Effect of Age and Cut on Tenderness of South African Beef

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ABSTRACT

The tenderness characteristics of 15 primal cuts of beef of three different age groups were assessed, and the most reliable cut to predict carcass tenderness was determined. Fifteen wholesale cuts from each age group, representing the full variation in fatness, were aged, cooked and underwent sensory evaluation, shear force resistance and proximate analysis. Collagen content and solubility was determined.

Percentage fat was used as a covariant during statistical analyses. Tenderness, residue and collagen solubility of all cuts decreased significantly with animal age. Collagen solubility was the largest discriminant between the three age groups, while animal age had no significant effect on collagen content. Tenderness of primal cuts from the same carcass varied considerably, with collagen content and shear force resistance as the largest discriminants between the cuts. Cuts most representative of total carcass tenderness were M. Vastus lateralis, M. semimembranosus, M. gluteobiceps, M. semitendinosus and M. triceps brachii caput longum.

Keywords: Age; tenderness; beef; collagen content; collagen solubility; shear force resistance

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INTRODUCTION

Tenderness is a primary determinant of the eating quality and acceptability of meat (Voges *et al*., 2007; Destefanis, Brugiapaglia, Barge & Molin, 2008). This is easily confirmed by the positive relationship between the price of a cut of meat and its relative tenderness (Miller, Carr, Ramsey, Crockett & Hoover, 2001). Consumer preference studies of sensory attributes in samples of whole cuts of beef usually rate tenderness as the most important criterion, compared to flavour and juiciness (Tornberg, 1996; Destefanis *et al*., 2008).

Meat tenderness is evaluated by both sensory and instrumental methods. The Warner Bratzler shear method is the most widely used and yields the best correlation with sensory panel scores for tenderness within muscles. However, the results are widely variable (Destefanis *et al*., 2008), and dependent on experimental conditions and are difficult to interpret in structural terms. Since meat is eaten, tenderness evaluation by the human senses (by consumers and/or trained sensory panels) is the ultimate test (Tornberg, 1996; Destefanis *et al*., 2008). When sensory measurements are related to consumer preference, it is evident that texture, and especially tenderness and juiciness, have a substantial effect on meat cut preference.

Meat tenderness originates in the structural and biochemical properties of skeletal muscle fibres, especially myofibrils and intermediate filaments, and in the intramuscular connective tissue, the endomysium and the perimysium, which are composed of collagen fibrils and fibres (Takahashi, 1996). According to Koohmaraie (1994) the tenderness of meat is influenced by the following variables: animal age and gender, rate and extent of glycolysis, amount and solubility of collagen, sarcomere length, ionic strength and degradation of myofibrillar proteins by the proteinases. In addition Belew, Brooks, McKenna and Savell (2003) states that post-mortem proteolysis, intramascular fat and marbling, connective tissue and the contractile state of the muscle is the characteristics that mostly influences tenderness. In young animals the relationship of connective tissue relative to myofibrils are important, especially in cuts such as the loin. As the animal ages, connective tissue becomes more prominent in cuts with high amounts of connective tissue, e.g. the rump.

Numerous researchers (Young and Braggins, 1993; Xiong, Mullins, Stika, Chen, Blanchard and Moody, 2007) have investigated the relationship between the age of the animal and the palatability traits of the beef. The results of these studies have consistently shown that as the age of the animal

advances the beef palatability (in terms of tenderness) decreases due to decreasing amounts of heat-labile collagen. Shorthose and Harris (1990) confirmed that animal age is an important factor in determining the tenderness and acceptability of meat. Their findings showed that the mean tenderness of twelve beef muscles from animals of eight age groups (ranging from one to approximately 60 months old), decreased significantly ($p < 0,001$) with age and that the rate of toughening of these individual muscles was related to their connective tissue strength. It should be noted that these carcasses were pre-treated to minimize pre-rigor myofibrillar shortening. The South African beef carcass classification system incorporates two variables, namely age by dentition (indicating tenderness) and carcass fat cover (indicating fatness and lean yield) (Government Gazette No. 5092, 1993). Age by dentition was the variable incorporated in this study, as it was deemed essential to elucidate how the tenderness of different cuts varies with age, and how the tenderness of one cut relates to that of others.

Fifteen wholesale beef cuts (Meat Science Section, 1981) are traditionally identified by the industry as representative of the portioned carcass. These cuts may be divided into two categories: those traditionally associated with a dry heat cooking method, and those traditionally associated with a moist heat cooking method.

The main objective of the study was to determine the effect of age on the tenderness-related quality characteristics of seven and eight primal cuts of beef cooked according to a dry and moist heat method respectively, from beef animals of three different age groups. This study formed part of a greater research project which formed the basis for the South African classification system for beef, and based on these results an additional age class was introduced. The carcass classification system was originally developed using young animals ($n = 25$) and the prime rib cut and extrapolated to include all carcasses produced and sold in the country (Naude, 1994). It was deemed imperative to investigate if this still holds true All data were statistically analysed with carcass fat content as a covariant to adjust for initial differences in carcass fat content as carcass fatness influences tenderness (Belew *et al*., 2003).

Since the beef carcass classification system in South Africa is a dynamic system and changes according to consumer demand, it could be useful to develop statistical models that adapt to changes in age groupings. Therefore, a second objective was identified namely the prediction of the tenderness characteristics of various age groups. Determining the most reliable cut in order to predict the tenderness of the carcass was investigated as the third objective.

MATERIALS AND METHODS

Source of materials

The beef carcasses (*n* = 102) used ranged in weight from 190 kg to 240 kg. No specific breed was chosen. Only steers and heifers were included in the study. The three age groups were the 0 (no permanent incisors) or A-age group, the 2 (permanent incisors) or B-age group, and the 8 tooth or C-age group. Carcasses representing the full spectrum of fat classes available in the South African market within each age group were selected. The research design is given in Table 1.

TABLE 1
Experimental Design for Determination of Tenderness and Collagen Characteristics of Beef Carcasses

Carcasses	Age group			Total number of carcasses
	A	**B**	**C**	
All right sides: Physical composition and Chemical analysis	35	34	33	102
Left sides: Tenderness determinations	21	20	20	61
Collagen determinations	14	14	13	41

The carcasses were obtained on the commercial market and had been selected by qualified classifiers. The carcasses were electrically stimulated (500 V) within 10 minutes of stunning, dressed, halved, chilled overnight at between 0°C and 5°C and were labelled and transported to the Animal Nutrition Animal Products Institute of the Agricultural Research Council (ARC-ANPI) in a refrigerated truck at between 5°C and 7°C.

Sample preparation

Each of the 102 right sides of beef was subdivided three days after slaughter into 15 wholesale cuts to determine its physical composition and for chemical analysis. This involved subdivision of the cuts into subcutaneous fat, meat and bone. The subcutaneous fat plus meat were cubed, thoroughly mixed and then minced first through a 5 mm and then through a 2 mm mesh plate. A representative sample of 300 g of the subcutaneous fat plus meat tissue obtained from each cut was analysed to determine the percentages of total moisture, fat, nitrogen (N *x* 6,25 = protein) and ash. These determinations were performed according to AOAC methods (1995). The chemical analysis results were combined with the subcutaneous fat and meat (muscle and inter- and intramuscular fat) content results obtained from the physical dissections for the calculation of muscle and total fat content of each specific cut, and expressed as a percentage of carcass mass (Carroll & Conniffe, 1967). The muscles included in this study were silverside (M. semitendinosus (ST)), hind shin (M. flexor digitorum medialis (FDM)), topside (M. semimmbranosus (SM)), silverside (M. glutebiceps (GB)), thick flank (M. vastus lateralis (VL)), fillet (M. psoas major (PM)), rump (M. gluteus medius (GM)), thin flank (M. obliques abdomimus externus (OAE), loin (M. longissimus lumborum (LL), wing rib (M. longissimus thoracis (LTW)), prime rib (M. longissimus thoracis (LTP)), brisket (M. pectoralis profundus (PP)), chuck (M. serratus ventralis (SV)), shoulder (M. triceps brachii caput longum (TBCL)), fore shin (M. extensor carpi radialis (ECR)) and neck (M. biventer cervicis (BC)).

Forty-one of the left beef sides were used for total collagen content and solubility determinations. The sides were separated three days after slaughter into 15 wholesale cuts (at 10°C), vacuum-packaged and aged at 4°C for 10 days post-slaughter. The cuts were then deboned if applicable and analysed as indicated: chuck (hump and thick elastin sinew removed), PP, neck (visible fat removed), thin flank (visible fat removed), and shins (thick collagen sinew and visible fat removed). The epimysium was removed from the following muscles: LTP, LL, LTW, GM, SM, ST, PM, TBCL, GB and VL. Whole cuts or muscles were homogenised, vacuum-packaged and stored at -40°C until analysed for collagen content and solubility.

Sixty-one left sides were used for sensory analysis and shear force measurements. They were portioned into 15 wholesale cuts with the rump and topside deboned. The cuts were then vacuum-packaged, aged at 4°C for 10 days post-slaughter and stored at -40°C prior to sensory analysis and

shear force resistance measurements. The cuts were defrosted at 6°C - 8°C for periods varying between 24 and 36 hours (depending on size) until the internal temperature reached 2°C - 5°C (American Meat Science Association (AMSA), 1978).

The largest muscle in each cut was selected for evaluation of tenderness. During the various pilot studies, it became clear that the internal temperature of certain muscles, e.g. *M. semimembranosus*, was considerably different from that of the rest of the topside cut due to its anatomical position. It was therefore decided to measure the internal temperature only of the muscle to be evaluated. A J-type thermocouple placed in the geometric centre of each muscle to be evaluated, linked to a centrally controlled computer system, was used to record internal temperature. A hand-model Kane-Mane probe equipped with a T-type thermocouple was used to check the final temperature (70°C) of the cut prior to removal from the oven.

