Influence of packaging method and storage time on shear value and mechanical strength of intramuscular connective tissue of chevon1

G. Kannan*2, C. B. Chawan†, B. Kouakou*, and S. Gelaye*

*Agricultural Research Station, Fort Valley State University, Fort Valley, Georgia 31030 and
†Department of Food and Animal Sciences, Alabama A&M University, Normal, Alabama

ABSTRACT: The objectives of this study were to determine the effects of storage time (ST) and packaging method (PM) on tenderness and changes in intramuscular connective tissue (IMCT) strength of chevon. Spanish does (8 mo of age, average BW 25 kg) were harvested (n = 12), chilled at 4°C for 24 h, and then fabricated into 2.5-cm-thick leg, shoulder/arm, and loin/rib cuts. The cuts from six carcasses were vacuum-packed and aged at 2°C for 0, 4, 8, or 12 d. To assess the influence of a packaging method that favors oxidation on postmortem tenderization, the cuts from the remaining six carcasses were placed on styrofoam trays, overwrapped with polyvinyl-chloride film, and stored at 2°C for similar periods. At each ST, longissimus (LM), semimembranosus (SM), and triceps brachii (TB) muscles were assessed for Warner-Bratzler shear (WBS) values. The WBS of uncooked meat, myofibrillar fragmentation index (MFI), and collagen solubility were assessed on LM. The IMCT samples were prepared to assess changes in mechanical strengths and for scanning electron microscopy (SEM). Intact honeycomb structures of endomysium, with no muscle fiber elements, were observable under SEM. The PM or ST did not influence the mechanical strength of IMCT preparations, as measured by a texture analyzer. Collagen solubility of LM muscles also did not change during aging. For both PM, cooked meat WBS values were higher (P < 0.01) in SM and TB than in LM. In the SM samples, the average WBS values were higher (P < 0.01) at d 0 than at other ST. Although MFI of LM increased with increasing aging time (P < 0.05), changes in WBS over ST were minimal in TB and LM samples. The WBS of uncooked LM decreased sharply up to 8 d postmortem in both PM (P < 0.05). However, there was no PM × ST interaction to indicate any adverse influence of packaging on tenderization of chevon. The results suggest that aging chevon cuts for more than 4 d may not result in significant additional improvement in tenderness.

Key Words: Aging, Connective Tissue, Goat Meat, Tenderness

Introduction

Tenderness may be the most important eating quality parameter that determines consumer acceptability (Miller, 1992; Savell and Shackelford, 1992). Chevon (goat meat) is considered to be lower in palatability than beef, pork, or lamb (Smith et al., 1974; Griffin et al., 1992). Retail managers can play an important role in popularizing chevon and expand the already existing market in the United States through planned aging; however, care should be exercised while determining storage conditions and durations since fresh chevon may undergo rapid oxidation due to its fatty acid composition (Kannan et al., 2001). Recent reports show that oxidation may have a negative effect on proteolytic activity of calpains in meat during aging because thiol proteases require reducing conditions for maximum activities (Guttmann and Johnson, 1998; Huff-Lonergan, 1999; Harris et al., 2001).

There are no data available on postmortem changes in the intramuscular connective tissue of chevon, although Schönfeldt et al. (1993) reported that the collagen content is higher, and solubility lower, in longissimus thoracis muscle of goats than that of sheep. The onset of structural weakening of intramuscular connective tissue (IMCT) during postmortem aging of meat varies widely between animal species (Liu et al., 1995). While the endomysium and perimysium of chicken begins disintegrating around 12 h postmortem (Liu et al., 1995), it takes at least 14 d of aging for noticeable changes in beef (Nishimura et al., 1998). However, studies on extended aging periods, similar to those in beef, may not be relevant for chevon because of its shorter

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2Correspondence: phone: 478/827-3085; fax: 478/825-6376; E-mail: govindak@mail.fvsu.edu.

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shelf life than other types of red meat (Strube, 1991). Therefore, the objectives of this study were to determine the effects of storage time (ST) and packaging method (PM) on tenderness and changes in intramuscular connective tissue strength of chevon.

