = rib I dorsal area; PD3 = rib I dorsal perimeter; WD3 = rib I dorsal width; CE 4 = rib II dorsal area; WD4 = rib II dorsal width; ARD4 = rib II dorsal aspect ratio; CE 5 = loin dorsal area; PD5 = loin dorsal perimeter; WD5 = loin dorsal width; ARD5 = loin dorsal aspect ratio; CE 6 = croup dorsal area; PD6 = croup dorsal perimeter; WD6 = croup dorsal width; CE 7 = right leg dorsal area; PD7 = right leg dorsal perimeter; LD7 = right leg dorsal length; AD8 = left leg dorsal area; PD8 = left leg dorsal perimeter; LD8 = left leg dorsal length; AS1 = carcass side area; CIRS1 = carcass side circularity; AS2 = shoulder side area; AS3 = rib side area; PS3 = rib side perimeter; WS3 = rib sidel width; CIRS3 = rib side circularity; AS5 = loin side area; PS5 = loin side perimeter; WS5 = loin side width; SOLS5 = loin side solidity; AS6 = croup side area; PS6 = croup side perimeter; WS6 = croup side width; ARS6 = croup side aspect radio; AS7 = leg side area; PS7 = leg side perimeter; WS7 = leg side width; ARS7 = leg side aspect ratio.

* Typification according to SEUROP carcass classification system.

have greater edible portion due to the lower bone proportion (Leg_B_Perc: r = −0.83, Shoul_B_Perc: r = −0.70 and Rib_B_Perc: r = −0.84).

Effectively, high SHAPE_VIA1, TISSUE_CARCASS, and TISSUE_PRIMALCUTS represent, individually, broad, massive and round carcass; heavy carcass with large edible portion and superior muscle and fat content; and heavier weight and edible portion of primal cuts; respectively. For QUALI_MEAT, lower scores correspond to juicy and tender meat.

The correlation between QUALI_MEAT and SHAPE_VIA1 was not significant ($P \geq 0.05$), a result that was not expected based on the assumption that carcass grading is widely based on muscle and subcutaneous fat distribution profiles, correlated with edible tissue composition (Ricardo et al., 2016; Lima et al., 2017), which would impact meat quality determination (Lambe et al., 2009). In addition, it was assumed these muscles content and subcutaneous fat distribution profiles could be captured by VIA (Craigie et al., 2013).

Nonetheless, the shape descriptors used in this study were considered sufficient to assess these profiles since the instrument created by associating multivariate techniques (RGCCA and PLS-PM) was validated, but this result suggests that either these descriptors do not allow reaching the totality of the profiles or, indeed, lambs carcass shape has only indirect effects on meat quality. In the latter case, the relations between lambs carcass shape – especially that assessed by subjective methodologies such as grading systems – and meat quality become even more questionable.

The shear force range of Cluster 2 (3.45–6.35 kgf/cm^2) comprises values that are considered acceptable for consumers (Rodas-González et al., 2009), but that characterize extremely tough to medium tenderness meats (Cezar and Souza, 2007). Given the mean cluster value (4.9 kgf/cm^2), this category was called "Acceptable Carcass - Standard," which comprises QUALI_MEAT scores between 0.57 and 0.15, SHAPE_VIA1 scores between -0.15 and 1.07, TISSUE_CARCASS scores between -0.11 and 0.95, and TISSUE_PRIMALCUTS scores between 0.24 and 0.84.

These results suggest that carcasses with SHAPE_VIA1, TISSUE_CARCASS and TISSUE_PRIMALCUTS scores above those of Cluster 1 generate lower values than QUALI_MEAT scores obtained by that cluster and must fit an exceptional carcass category that is uncommon for the type of hair sheep lamb studied herewith, which was called "Supreme Carcass."

Although the CCW was not a variable used for the clusters formation, its influence in the formation of the designed classes that promoted well defined and distinct CCW amplitudes is clearly evident, highlighting its importance for the carcass typing methodologies, linked in this study, mainly the great influence that it exerts on the carcass shape, since larger, larger and longer carcasses presented larger weights. In addition, shorter carcasses presented low CCW (Rius-Vilarrasa et al., 2010). Nevertheless, it is important to emphasize that to classify and typify a carcass requires more factors that exclusively or primarily the weight, since the heterogeneity of the Brazilian hair sheep lambs formations crosses, as well as the production systems and slaughter criteria, allow carcasses with similar weights present completely different conformations, so the categorization of carcasses proposed here, which includes a robustest methodology that considers different aspects of the carcass, including tissue composition and meat quality information, may be of great commercial interest.