Cooking methods

Dry heat cooking methods

The following cuts (*muscles*) were used: Prime rib - 8th to 10th rib (*M. longissimus thoracis* (LTP)); Loin (*M. longissimus lumborum* (LL)); Wing rib - 11th to 13th rib (*M. longissimus thoracis* (LTW)); Rump (*M. gluteus medius* (GM)); Topside (*M. semimembranosus* (SM)); Silverside (*M. semitendinosus* (ST)) and Fillet (*M. psoas major* (PM)) (Weniger, Steinhof & Pahl, 1963). All these cuts, excluding the loin, were cooked in primal form. The cuts were roasted whole at 160°C, on a rack in an open oven pan, until the muscle to be evaluated reached an internal temperature of 70°C. The loin cuts were portioned into 25 mm thickness beefsteaks (AMSA, 1978), vacuum-packaged and stored at -40°C. The defrosted steaks were cooked according to an oven-broiling method where the meat is cooked by direct radiant heat (> 200°C) to an internal temperature of 70°C.

Moist heat cooking methods

The following cuts (*muscles*) were used: Silverside (*M. gluteobiceps* (GB)); Thick flank (*M. vastus lateralis* (VL)); Chuck (*M. serratus ventralis* (SV)); Brisket (*M. pectoralis profundus* (PP)); Neck (*M. biventer cervicis* (BC)); Shoulder (*M. triceps brachii caput longum* (TBCL)); Thin flank (*M.*

obliquus abdominis externus (OAE)) and Fore as well as Hind Shins (*M. extensor carpi radialis* (ECR)) and *M. flexor digitorum medialis* (FDM)) (Nomina-Anatomica Veterinaria, 1983).

The silverside, thick flank, chuck, shoulder and neck were cooked in primal form. The brisket and thin flank cuts were formed into meat rolls and covered with mesh before ageing. Before cooking commenced, the frozen fore and hind-shins were portioned into cuts of 5 cm thickness. All the cuts were broiled at 160ºC, on a rack in a covered stainless steel casserole dish, until the muscle to be evaluated reached an internal temperature of 70ºC. Distilled water (100 ml) at room temperature was added to each dish before cooking commenced.

All the cuts (dry and moist) were held for a standing period of 10 minutes at room temperature following cooking. Thereafter, all the different muscles were dissected and halved for sensory analysis and shear force measurements, respectively. Half of the muscle designated for sensory analysis was cut up immediately after cooking. Ten cubed samples were taken from the middle of each muscle and immediately individually wrapped in foil marked with random three digit codes. These samples were then served at an internal temperature of 60ºC within 30 minutes from the time the whole cut was removed from the oven. A 100 g sample of the cooked muscle was analysed to determine the percentages of total moisture, fat, nitrogen (N *x* 6,25 = protein) and ash according to AOAC methods (1995).

In order to compare age effects, the sensory panel was presented with samples of the identical muscle from the three age groups with comparable fatness levels. Samples were tasted at each of the 20 sessions during seven consecutive working days, with the order of the age groups randomised for each session. Cooking, sensory analysis and shear force resistance measurements were then performed on the following cut without any particular order of cooking for the various cuts (3 samples *x* 20 sessions *x* 15 cuts = 900 samples tasted).

Data recorded

Descriptive tenderness attributes

A ten-member, trained, descriptive sensory panel was used to evaluate the tenderness attributes of each cut. Panellists were selected and trained in accordance with the AMSA Guidelines for Cooking and Sensory Evaluation of Meat (AMSA, 1978) and the procedures of Cross, Moen and Stanfield (1978).

Panellists received a set of three samples, wrapped and marked with randomly selected three digit codes. Distilled water at room temperature was used to cleanse the palate between samples. Samples (1 cm^3) taken from the middle of each muscle were evaluated for tenderness and residue (connective tissue amount) on an 8-point scale ("one" denoting the least favourable condition and an "eight" the most favourable).

Tenderness determination

The shear force samples were wrapped in aluminium foil and stored at 6°C - 8°C for 24 hours. They were then removed from the refrigerator and allowed to stand for up to four hours to reach room temperature (22°C) before samples were cored. The exception was the prime rib (LTP) cut which was allowed, on an experimental basis, to stand at room temperature on the same day of cooking until it reached room temperature, before samples were cored. Crouse and Koohmaraie (1990) found that neither time of storage nor storage temperature appreciably affected shear-force values or variation of shear-force within treatments. The taste panel found the LTP of the A- and B-age groups significantly ($p \leq 0,05$) more tender than from the C-age group. However, this method was not repeated with the other muscles because no significant differences were found in the shear-force measurements for the LTP.

Cylindrical cores were cut from all the muscles (using a standard 25 mm diameter bore) at room temperature, except for the LL and PP (where a 13 mm bore was used) and the OAE (for which a cherry-pitter with a 12,7 mm diameter attachment was used). These exceptions were due to the shape and size of these muscles. Due to insufficient sample material, no shear force analyses were performed on the BC. Tenderness was measured as the maximum force (Newtons) required to shear a cylindrical core of cooked muscle perpendicular to the grain, at a crosshead speed of 400 mm per minute. The shear force measurements were generated with a Warner Bratzler shear attachment, fitted to an Instron Universal Testing Machine Model 1140 (Instron Food Testing Instrument, 1974). Increasing values indicated greater shear forces and, therefore, tougher meat.

Collagen content and solubility

The total collagen content of each of the respective muscles/cuts was determined according to the method of Weber (1973) and hydroxyproline according to Bergman and Loxley (1963). Total collagen

content was calculated as the ratio of hydroxyproline nitrogen relative to the total nitrogen content, expressed as a numeric value multiplied by 1 000 (Boccard, Naude, Cronje, Smith, Venter & Rossouw, 1979). Collagen solubility was determined according to a combination of the methods of Hill (1966) and Bergman and Loxley (1963), being expressed as the hydroxyproline content of the filtrate as a percentage of total hydroxyproline (filtrate plus residue).

STATISTICAL ANALYSIS

In order to establish which of the large set of correlated variates were the most important in discriminating between the age groups (A, B and C) and/or the 15 cuts, canonical variate analysis (CVA) (GENSTAT 5, 1996), also known as linear discriminant analysis, was used. Multivariate techniques, such as principal component analysis (PCA) are used to reduce a large set of variates into a smaller set, which explains most of the variation in the entire data set. PCA (GENSTAT 5, 1996) was performed on all the different variates for each of the 15 cuts, but will not be presented due to limited space (n = 5 tenderness parameters x 15 cuts = 75 plots). Through the PCA, it was identified that fatness of the carcass was one of the most important gradients, or factors, identified in this multivariate data space (data matrix) and, for that reason it was used as covariant in the ANOVA-analyses. PCA is suitable when one is interested in the groupings of individuals, and as definite groupings were observed in this data set, CVA was applied. The variability in this large number of variates was firstly reduced to a smaller set of variates, which accounted for most of the variability. If there was a strong grouping, or trend, in the data set, usually only a few of the important variates which influence the new variate, called canonical variates (CV), were obtained. A plot of the mean scores of each group is obtained. This plot is a visual and easily understandable graphical representation of the similarity or groupings of the original age and/or cut groups. Furthermore, by correlating the scores with the original variates, the most important variates discriminating between the new groups were identified (Digby & Kempthorne, 1987). In this study, the variates were the tenderness characteristics that were measured in each cut. The logarithms of the variates were used to stabilise variances.

As only the directions of the main variability in the data matrix are given attention in these analyses, the more subtle sources of variation were investigated by ANOVA-analyses (SAS, 1996) as proposed by Næs, Baardseth, Helgesen and Isakson (1996). A correlation matrix was constructed to test for

correlations between the different variables. To ensure that the effect of animal age was determined and not the effect of fatness of the carcass, the percentage chemical fat of the carcass (as determined by proximate analyses for the 15 wholesale cuts and calculated for the carcass according to the relative mass of each cut) was used as covariant (X), both as natural X and X^2 in a PROC GLM (SAS, 1996) procedure. In searching for the most simplistic model the covariant was removed from the model if not significant (very generously at $p \geq 0{,}15$), starting with X^2 and continuing with X. Separation of the mean scores for interaction of the different variables for the various cuts for the three age groups was achieved by the application of Tukey's method (SAS, 1996).

In order to achieve the second objective, namely the prediction of the tenderness characteristics for the various age groups, regression equations ($Y = A + BX$) were used as the main model. In the regression equation age of the animal (X) was tested against the various tenderness characteristics (Y) of each cut and the entire carcass. Due to the fact that most of the data were not normally distributed, the dependent variates in the equation (Y) were transformed to Y^2, Y^3, $\sqrt{Y}$ and *ln* Y's (natural logs). These four transformations, together with the natural Y, were combined in forward stepwise regression analysis and tested against tenderness as analysed by the taste panel.

The above-mentioned formulae should be of a specific accuracy to obtain repeatable and reliable predictions of mean carcass and individual cut tenderness. The accuracy of these formulae is determined by the R^2 (percentage variation) and the residual standard deviation or RSD (error variance around the regression line). As very few of the $R^2 \geq 50\%$ this was not considered a reliable method of predicting the tenderness characteristics in animals. Therefore, the data were submitted to an analysis of variance for the three age groups as described above in which the R^2 and p-value of the model were also presented. During this study it became evident that this also was not a reliable method for predicting tenderness in animals. Therefore, no satisfactory statistical model was identified within the scope of this study to predict tenderness parameters of animals of different age groups accurately.