Materials and Methods

Animals and Carcass Fabrication

Spanish does (8 mo of age, average weight 25 kg) raised on pasture with a grain supplement, were harvested (n = 12), and carcasses were chilled at 4°C. After the 24-h chilling period, carcasses were fabricated according to the procedures described by Olson et al. (1999). Barbeque style was selected because carcasses were within the weight range of 9 to 13.5 kg. The primal cuts were sliced into 2.5-cm-thick leg, shoulder/arm, and loin/rib cuts. To the extent possible, the cuts were carefully made such that the cut surfaces were at right angles to the axes of longissimus (LM), semimembranosus (SM), and triceps brachii (TB) muscle fibers in the loin/rib, leg, and shoulder/arm cuts, respectively. The cuts from six carcasses were vacuum-packed (oxygen transmission rate = 40 cc/m²/24 h at 25°C) and aged at 2°C for 0, 4, 8, or 12 d (ST). To assess the influence of packaging method on tenderization, the cuts from the remaining six carcasses were placed on styrofoam trays, overwrapped with polyvinyl-chloride film (oxygen transmission rate = 3000 cc/m²/24 h at 5°C), and stored at 2°C for 0, 4, 8, or 12 d.

Warner-Bratzler Shear (WBS) Force Values

At the end of each storage time the cuts were frozen and stored at −30°C until assessment of tenderness (< 1 mo). The cuts were thawed at 4°C, placed on aluminum pans, and covered with aluminum foil. The cuts were then cooked in a convection oven (Lindberg/Blue, Model #GO1350SC, Ashville, NC) to an internal temperature of 71°C. The internal temperature was measured in a representative cut from each pan using thermocouple thermometers (Fisher Scientific, Suwanee, GA). In a randomly chosen cut from each pan, the thermocouple probe was placed in the geometric center of the muscle studied. After cooking, cuts were chilled for 24 h at 4°C before core removal. To standardize the temperature of the cores between samples, the cuts were allowed to come to room temperature before 1-cm diameter cores were removed parallel to muscle fiber orientation. Cores were sheared at room temperature perpendicular to the axis of muscle fibers using a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) fitted with a Warner-Bratzler shear attachment (Texture Technologies Corp.). The instrument was set with a 25-kg load cell and a crosshead speed of 200 mm/min.

Intramuscular Connective Tissue (IMCT) Preparations

The IMCT samples were prepared according to the methods of Ohtani et al. (1988) and Nishimura et al. (1996) with slight modification in sample dimensions. With the long axis parallel to the axis of muscle fibers, samples measuring 1 × 1 × 2 cm were cut from LM and fixed for 3 d with 2.5% gluteraldehyde in a 0.1 M phosphate buffer (pH 7.3) solution. Samples were then immersed in 10% aqueous solution of NaOH for 5 d and rinsed in distilled water for 5 d at room temperature. These samples were then prepared for scanning electron microscopic studies. Briefly, the NaOH-treated samples were embedded in an acrylamide solution (7.5%) with 1.5 mg/mL ammonium persulfate for 3 h at room temperature and then polymerized using 0.75 μL/mL of N, N, N', N'-tetramethylethylenediamine. The IMCT preparations were assessed for shear force values at room temperature similar to that of cooked samples. Samples were sheared perpendicular to the axis of the muscle fibers using a TA-XT2 Texture Analyzer fitted with a Warner-Bratzler shear attachment. Three to four cuts from each animal were used for IMCT preparations.

Scanning Electron Microscopy (SEM)

The NaOH-treated samples were immersed in 1% tannic acid for 3 h, rinsed in distilled water, and fixed with osmium tetroxide (1%) for 1 h. Samples were then dehydrated with graded concentrations of ethanol, fractured in liquid nitrogen, and dried. The freeze-dried samples were coated with gold and observed under a scanning electron microscope (Model ISI SX-40, Topcon Technologies Inc., Paramus, NJ).

Collagen Content and Solubility

Collagen content and solubility were analyzed in duplicate vacuum-packed LM samples aged for different periods. Soluble and insoluble fractions of collagen were determined using the procedures of Hill (1966). Hydroxyproline concentrations were determined as described by Bergman and Loxley (1963). The soluble and insoluble collagen contents were calculated by multiplying the hydroxyproline content of the residue and the supernatant by 7.25 and 7.52, respectively (Cross et al., 1973). The collagen concentrations were expressed in mg/g dry muscle. Percent soluble collagen was determined by dividing soluble collagen by total collagen (soluble + insoluble collagen) and multiplying by 100.

Myofibrillar Fragmentation Index (MFI)

Two 1-g muscle samples were taken from vacuum-packed LM (loin cuts) after each storage time for MFI assessment using the method of Takahashi et al. (1967) as modified by Watanabe et al. (1996). The muscle samples were snipped into small pieces using scissors and homogenized for 2 min at 15,000 rpm with 10 mL of 0.1 M KCl, 1 mM dithiothreitol, 1 mM NaNO₃, and 10 mM Tris-acetate buffer (pH 7.0). The myofibrils were studied under a phase contrast microscope and two
photographs were taken from homogenate of each sample. On each photograph, the MFI was calculated using the formula:

\[ \text{MFI(\%)} = \frac{F \times 100}{\Sigma} \]

where \( F \) is the number of myofibrils that were 1 to 4 sarcomeres long, and \( \Sigma \) is the total number of myofibrils in the view. The average of the MFI percentages calculated for 4 views (photographs) was taken as the MFI of the sample.