Finally, it must be pointed out that no difference ($P \geq 0.05$) was

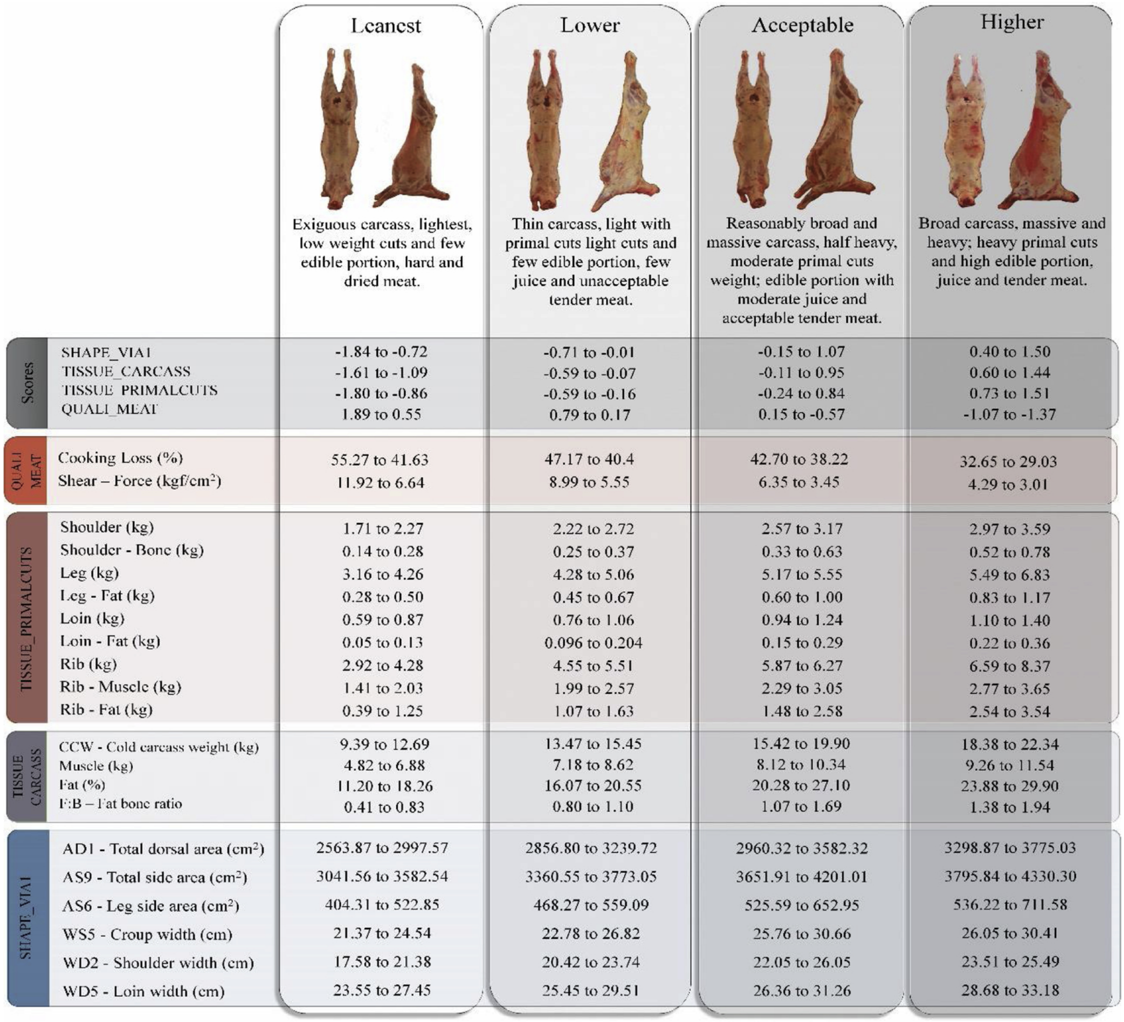

Fig. 5. Carcass categories to hair sheep lambs established from the clusters formed by latent variables scores of model VIA1.

found among the conformation scores of Clusters 1, 2, and 3 or finishing scores between Clusters 1 and 2 and Clusters 2 and 3 (Table 5), which indicates the categorization proposed based on LVs scores of the instrument established differs from the commonly used grading system, SEUROP (Regulation EEC no. 2137/92, 1992/1993Regulation (EEC, 1992Regulation EEC no. 2137/92, 1992/1993), since the categorization infers meat quality based not only on the quantification of carcass shape but also from carcass tissue composition and primal cuts characteristics. That is in accordance with several studies on different animal production species that suggest additional variables to improve carcass characterization regarding meat quality (Pabiou et al., 2011; Lorenzo et al., 2017; Monteils et al., 2017) and with Lima et al. (2017), who specifically reported on the problem with hair sheep lambs carcass grading in Brazil as the usual is based on international classification systems that are not able to capture the actual condition of carcasses in many regions of the country.

5. Conclusions

The instrument validated based on a systematic assessment methodology from video image analysis information allows obtaining more accurate associations among meat quality, carcass and cut tissues characteristics. It enables establishing categories for carcass classification of hair sheep lambs that directly associate meat juiciness and tenderness from the latent variables considered from carcass shape and the description of tissue carcass and primal cuts.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.smallrumres.2019.106024.

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