Tenderness and residue was so closely related to each other in all the cuts (according to the forward stepwise regression analysis) that a simple linear regression equation ($Y = A + BX$) is sufficient. This is in accordance with the results of Cross, Carpenter and Smith (1973) who described sensory panel ratings as closely interrelated and probably mutually dependent. Therefore, all the sensory panel ratings were excluded from the model and the data were again submitted to forward stepwise regression analysis.

In order to determine the most reliable cut to predict tenderness of the carcass (third objective), correlation coefficients and R^2-values were determined between the tenderness characteristic obtained for a specific muscle with the mean of the same measurement of all the individual muscles combined.

RESULTS AND DISCUSSION

Effect of age on tenderness characteristics

According to the canonical variate analyses results, the first canonical variate (CV1) alone accounted for 99,8 % of the total variation in the data but the latent root was 0,8038 (should be >1). The canonical variate means for tenderness, residue and collagen solubility were positive and for shear force resistance and collagen content negative, thus CV1 clearly contrasts between these variables. The parameter discriminating between the tenderness parameters was collagen solubility (r = 0,807) as this correlated the strongest with the CV scores (horizontal). The CV mean scores are presented in Figure

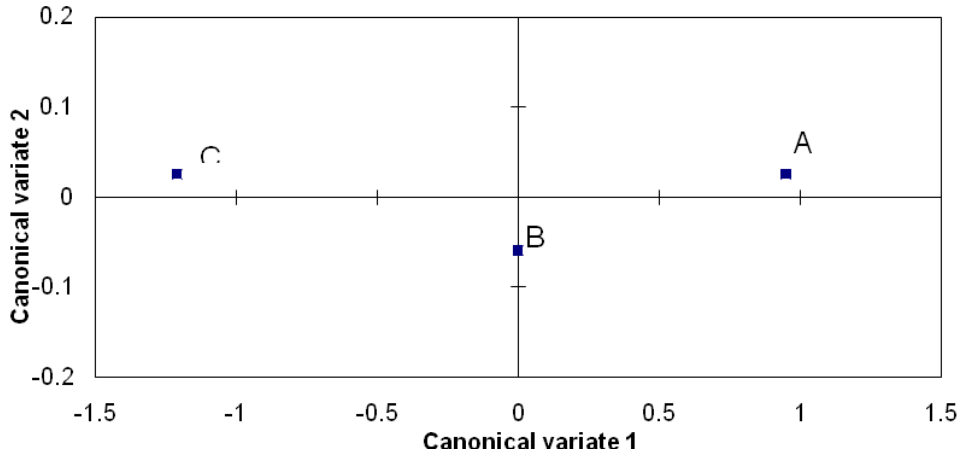

Figure 1: Plot of CV mean scores of three age groups

[1] A-age group – no permanent incisors; B-age group – 2 permanent incisors; C-age group ≥ 8 permanent incisors

1. Collagen solubility was therefore the largest discriminant between the three age groups and it declined with age. This finding was expected, as the effect which myofibrillar shortening may have on

tenderness has been minimized through electrical stimulation and controlled aging of the carcasses prior to dissection. This result was due to the proportion of heat stable cross-links in collagen that increases with increasing animal age and was in accordance with results of many researchers such as Young and Braggins (1993), Cross *et al.* (1973). The hypothesis that collagen is a major determinant of the texture of cooked meat, as proposed by Bailey (1989), and that it is the quality as well as the quantity that accounts for the variability, is, therefore, validated.

For the analyses of variance (ANOVA), the chemical analysis data were combined with the subcutaneous fat, meat (muscle and intermuscular fat) and bone content results obtained from the physical dissections for the calculation of percentages meat, total fat and bone content of each specific cut (Carroll & Conniffe, 1967). These values were summed to obtain the chemical (fat, protein and moisture) and physical composition (meat, total fat and bone) of the carcass. This percentage total fat content of the carcass was used as covariant in the PROC GLM procedure to adjust for differences between initial fat content and was 15,74% with a minimum of 8,03% and a maximum of 29,75%.

The other fat attributes measured for this data set were:

- Subcutaneous fat (%) of the carcass: Mean = 6,214; Minimum = 1,170; Maximum = 13,360;
- Proximate fat (%) in the carcass: Mean = 13,46; Minimum = 1,61; Maximum = 42,89;
- Proximate fat (%) in the cooked muscles: Mean = 4,93; Minimum = 0,98; Maximum = 26,61.

The age of the animal (Tables 2 to 6) had a significant effect on the tenderness, residue of the various muscles and collagen solubility of various cuts or muscles. According to the taste panel scores, all 15 muscles of the A-age group (0 tooth) were significantly ($p \leq 0,01$) more tender and contained less residue than those from the C-age group (8 tooth) (Tables 2 and 3). The ST, SM, PM, GB, SV, PP, TBCL, ECR and FDM of the A-age group (0 tooth) were significantly ($p \leq 0,01$) more tender and contained less residue than those from the B-age group (2 tooth).

The two muscles in the silverside (ST and GB) and OAE of the A-age group showed significantly ($p \leq 0,01$) less resistance to shear than those from the B-age group which in turn showed significantly ($p \leq 0,01$) less resistance to shear than those from the C-age group (Table 4). The LTW, VL, SV and TBCL of A-age group (0 tooth) showed significantly ($p \leq 0,05$) less resistance to shear than those from the C-age group (8 tooth).

TABLE 2
Least Square Mean Values (± Standard Error of Mean) for Sensory Panel Trait (Tenderness) for Muscles from Three Age Groups (Average Chemical Fat of the Carcass used as Covariant = 15.74 %)

Muscle[1]	Model		Co-variant[2]			Age					
	R^2 %	p-Value	*X* p-Value	X^2 p-Value	Age p-Value	A		B		C	
						Mean[3]	SEM	Mean[3]	SEM	Mean[3]	SEM
Dry Heat Cooking Method											
LTP	10	0.0001	0.3145	0.0328	0.0129	5.22^{a}	0.11	5.23^{a}	0.11	4.84^{b}	0.10
LL	5	0.0001	0.0001	-	0.0023	4.78^{a}	0.10	4.52^{ab}	0.10	4.29^{b}	0.10
LTW	15	0.0001	0.0001	-	0.0001	5.66^{a}	0.10	5.53^{a}	0.11	4.64^{b}	0.10
ST	22	0.0001	0.0001	0.0001	0.0001	5.80^{a}	0.09	5.35^{b}	0.09	4.56^{c}	0.08
GM	5	0.0001	0.0001	-	0.0002	5.53^{a}	0.09	5.29^{ab}	0.10	4.98^{b}	0.09
SM	12	0.0001	0.0932	0.0488	0.0001	5.33^{a}	0.08	4.78^{b}	0.08	4.41^{c}	0.08
PM	8	0.0001	0.0095	0.0060	0.0001	6.72^{a}	0.07	6.44^{b}	0.08	6.09^{c}	0.07
Moist Heat Cooking Method											
GB	29	0.0001	-	-	0.0001	5.56^{a}	0.09	4.73^{b}	0.10	3.51^{c}	0.09
VL	13	0.0001	0.0968	0.0323	0.0001	5.56^{a}	0.08	5.39^{a}	0.09	4.63^{b}	0.08
SV	18	0.0001	0.0026	0.0002	0.0001	5.74^{a}	0.09	5.44^{b}	0.10	4.53^{c}	0.09
PP	26	0.0001	0.0001	-	0.0001	4.76^{a}	0.10	4.16^{b}	0.10	2.94^{c}	0.10
BC	16	0.0001	0.0519	0.0494	0.0001	5.49^{a}	0.10	5.20^{ab}	0.11	4.04^{b}	0.10
TBCL	9	0.0001	0.0267	0.0136	0.0001	5.23^{a}	0.10	4.92^{b}	0.11	4.26^{c}	0.10
OAE	11	0.0001	0.0012	0.0013	0.0001	5.67^{a}	0.10	5.60^{a}	0.10	4.69^{b}	0.10
ECR&FDM	12	0.0001	0.2952	0.1057	0.0001	4.20^{a}	0.10	3.77^{b}	0.11	3.07^{c}	0.10

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

[2] p-values are of the full model. if not significant ($p \geq 0.15$) covariant was removed from the model starting with X^2 and continuing with *X*

[3] Scored on a scale from 1 to 8 (8=extremely Tender.1=extremely Tough)

[abc] Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

TABLE 3
Least Square Mean Values (± Standard Error of Mean) for Sensory Panel Trait (Residue) for Muscles from Three Age Groups (Average Chemical Fat of the Carcass used as Covariant = 15.74 %)

Muscle[1]	Model		Co-variant[2]			Age					
	R^2 %	p-Value	*X* p-Value	X^2 p-Value	Age p-Value	A		B		C	
						Mean[3]	SEM	Mean[3]	SEM	Mean[3]	SEM
Dry Heat Cooking Method											
LTP	9	0.0001	0.6241	0.1165	0.0464	5.13[a]	0.10	5.07[a]	0.10	4.80[b]	0.10
LL	3	0.0006	0.0031		0.0192	4.61[a]	0.09	4.45[ab]	0.10	4.24[b]	0.09
LTW	17	0.0001	0.0001		0.0001	5.54[a]	0.10	5.35[a]	0.11	4.56[b]	0.10
ST	21	0.0001	0.0001	0.0001	0.0001	5.72[a]	0.08	5.32[b]	0.09	4.61[c]	0.08
GM	5	0.0001	0.0005		0.0001	5.48[a]	0.09	5.24[a]	0.10	4.90[b]	0.09
SM	1	0.0001	0.1573	0.1286	0.0001	5.19[a]	0.08	4.72[b]	0.08	4.33[c]	0.08
PM	8	0.0001	0.0047	0.0035	0.0001	5.56[a]	0.07	6.33[b]	0.07	5.99[c]	0.07
Moist Heat Cooking Method											
GB	28	0.0001	0.1391		0.0001	5.47[a]	0.09	4.70[b]	0.10	3.51[c]	0.09
VL	11	0.0001	0.0012		0.0001	5.34[a]	0.08	5.14[a]	0.08	4.49[b]	0.08
SV	19	0.0001	0.0406	0.0056	0.0001	5.62[a]	0.09	5.23[b]	0.09	4.39[c]	0.09
PP	25	0.0001	0.0001		0.0001	4.52[a]	0.09	4.06[b]	0.10	2.88[c]	0.09
BC	11	0.0001	0.0522	0.0411	0.0001	5.04[a]	0.10	4.91[a]	0.11	3.94[b]	0.10
TBCL	9	0.0001	0.0632	0.0268	0.0001	4.92[a]	0.10	4.62[b]	0.10	3.98[c]	0.10
OAE	11	0.0001	0.8448	0.0001	0.0001	5.36[a]	0.10	5.22[a]	0.10	4.44[b]	0.10
ECR&FDM	11	0.0001	0.0003		0.0001	3.94[a]	0.10	3.54[b]	0.11	2.86[c]	0.10

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

[2] p-values are of the full model. if not significant ($p \geq 0.15$) covariant was removed from the model starting with X^2 and continuing with *X*

[3] Scored on a scale of 1 to 8 (8=no residue. 1=abundant residue):

[abc] Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

According to Table 5 collagen content of cuts/muscles did not differ significantly between the various age groups. In Table 6 the LTP, LL, ST, GB, VL, chuck, PP, neck, TBCL and thin flank were significantly ($p \leq 0{,}001$) more soluble in cuts/muscles obtained from the A-age group compared to the B-age group which, in turn, were significantly ($p \leq 0{,}001$) more soluble than cuts/muscles obtained from the C-age group. The collagen of all 16 cuts/muscles measured in the A-age group was significantly ($p \leq 0{,}05$) more soluble than those from the C-age group.

TABLE 4
Least Square Mean Values (± Standard Error of Mean) for Shear Force Resistance (N/2.54cm) for Muscles Obtained from Three Age Groups (Average Chemical Fat of the Carcass Covariant = 15.74%)

Muscle[1]	Model		Co-variant[2]			Age					
	R^2 %	p-Value	*X* p-Value	X^2 p-Value	Age p-Value	A		B		C	
						Mean	SEM	Mean	SEM	Mean	SEM
Cooked (Dry Heat)											
LTP	11	0.0777	0.0169	-	0.5951	127	7.79	117	8.01	118	7.62
LL [3]	11	0.1601	0.0693	0.0428	0.6909	56.5	3.00	58.3	3.15	60.2	2.98
LTW	23	0.0022	0.0077	-	0.0264	97.8[a]	5.77	96.8[a]	6.24	117[b]	5.92
ST	29	0.0006	0.1003	0.0936	0.0003	91.8[a]	3.54	101[b]	3.72	114[c]	3.53
GM	29	0.0008	0.0001	0.0001	0.0866	95.8	3.31	92.9	3.40	103	3.23
SM	2	0.5058	-	-	0.5058	135	5.44	128.3	6.01	138	5.70
PM	13	0.0842	0.1694	0.0810	0.6621	80.8	2.70	78.3	2.84	77.5	2.70
Cooked (Moist Heat)											
GB	50	0.0001	-	-	0.0001	85.0[a]	6.25	113[b]	6.55	154[c]	6.55
VL	20	0.0014	-	-	0.0014	96.0[a]	4.96	104[a]	5.34	123[b]	5.08
SV	18	0.0128	0.1141	-	0.0190	58.4[a]	2.85	63.1[ab]	3.02	70.3[b]	2.94
PP [3]	47	0.0001	0.0008	-	0.0001	42.1	2.03	47.1	2.21	57.9	2.09
TBCL	20	0.0114	0.0302	0.0386	0.0101	92.8[a]	4.27	87.7[a]	4.61	107[b]	4.48
OAE [3]	40	0.0001	0.0003	-	0.0002	82.4[a]	5.82	103[b]	6.15	119[c]	5.83
ECR&FDM	24	0.0004	-	-	0.0004	52.7	3.75	62.4	4.03	75.5	3.84

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - M. flexor digitorum medialis

[2] p-values are of the full model. if not significant ($p \geq 0.15$) covariant was removed from the model starting with X^2 and continuing with *X*

[abc] Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

[3] LL and PP cored with a 13 mm diameter bore and OAE with a 12.7 mm diameter cherry-pitter

TABLE 5
Least Square Mean Values (± Standard Error of Mean) for Collagen Content (Hypro N /Total Nx10[3]) for Muscles/cuts Obtained from Three Age Groups (Average Chemical Fat of the Carcass Covariant = 15.74%)

Muscle [1]	Model		Co-variant [2]			Age					
	R^2 %	p-Value	*X* p-Value	X^2 p-Value	Age p-Value	A		B		C	
						Mean	SEM	Mean	SEM	Mean	SEM
Cooked (Dry Heat)											
LTP	6	0.2769	-	-	0.2769	3.05	0.31	3.53	0.32	3.78	0.34
LL	9	0.3212	0.1048	-	0.8023	2.90	0.16	2.79	0.16	2.93	0.17
LTW	1	0.7700	-	-	0.7700	2.68	0.13	2.59	0.13	2.70	0.14
ST	12	0.0808	-	-	0.0808	4.31	0.27	4.58	0.28	5.23	0.30
GM	4	0.4021	-	-	0.4021	3.67	0.18	3.32	0.19	3.47	0.20
SM	0.4	0.9271	-	-	0.9271	3.00	0.09	3.03	0.09	2.98	0.10
PM	10	0.1242	-	-	0.1242	2.23	0.17	2.76	0.18	2.52	0.19
Cooked (Moist Heat)											
GB	2	0.6383	-	-	0.6383	6.26	0.34	6.09	0.36	5.78	0.38
VL	2	0.7141	-	-	0.7141	4.04	0.18	4.18	0.20	3.95	0.20
Chuck	18	0.1628	0.1478	0.0998	0.1613	8.27	0.44	8.46	0.49	9.49	0.48
PP	29	0.0051	0.0024	-	0.1500	6.26	0.38	7.28	0.38	7.08	0.40
Neck	2	0.7216	-	-	0.7216	10.9	0.94	12.0	0.97	11.3	1.04
TBCL	6	0.3420	-	-	0.3420	5.02	0.38	5.21	0.39	5.90	0.47
Thin flank	3	0.5805	-	-	0.5805	11.9	0.72	13.0	0.91	11.9	0.91
Fore shin	10	0.1431	-	-	0.1431	13.5	0.80	15.4	0.80	13.2	0.90
Hind shin	21	0.0366	0.0145	-	0.4982	18.8	0.97	20.4	1.02	19.3	1.06

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobicepss*; VL - *M. vastus lateralis*; PP - *M. pectoralis profundus*; TBCL - *M. triceps brachii caput longum*

[2] p-values are of the full model. if not significant ($p \geq 0.15$) covariant was removed from the model starting with X^2 and continuing with *X*

[abc] Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

These results are in accordance with Shorthose and Harris (1990) who reported a significant decrease in tenderness with increased age. Similar results were found by Wulf, Morgan, Tatum & Smith (1996) and Xiong *et al.* (2007). All the objective measurements they used (Instron-compression, adhesion, Warner-Bratzler shear) indicated strong linear (and in some cases, curvilinear) relationships with animal age. However, when considering results from taste panel evaluations of the meat, Wulf *et al.* (1996), found that age did not have a constant effect on tenderness of the PM muscles and that the results for the other muscles all showed non-linearity ($p \leq 0{,}001$). Similarly Davis, Smith, Carpenter, Datson and Cross (1979) found that neither collagen content nor collagen solubility was significantly related to tenderness of cooked beef from carcasses of the A- (very young) or B- (young) maturity.

Results of the current study are in agreement with Cross *et al.* (1973) who found that initial and fibre tenderness ratings, amount of connective tissue ratings, shear force values, percentages of fat on a

TABLE 6
Least Square Mean Values (± Standard Error of Mean) for Collagen Solubility (%) for Muscles/cuts Obtained from Three Age Groups (Average Chemical Fat of the Carcass Covariant = 15.74%)

Muscle [1]	Model		Co-variant [2]			Age					
	R^2 %	p-Value	*X* p-Value	X^2 p-Value	Age p-Value	A		B		C	
						Mean	SEM	Mean	SEM	Mean	SEM
Cooked (Dry Heat)											
LTP	50	0.0001	-	-	0.0001	19.9^{a}	0.85	15.0^{b}	0.91	12.1^{c}	0.94
LL	29	0.0008	-	-	0.0008	21.5^{a}	1.35	17.6^{b}	1.40	13.2^{c}	1.50
LTW	24	0.0036	-	-	0.0036	18.9^{a}	1.31	14.7^{b}	1.36	11.9^{b}	1.46
ST	47	0.0001	-	-	0.0001	19.0^{a}	0.86	16.0^{b}	0.89	11.4^{c}	0.95
GM	44	0.0003	0.0456	0.0979	0.0006	20.3^{a}	1.34	16.8^{a}	1.38	11.9^{b}	1.41
SM	38	0.0005	0.0602	-	0.0011	15.0^{a}	0.87	12.3^{b}	0.87	9.87^{b}	0.91
PM	47	0.0001	0.0566	-	0.0001	16.0^{a}	0.73	14.6^{a}	0.73	10.9^{b}	0.76
Cooked (Moist Heat)											
GB	49	0.0001	-	-	0.0001	20.0^{a}	0.91	16.6^{b}	0.94	11.6^{c}	1.00
VL	48	0.0001	0.0026	-	0.0005	23.9^{a}	1.42	19.4^{b}	1.43	14.8^{c}	1.55
Chuck	50	0.0001	0.0373	-	0.0373	28.7^{a}	1.54	21.9^{b}	1.55	16.5^{c}	1.62
PP	41	0.0002	0.0830	-	0.0003	17.8^{a}	0.90	14.8^{b}	0.90	12.0^{c}	0.94
Neck	48	0.0001	-	-	0.0001	25.7^{a}	1.23	20.0^{b}	1.27	14.6^{c}	1.36
TBCL	48	0.0001	-	-	0.0001	27.8^{a}	1.19	21.7^{b}	1.23	17.1^{c}	1.32
Thin flank	59	0.0001	0.0883	0.1044	0.0001	29.7^{a}	1.29	22.4^{b}	1.33	17.0^{c}	1.36
Fore shin	55	0.0001	0.0338	0.0506	0.0001	35.6^{a}	1.75	32.7^{a}	1.81	20.6^{b}	1.85
Hind shin	37	0.0020	0.0493	0.0731	0.0015	26.5^{a}	1.88	23.3^{a}	1.94	15.9^{b}	1.98

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobicepss*; VL - *M. vastus lateralis*; PP - *M. pectoralis profundus*; TBCL - *M. triceps brachii caput longum*

[2] p-values are of the full model. if not significant ($p \geq 0.15$) covariant was removed from the model starting with X^2 and continuing with *X*

[abc] Means in the same row with different superscripts differ significantly ($p \leq 0.05$)

moisture free basis and the amount of soluble collagen differed significantly ($p \leq 0,05$) among age groups (1 yr vs. 4 yr vs. 10 yr), with no significant difference in collagen content between the groups. Herring, Cassens and Briskey (1967) also reported that collagen solubility decreased significantly with each advancing maturity group (USDA meat-grading standards) in both *longissimus dorsi* and *semimembranosus*, and Young and Braggins (1993) who found that in both the SM and GM the collagen solubility declined with age. Similar results were found by Jurie, Martin, Listrat, Jailler, Culioli & Pichard (2005). Collagen content remained unchanged in the SM and GM (Young & Braggins, 1993) and *longissimus dorsi* between the age groups but the *semimembranosus* in the E-age group (older) had more collagen ($p \leq 0,05$) than in the A- (very young) and B- (young) maturity groups and concentrations (Herring *et al.*, 1967). In the current study, no significant difference was found in the collagen content (%) between the different age groups for any of the cuts/muscles evaluated when analysed on an equal chemical fat content. Significant differences in collagen solubility were found in

12 of the 16 cuts from carcasses of the A- (0 teeth) and B- (2 teeth) age groups.

Discrimination between cuts/muscles

According to the results of canonical variate analyses, the first two canonical variates (CV1 and CV2) accounted for 95,5% of the total variation in the data, with latent roots 10,1 and 1,0 (should be >1). The canonical variate means for tenderness, residue and shear force resistance were negative and for collagen content and collagen solubility positive, thus, CV1 clearly contrasted between the groups of cuts. The variate mainly discriminating between the tenderness characteristics for the different cuts is collagen content (r = 0,986) as this correlated the strongest with the CV1 scores. Shear force resistance (r = -0,702) mainly discriminated between groups in the CV2 for the different cuts. The CV mean scores are presented in Figure 2.

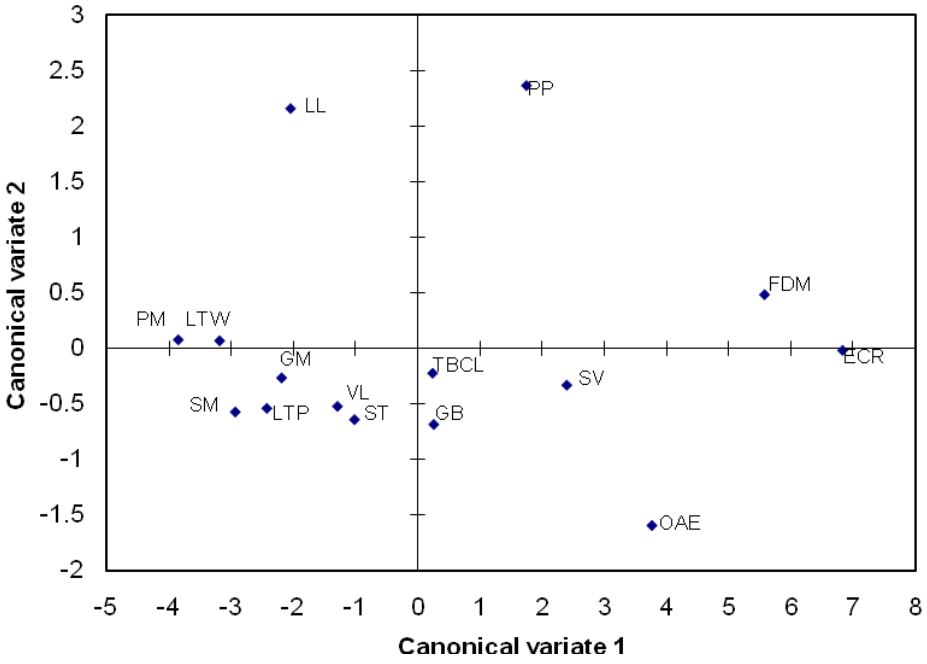

Figure 2: Plot of CV mean scores of various cuts

[1] LTP – *M. longissimus thoracis*; LL – *M. longissimus lumborum*; LTW – *M. longissimus thoracis*; ST – *M. semitendinosus*; GM – *M. gluteus medius*; SM – *M. semimembranosus*; PM – *M. psoas major*; GB – *M. gluteobiceps*; VL – *M. vastus lateralis*; SV – *M. serratus ventralis*; PP – *M. pectoralis profundus*; BC – *M. biventer cervicis*; TBCL – *M. triceps brachii caput longum*; OAE – *M. obliquus abdominis externus*; ECR – *M. extensor carpi radialis* and FDM – *M. flexor digitorum medialis*

Inspection of the graphical representation of the results (points close together are similar and those far apart are dissimilar) shows that, PM, LTW, SM, LTP, GM and LL are contrasted against the ECR, FDM, OAE, SV and PP according to collagen with the former being lower in collagen and the latter higher on the CV1 axis (horizontal). This difference in collagen content between the various muscles is also tabulated by Seideman (1986) in descending order as ST>GB>LL>SM>PM. Light, Champion, Voyle and Bailey (1985) also reported a higher total collagen content in the tougher muscles with PP higher in total collagen content than *longissimus dorsi* (in this instance represented by LL, LTP and LTW), which, in turn, contained more collagen than the PM.

In studying CV2 (vertical axis) and taking into consideration the fact that CV2 only accounted for 8,8% of the total 95,5%, the OAE (cherry pipper attachment) showed the highest resistance to shear and the LL and PP (only two cuts analysed with a 13 mm bore) the lowest. In contrasting the muscles that were analysed with the identical 25 mm cores and cooked according to a dry heat cooking method, the PM and LTW contrasted against ST, with the former showing the least resistance to shear. With contrasting cuts cooked according to a moist heat cooking method the FDM and ECR showed the least resistance to shear and the GB the highest. This is in accordance with a study of Mc Keith, De Vol, Miles, Becktel and Carr (1985) who reported the lowest scores (in ascending order) for PM, LL, GM, ST, LD-Rib (similar to LTP and LTW) and the highest (in descending order) for SM and GB. Table 7 gives the mean scores (CVAs) for the determination of the tenderness characteristics of the various cuts for the three age groups. An ANOVA or similar analysis that tests for differences between the means e.g. Bonferoni was not performed due to the fact that the muscles were not similarly treated. With the exception of the OAE, the sensory panel for muscle fibre tenderness and the amount of detectable connective tissue residue almost identically ranked the cuts. The PM was the most tender muscle, had the least amount of detectable connective tissue residue and the lowest collagen content of all the muscles. These findings are identical to the results of Mc Keith *et al*. (1985) in which the properties of 13 major beef muscles were studied.

The tenderness values (muscle fibre tenderness, residual connective tissue and shear force resistance) found in this study for the various muscles are similar to those of Shorthose and Harris (1990) who reported tenderness in order of most to least PM>GM>SM>GB in animals aged 10 - 60 months. Seideman (1986) reported the collagen content of various muscles (14 month old steers) in more or less

TABLE 7
Ranking of 16 Muscles[1] According to Tenderness and Collagen Characteristics

Score	Muscle fibre tenderness [2]	Residual connective tissue [3]	Shear force resistance [4]	Collagen content [5]	Collagen solubility [6]
1	PM (6.40)	PM (6.28)	SM (134)	PM (2.43)	FDM[(all)] (30.2)
2	OAE [(moist)8] (5.32)	GM (5.22)	LTP (120)	LTW (2.65)	OAE [(all)] (23.8)
3	GM (5.29)	ST (5.22)	GB (116)	LL (2.91)	ECR [(all)] (23.1)
4	LTW (5.28)	LTW (5.14)	VL (107)	SM (3.00)	SV [(all)] (23.0)
5	ST (5.24)	SV (5.08)	LTW (107)	LTP (3.43)	TBCL (22.7)
6	SV [(moist)] (5.23)	OAE (5.03)	ST (102)	GM (3.50)	BC [(all)] (20.8)
7	VL [(moist)] (5.19)	LTP (5.01)	OAE (100)	VL (4.06)	VL (20.2)
8	LTP (5.11)	VL (4.98)	GM (97.7)	ST (4.70)	LL (18.1)
9	BC [(moist)] (4.90)	SM (4.78)	TBCL (95.8)	TBCL (5.43)	GB (16.4)
10	SM (4.87)	BC (4.61)	PM (79.1)	GB (5.97)	GM (16.3)
11	TBCL [(moist)] (4.81)	GB (4.57)	SV (67.5)	PP [(all)] (6.83)	LTP (16.0)
12	GB [(moist)] (4.61)	TBCL (4.52)	ECR (63.4)	SV [(all)] (8.86)	ST (15.8)
13	LL (4.54)	LL (4.44)	FDM (63.42)	BC [(all)] (11.6)	LTW (15.4)
14	PP [(moist)] (3.97)	PP (3.83)	LL (58.17)	OAE [(all)] (12.1)	PP [(all)] (14.9)
15	ECR [(moist)] (3.66)	ECR (3.43)	PP (45.43)	FDM [(all)] (14.0)	PM (14.0)
16	FDM [(moist)] (3.66)	FDM (3.43)	–	ECR[(all)7] (19.2)	SM (12.7)

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; ST - *M. semitendinosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*
[2] 8 = Extremely tender. 1 = Extremely tough
[3] 8 = None. 1 = Abundant
[4] N/2.54 cm
[5] Hypro N/Total N x 10^3
[6] %
[7] All: With epimysium
[8] Moist heat cooking method

the same order ST>GB>LD>SM>PM and the quantity of soluble collagen GB>PM>SM. The ECR and FDM were the least tender and contained the highest amount of connective tissue (residual and as determined), despite the fact that these muscles contained the most soluble collagen and that it was

cooked according to a moist heat cooking method. However, the shear force resistance results showed that ECR and FDM had the least resistance to shear with the exception of two muscles. This is in contrast to the OAE, which was high in collagen, high in soluble collagen and was evaluated by the panel as very tender. According to Young and Braggins (1993) their panel data showed that collagen concentration as opposed to solubility, was the more important determinant of eating quality, whereas shear data were more clearly related to solubility.

As expected, the cuts in which the epimysium had not been removed prior to the determination of the collagen parameters contained on average the highest amount of collagen (ECR>FDM>OAE>BC>SV>PP). The collagen solubility of these cuts formed a similar pattern with the exception of the PP which had much less soluble collagen. This could explain the low sensory panel scores for tenderness and residue for the PP.

Effect of age by cut

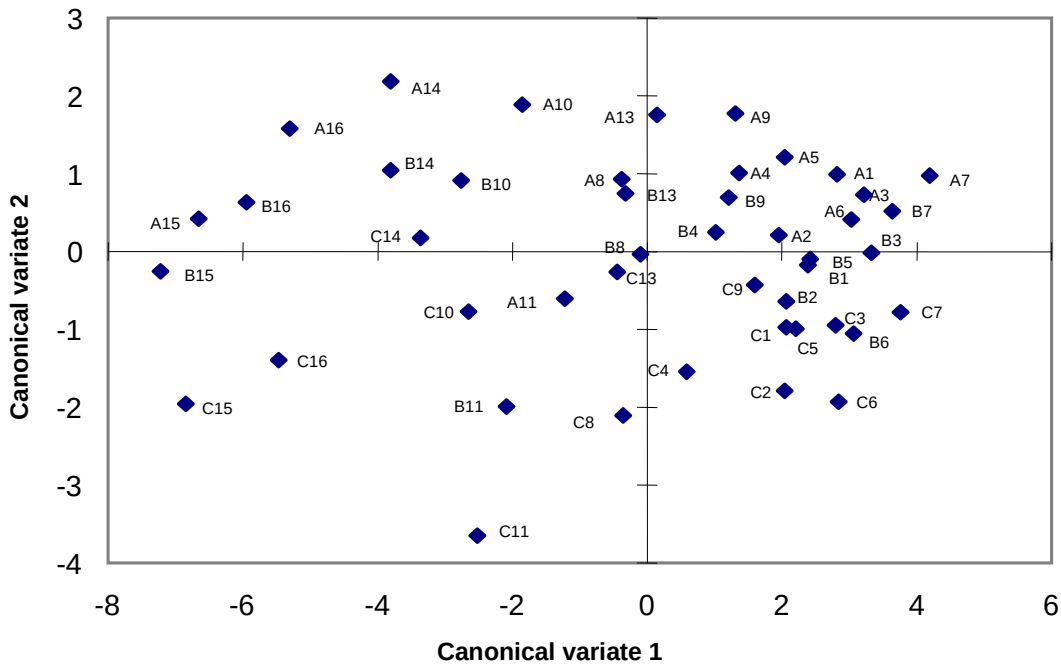

Figure 3: Plot of CV mean scores of age groups by cuts

[1] A-age group – no permanent incisors; B-age group – 2 permanent incisors; C-age group ≥ 8 permanent incisors

[2] 1 – *M. longissimus thoracis (LTP)*; 2 – *M. longissimus lumborum (LL)*; 3 – *M. longissimus thoracis (LTW)*; 4 – *M. semitendinosus (ST)*; 5 – *M. gluteus medius (GM)*; 6 – *M. semimembranosus (SM)*; 7 – *M. psoas major (PM)*; 8 – *M. gluteobiceps (GB)*; 9 – *M. vastus lateralis (VL)*; 10 – *M. serratus ventralis (SV)*; 11 – *M. pectoralis profundus (PP)*; 12 – *M. biventer cervicis (BC)*; 13 – *M. triceps brachii caput longum (TBCL)*; 14 – *M. obliquus abdominis externus (OAE)*; 15 – *M. extensor carpi radialis (ECR)* and 16 – *M. flexor digitorumi medialis (FDM)*

According to the canonical variate analyses, the first two canonical variates (CV1 and CV2) accounted for 89,2% of the total variation in the data, with latent roots 10,9 and 1,7. The canonical variate means for tenderness, residue and shear force resistance were positive and for collagen content and collagen solubility negative, thus CV1 clearly contrasts between these variables. The parameter discriminating between the tenderness parameters for the different cuts is collagen content (r = -0,985) as this correlated the strongest with the CV1 scores. Collagen solubility (r = 0,769) and tenderness (r = 0,615) is contrasted by CV2 for the different cuts. The CV mean scores are presented in Figure 3. Due to the fact that all three age groups are neatly grouped together for each cut, it indicates that the differences between cuts are much more discriminating than for age, also indicated by the latent root < 1.

The correlation of age with tenderness

In the previous section it was shown that the overall tenderness, residue and collagen solubility of beef carcass cuts were closely and significantly ($p \leq 0,05$) related to animal age. To determine whether these relationships were linear, a correlation matrix (Tables 8 and 9) was constructed and it is summarised in. Tenderness and residue, as evaluated by the sensory panel for the various muscles had significant correlations of between r = -0,312 in the GM and r = -0,348 ($p \leq 0,05$) in the VL respectively, and r = -0,708 and r = -0,675 ($p \leq 0,001$) respectively in the FDM, with age of the animal.

Shear force resistance of the various muscles studied had a lower order of significant correlation (between r = 0,410 with $p \leq 0,05$ for the VL and r = 0,436 with $p \leq 0,01$ for the ST) with age, with the exception of the GB (r = 0,750 with $p \leq 0,001$) and the ECR (r = 0,566 with $p \leq 0,01$), than those generally found for tenderness and residue (Table 8). This can probably be explained by the fact that shear-force measures myofibrillar toughness and in this study myofibrillar toughness has been reduced to a low level by electrical stimulation and ageing (Bouton, Harris & Shorthose, 1975). Shorthose and Harris (1990) also found that initial yield values, which are associated with myofibrillar toughness, had a variable and low dependence on animal age.

The age of the animal was not significantly correlated with collagen content (between r = 0,001 with $p > 0,05$ in the SM and r = 0,308 with $p > 0,05$ in the ST). However, for all 16 muscles, age negatively correlated with collagen solubility (between r = -0,412 with $p \leq 0,01$ in the LTW and r = -0,735 with p

TABLE 8
Correlation Coefficient (r) of Tenderness Related Characteristics of Muscles with Age as Independent Variable

Muscle [1]	Dependent Variables				
	Tenderness [2]	Residue [3]	Shear Force Resistance [3]	Collagen Content [5]	Collagen Solubility [6]
LTP	-0.186	-0.192	-0.108	0.239	-0.638***
LL	-0.247	-0.231	0.167	0.048	-0.590***
LTW	-0.077	-0.092	0.024	-0.064	-0.412*
ST	-0.547***	-0.517***	0.436**	0.308	-0.678***
GM	-0.312*	-0.374*	0.065	-0.095	-0.553***
SM	-0.473**	-0.445**	-0.030	-0.001	-0.566***
PM	-0.403**	-0.393**	-0.035	0.164	-0.653***
GB	-0.674***	-0.673***	0.750***	-0.154	-0.698***
VL	-0.396*	-0.348*	0.410*	-0.065	-0.574***
SV	-0.418*	-0.437*	0.086	0.211	-0.690***
PP	-0.666***	-0.691***	0.215	0.175	-0.513**
BC	-0.583**	-0.530	-	0.010	-0.669***
TBCL	-0.539**	-0.526**	0.424*	0.289	-0.658***
OAE	-0.455*	-0.419*	0.440*	0.025	-0.735***
ECR	-0.694***	-0.663***	0.566**	-0.044	-0.696***
FDM	-0.708***	-0.675***	0.437*	-0.198	-0.727***

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

[2] 8 = Extremely tender. 1 = Extremely tough

[3] 8 = None. 1 = Abundant

[4] N/2.54 cm

[5] Hypro N/Total N X 10^3

[6] %

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

TABLE 9
Correlation Coefficient (r) of Residue and Shear Force Resistance of Muscles with Tenderness as Independent Variable

Muscle [1]	Dependent Variables			
	Residue [2]	Shear Force [3]	Collagen Content [4]	Collagen Solubility [5]
LTP	0.977***	-0.785***	0.120	0.042
LL	0.976***	-0.653***	0.303	-0.007
LTW	0.982***	-0.848***	0.028	-0.018
ST	0.989***	-0.850***	-0.244	0.361*
GM	0.974***	-0.547***	0.127	0.222
SM	0.985***	-0.463**	0.058	0.359*
PM	0.970***	-0.532***	-0.138	0.112
GB	0.990***	-0.797***	0.140	0.387**
VL	0.971***	-0.803***	-0.021	0.337*
SV	0.983***	-0.766***	0.008	0.452**
PP	0.973***	-0.554**	-0.256	0.323
BC	0.972***	-	0.039	0.359
TBCL	0.940***	-0.604**	-0.219	0.437*
OAE	0.981***	-0.471*	0.254	0.280
ECR	0.968***	-0.676***	-0.100	0.597**
FDM	0.971***	-0.557**	0.217	0.668***

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

[2] 8 = None. 1 = Abundant

[3] N/2.54 cm

[4] Hypro N/Total N x 10^3

[5] %

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

≤ 0,001 in the OAE). Many studies concerning the relationship of the total amount of collagen to meat tenderness have shown that as tenderness decreases due to increased animal age there is essentially no change in the total amount of collagen present in the muscle (Prost, Reczyska & Kotula, 1975).

The correlation between the tenderness characteristics

The correlation coefficient between tenderness and residue was highly significant ($p \leq 0,001$) for all the muscles studied (Table 9). With the exception of ratings for connective tissue, Cross *et al.* (1973)

found that sensory panel ratings were closely interrelated and probably mutually dependent. Brady and Hunecke (1985) also found very strong correlations between the sensory characteristics of chewiness, hardness and tenderness and speculated that this would indicate that these parameters were measuring either the same element of tenderness or ones that were strongly related.

Tenderness and shear force resistance measurements showed a high correlation of between r = -0,850 with $p \leq 0,001$ for the ST and r = -0,463 with $p \leq 0,01$ for the SM in this study, even though different core diameters were used for the LL (r = -0,653 with $p \leq 0,001$) and PP (r = -0,554 with $p \leq 0,01$) and that a cherry pitter attachment was used for the OAE (r = -0,471 with $p \leq 0,05$). These results are in accordance to those of Destefanis *et al.* (2008). However, Harris (1976) cautioned against putting too much emphasis on the results of only one type of mechanical device of tenderness, as a single objective device is not sensitive to the same structural components that influence the taste panel assessment. Several criteria should rather be used to express the complex perception of tenderness in meat, because the relationship between mechanical measurements of tenderness and panel assessments has not been definitely established.

In the present study the correlation between tenderness and collagen content was not significant. The correlation between tenderness and collagen solubility were low, even if significant, (between r = -0,337 in the VL with $p \leq 0,05$ and r = 0,452 with $p \leq 0,01$ in the SV for collagen solubility, with the exceptions of ECR (r = 0,597 and $p \leq 0,01$) and the FDM (r = 0,668 and $p \leq 0,001$). This is similar to the findings of Mc Keith *et al*. (1985) that total collagen content was not a good predictor of overall tenderness for thirteen muscles (r = -0,10; $p > 0,05$). Herring *et al.* (1967) previously also found that collagen content was not related ($p > 0,05$) to sensory tenderness in either the *longissimus dorsi* (r = -0,42) or *semimembranosus* (r = -0,48), but found that collagen solubility was related to tenderness in both muscles (r = 0,77 and 0,81 with $p \leq 0,01$ respectively). Young and Braggins (1993) also reported a low correlation between collagen solubility and tenderness (r = 0,38; $p > 0,05$).

The relationship between collagen solubility and age is very strong but not linear, based on the results from:

- In the canonical variate analysis: collagen solubility was the main discriminant between the three age groups and that it declined with age.

- ANOVA-analysis: showed that collagen content of the same muscle did not differ significantly between the ages, but that all 16 cuts of the A-age group were significantly more soluble than those of the C-age group.

This was in accordance to Tornberg (1996) who described the relationship between mechanical and sensory data-as non-linear (S-shaped as reported by Harris and Shorthose, 1988), due to non-linearity in the sensory evaluation and the fact that muscle fibre orientation is easier to control in instrumental than in sensory evaluation.

Prediction of tenderness

Stepwise regression analysis was used to show the significant factors affecting tenderness. The R^2 values in Table 10 accounted for between 73,0% and 20,6% of the variation in taste panel scores for tenderness, e.g., in the most simplistic equation of $Y = A + BX$, depending on the muscle and age group. For instance the tenderness (*Y*) of the LTP for all three the age groups can be predicted with 72,4% accuracy, viz.

Y = -0,58 - 0,02 *Instron* - 0,065 *Age* + 0,0076 *KWTsubf* + 0,107 *Cmuscle*.

However, only the attributes, R^2 values and p-values are listed in Table 10 and not the full equations due to limited space. Shorthose and Harris (1990) reported in a similar forward stepwise regression analysis that tenderness (*T*) can be expressed as an equation with a Warner Bratzler shear measurement of peak force (*PF*) and Instron compression measurements (*IC*) values which accounted for 70,2% of the variation in taste panel tenderness scored, viz. T=-1,04 + 1,157 *PF* - 3,24 *IC* (both expressed in terms of kg).

TABLE 10
Forward Stepwise Regression Analysis[1] for the Prediction of Tenderness without Sensory Evaluation Scores

Mus-cle[2]	Attribute	R^2	p-Value	Regression Coefficient	Standard error of observation
LTP	Constant	-	-	-0.58	4.37
	Instron	62.4	0.001	-0.02	0.002
	Age	68.1	0.001	-0.07	0.02
	KWTsubf	71.0	0.001	0.01	0.002
	Cmusl	72.4	0.001	0.11	0.06
LL	Constant	-	-	8.93	1.01
	Instron	39.0	0.001	-0.04	0.006
	Cbone	42.9	0.001	-0.13	0.06
LTW	Constant	-	-	8.19	0.03
	Instron	73.0	0.001	-0.03	0.003
ST	Constant	-	-	9.95	0.42
	Instron	72.6	0.001	-0.04	0.004
	Age	73.8	0.001	-0.04	0.02
GM	Constant	-	-	10.0	1.01
	Cbone	26.0	0.001	-0.27	0.05
	Instron	48.3	0.001	-0.02	0.004
	Rprot	50.6	0.001	0.09	0.05
SM	Constant	-	-	7.01	0.45
	Age	20.6	0.001	-0.10	0.02
	Instron	38.2	0.001	-0.01	0.003
PM	Constant	-	-	9.32	0.50
	Instron	20.8	0.001	-0.03	0.005
	Age	36.6	0.001	-0.09	0.02
	LNCsubf	42.9	0.001	-0.30	0.14
GB	Constant	-	-	-229	109
	Instron	57.8	0.001	-0.02	0.003
	Age	62.2	0.001	-0.11	0.03
	LNTsubf	66.0	0.001	-0.10	0.29
	SQCfatcr	68.2	0.001	-1.16	0.31
	Csubf	70.6	0.001	-0.30	0.107
	Tmeat	72.5	0.001	2.39	1.09
VL	Constant	-	-	7.62	0.26
	Instron	63.5	0.001	-0.21	0.03
	Age	67.0	0.001	-0.05	0.02
SV	Constant	-	-	8.86	0.45
	Instron	60.0	0.001	-0.04	0.004
	Age	73.0	0.001	-0.12	0.02
	Tbone	75.5	0.001	-0.07	0.03
PP	Constant	-	-	6.13	0.45
	Age	40.0	0.001	-0.16	0.04
	Instron	55.4	0.001	-0.36	0.10
BC	Constant	-	-	13.5	1.87
	Age	28.9	0.001	-0.11	0.04
	Rprot	44.8	0.001	-0.28	0.08
TBCL	Constant	-	-	21.9	5.44
	Age	30.4	0.001	-0.05	0.04
	Tbone	38.9	0.001	-0.58	0.15
	LNSEfat	44.5	0.001	-0.79	0.25
	Cmusl	49.7	0.001	-0.14	0.06
OAE	Constant	-	-	6.69	0.46
	Instron	25.4	0.001	-0.01	0.005
	Age	30.6	0.001	-0.09	0.05

ECR&	Constant	-	-	6.70	0.91
FDM	Age	39.5	0.001	-0.11	0.03
	Cbone	47.8	0.001	-0.13	0.06
	Instron	50.5	0.001	-0.01	0.005

[1] *Carcass parameters (%):* Cfatcr - Proximate fat content of carcass; Csubf - Subcutaneous fat of carcass; Cmusl - Muscle content of carcass; Cbone - Bone content of carcass; Cmeat - Meat contant (Csubf and Cmusl) of carcass;
Cut parameters (%): Rfat - Proximate fat content of cut; Rprot - Protein content of cut; Rmoist - Moisture content of cut; Tsubf - Subcutaneous fat of cut; Tmusl - Muscle content of cut; Tbone - Bone content of cut; Tmeat - Meat content (Tsubf and Tmusl) of cut; SEfat - Proximate fat in cooked muscle; *Transformations:* LN - Log X; SQ -$\sqrt{x}$; KW – X^{2}; TR – X^{3}

[2] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

Determine the most reliable cut to predict tenderness

Bouton, Ford, Harris, Shorthose, Ratcliff and Morgan (1978) reported that muscles selected for testing meat quality are often picked for reasons of convenience, rather than how their properties reflect the properties of other muscles in the carcass. The individual lean muscles of traditional cuts comprise only a relatively small percentage of the carcass lean muscle. Most studies on the quality aspects of muscles often use only one or a few muscles of the carcass and the conclusions drawn appear as though the results are representative of the carcass. In the present study 16 muscles of animals of three age groups have been tested for the various tenderness characteristics.

The correlation (in descending order) between the tenderness characteristic obtained for a specific muscle with the mean of the same measurement of all the individual muscles combined are listed in Tables 11 to 14. Both the model and the slope are significant at the $p \leq 0{,}001$ level. The PM, LL, FDM and ECR have the lowest correlation of all muscles with total carcass sensory analysis of tenderness and residue, as well as resistance to shear force. Shorthose and Harris (1990) listed the LD, GB (in the rump), *gracilis* (in the silverside) and PM as showing the lowest correlation of all muscles for all the objective measurements and concluded that these muscles would appear to give the worst indication of the overall carcass tenderness.

The highest correlation coefficients were obtained for the VL, SM, GB, ST and TBCL for overall carcass sensory analysis of tenderness and residue and for the GB, VL, PP, ST and LTW for resistance to shear force. Shorthose and Harris (1990) also reported the ST, GB and SM as having the highest correlation for the mechanical measurement of overall carcass tenderness. Overall carcass collagen solubility did not follow the same pattern as the sensory tenderness, residue and shear force resistance measurements. The highest correlations of collagen solubility of cuts/muscles with carcass collagen

TABLE 11
The Correlation of Sensory Tenderness of Muscles with the Carcass Sensory Tenderness Value

Muscle [1]	Correlation coefficient	R-Squared model	p-Value	Std.Err.Est. model	Slope p-value	Intercept p-value
VL	0.81	66.0	0.001	0.45	0.001	0.07
SM	0.80	63.8	0.001	0.48	0.001	0.44
TBCL	0.78	61.0	0.001	0.58	0.001	0.58
GB	0.76	57.2	0.001	0.80	0.001	0.01
ST	0.75	55.6	0.001	0.70	0.001	0.75
SV	0.74	55.2	0.001	0.69	0.001	0.81
OAE	0.73	52.9	0.001	0.70	0.001	0.85
LTW	0.73	52.7	0.001	0.79	0.001	0.45
BC	0.72	51.9	0.001	0.78	0.001	0.30
PP	0.70	49.0	0.001	0.86	0.001	0.01
FDM	0.69	47.2	0.001	0.58	0.001	0.79
ECR	0.69	47.2	0.001	0.58	0.001	0.79
LTP	0.68	46.8	0.001	0.79	0.001	0.98
GM	0.64	40.7	0.001	0.58	0.001	0.00
LL	0.61	36.9	0.001	0.70	0.001	0.23
PM	0.50	24.7	0.001	0.57	0.001	0.01

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

TABLE 12
The Correlation of Sensory Residue of Muscles with the Carcass Sensory Residue Value

Muscle [1]	Correlation coefficient	R-Squared model	p-Value	Std.Err.Est. model	Slope p-value	Intercept p-value
	0.79	61.7	0.001	0.46	0.001	0.10
SM	0.78	61.5	0.001	0.48	0.001	0.49
TBCL	0.78	61.1	0.001	0.54	0.001	0.39
ST	0.75	56.3	0.001	0.65	0.001	0.87
GB	0.75	56.0	0.001	0.79	0.001	0.01
SV	0.74	54.7	0.001	0.66	0.001	0.78
OAE	0.73	53.7	0.001	0.65	0.001	0.86
LTW	0.72	52.5	0.001	0.75	0.001	0.42
BC	0.71	51.0	0.001	0.71	0.001	0.39
LTP	0.71	50.4	0.001	0.66	0.001	0.77
PP	0.69	47.4	0.001	0.77	0.001	0.02
FDM	0.67	44.5	0.001	0.60	0.001	0.41
ECR	0.67	44.5	0.001	0.60	0.001	0.41
GM	0.64	41.0	0.001	0.53	0.001	0.01
LL	0.59	35.3	0.001	0.64	0.001	0.11
PM	0.49	23.8	0.001	0.51	0.001	0.01

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

TABLE 13
The Correlation of Shear Force of Muscles with the Carcass Shear Force Value

Muscle [1]	Correlation coefficient	R-Squared model	p-Value	Std.Err.Est. model	Slope p-value	Intercept p-value
GB	0.81	66.0	0.001	23.9	0.001	0.01
VL	0.73	53.3	0.001	17.7	0.001	0.49
PP	0.70	48.4	0.001	8.77	0.001	0.43
ST	0.69	48.1	0.001	13.5	0.001	0.05
LTW	0.69	47.2	0.001	2.52	0.001	0.06
OAE	0.68	46.4	0.001	28.1	0.001	0.01
SM	0.67	44.4	0.001	19.2	0.001	0.11
TBCL	0.64	40.6	0.001	16.8	0.001	0.48
GM	0.54	28.9	0.001	15.1	0.001	0.01
SV	0.53	28.5	0.001	16.5	0.001	0.84
LTP	0.47	21.9	0.001	32.1	0.001	0.55
LL	0.45	19.9	0.001	12.6	0.001	0.06
ECR	0.44	19.2	0.001	18.1	0.001	0.55
FDM	0.44	19.2	0.001	18.1	0.001	0.55
PM	0.21	4.52	1.000	12.6	0.100	0.01

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

TABLE 14
The Correlation of Collagen Solubility of Cuts/Muscles with the Carcass Collagen Solubility Value

Cut/Muscle [1]	Correlation coefficient	R-Squared Model	p-Value	Std.Err.Est. model	Slope p-value	Intercept p-value
SV	0.92	85.3	0.001	2.98	0.001	0.07
OAE	0.90	80.7	0.001	3.26	0.001	0.53
FDM	0.89	79.6	0.001	4.02	0.001	0.76
BC	0.88	77.8	0.001	3.20	0.001	0.50
ECR	0.84	70.3	0.001	4.49	0.001	0.25
VL	0.77	59.0	0.001	4.72	0.001	0.68
TBCL	0.77	58.8	0.001	4.34	0.001	0.23
LL	0.75	56.6	0.001	4.15	0.001	0.95
GM	0.75	55.5	0.001	4.42	0.001	0.54
SM	0.74	54.9	0.001	2.77	0.001	0.47
PP	0.74	54.4	0.001	2.90	0.001	0.11
PM	0.73	53.6	0.001	2.46	0.001	0.01
ST	0.71	50.6	0.001	3.33	0.001	0.14
LTP	0.66	43.6	0.001	3.59	0.001	0.07
GB	0.64	41.1	0.001	3.80	0.001	0.06
LTW	0.63	39.9	0.001	4.95	0.001	0.88

[1] LTP - *M. longissimus thoracis*; LL - *M. longissimus lumborum*; LTW - *M. longissimus thoracis*; ST - *M. semitendinosus*; GM - *M. gluteus medius*; SM - *M. semimembranosus*; PM - *M. psoas major*; GB - *M. gluteobiceps*; VL - *M. vastus lateralis*; SV - *M. serratus ventralis*; PP - *M. pectoralis profundus*; BC - *M. biventer cervicis*; TBCL - *M. triceps brachii caput longum*; OAE - *M. obliquus abdominis externus*; ECR - *M. extensor carpi radialis* and FDM - *M. flexor digitorum medialis*

solubility were obtained by muscles/cuts containing the highest collagen solubility namely SV, OAE, FDM, BC, ECR and VL (Table 14), although not necessary in the same order. FDM, OAE, ECR, SV, TBCL, BC and VL contained (Table 7) the highest collagen solubility in descending order. It should again be noted that all carcasses were electrically stimulated.

CONCLUSIONS AND RECOMMENDATIONS

Age did not have any effect on collagen content but collagen solubility showed definite age dependence. In general, tenderness, residue and collagen solubility decreased significantly (although not linearly) with age, irrespective of the muscle. Shear force resistance only increased significantly with age in seven of the 14 cuts. The PM was the most tender muscle, had the least amount of

detectable connective tissue residue and the lowest collagen content of all the muscles. The ECR and FDM were the least tender and contained the highest amount of connective tissue (residual and as determined), despite the fact that these muscles contained the most soluble collagen and that they were cooked according to a moist heat cooking method.

However, with the exception of two muscles, they showed the least resistance to shear. This is opposed to the OAE which, although being high in collagen, which was highly soluble, was evaluated by the panel as very tender. An important conclusion is that the results of this study is in agreement with those of Shorthose and Harris (1990) with respect to the representativeness of muscles chosen for the determination of carcass tenderness. In order to determine carcass tenderness in future, the ST and GB (both muscles from the silverside), rather than the PM and the popular LD (LTP, LL and LTW in the present study) should be used.

In conclusion, it can be recommended that as cuts that are grouped together exhibit similar traits, in future only one of these cuts could be used and will be sufficient to describe the group's behaviour for these characteristics. It is proposed that it is not necessary to discriminate between the FDM and ECR cooked as beef retail cuts of 5 cm thickness; that LTW or LTP will sufficiently describe the cuts cooked as intact joints subjected to a dry heat cooking method; and that either GB or TBCL will describe the group subjected to a moist heat cooking method. The LL cooked as beef steak retail cuts and the SV are not included in these groupings. This implies that the 16 cuts could sufficiently be described by six cuts for the tenderness characteristics, which means a great saving in cost and time. These groups were more clearly defined applying CVA rather than PCA - as the variability in such data was large and CVA is more appropriate for well-defined groups. The usual correlation coefficients could not effectively describe the true groupings of similar or dissimilar cuts.

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