**Statistical Analysis**

The shear force values of cooked meat samples were analyzed as a split-split-plot design using General Linear Models Procedure in SAS (SAS Institute, Inc., Cary, NC). Replication (Rep) and PM were included in the model as whole-plot factors, and the effect of PM was tested with Rep \( \times \) PM as the error term. The split-plot factors were type of cut (Cut) and Cut \( \times \) PM and these effects were tested with Cut \( \times \) PM \( \times \) Rep as the error term. The split-split-plot factors were ST and its interactions. These factors were tested with residual error. Additionally, uncooked LM and IMCT shear force values were analyzed as split-plot designs. Replication and PM were included in the model as whole-plot factors, and the effect of PM was tested with Rep \( \times \) PM interaction. The split-plot factors were ST and its interactions. These effects were tested with residual error. Collagen solubility and MFI data were analyzed as one-way analysis of variance to study the effects of aging time. Whenever significant by ANOVA \( (P < 0.05) \), the means were separated using least significant difference (LSD) test.

**Results and Discussion**

Type of cut had a significant effect on WBS values of cooked chevon in both PM groups \( (P < 0.05) \). Consistent with earlier results from our laboratory (Kannan et al., 1999), the overall means were higher in SM and TB than in LM samples (Figure 1). In addition to muscle differences, chevon tenderness has also been reported to be influenced by breed, sex, and age. Based on sensory panel evaluation, collagen determination, and shear force measurements, longissimus and semimembranosus cuts of Angora goat carcasses were more tender than those of Boer goat carcasses (Söhnfeldt et al., 1993). Female goats produce more tender and juicier meat than castrates (Hogg et al., 1992; Devendra, 1981), whereas meat from younger goats was more tender and juicy than older goats (Pike et al., 1973; Söhnfeldt et al., 1993).

There was no effect of PM or the PM \( \times \) ST interaction on WBS force values of cooked meat. The lack of a PM \( \times \) ST interactive effect suggests there was no adverse effect of packaging on the postmortem tenderization process. The extent of oxidation that occurred in overwrapped samples was not measured, but it was reported that TBARS values increased rapidly when chevon cuts were overwrapped with an oxygen-permeable polyvinyl-chloride film and stored at 2°C (Kannan et al., 2001). Protease activity responsible for postmortem tenderization during early periods of aging is greatly influenced by the redox potential of the cell (Guttmann and Johnson, 1998). In addition to calcium requirements, calpains also require a reducing environment for their activity (Guttmann et al., 1997). Harris et al. (2001) found that vitamin E supplementation in cattle resulted in a more rapid tenderization of beef after calcium chloride injection, compared to beef from unsupplemented animals. They suggested that the antioxidant property of vitamin E may enhance the proteolytic activity of calpains by preventing oxidation in beef.

There was a significant effect of ST on WBS of cooked SM in both PM groups (ST main effect, \( P < 0.01 \)). Overall WBS means for ST were higher at 0 d compared to the remaining aging periods. The WBS values of SM samples decreased \( (P < 0.05) \) within the first 4 d of storage, irrespective of the PM studied, thereafter, the change in WBS was insignificant (Figure 2). However, WBS values of cooked LM and TB did not differ \( (P > 0.05) \) in response to either ST or PM. McKeith et al. (1979) observed improvement in cooked meat tenderness after 7 d of aging in semimembranosus and biceps femoris muscles, but not in longissimus muscle from goat carcasses. Hogg et al. (1992) reported that chevon from carcasses aged for 2 d was significantly more tender than that from carcasses aged only for 1 d. In

![Figure 1. Effect of muscle type (semimembranosus, SM; triceps brachii, TB; longissimus, LM) on Warner-Bratzler shear (WBS) force values of cooked chevon. Bars lacking a common letter differ \( (P < 0.05) \).](image-url)
Several authors have reported that chevon is less tender than other types of red meat (Smith et al., 1974; Griffin et al., 1992; Schönfeldt et al., 1993). The lower shear values observed in the present study may be due to the fact that the diameter of cores used in this study was 1 cm instead of 1.27 cm that is specified by AMSA (1995) guidelines. This core diameter was chosen to facilitate removal of at least two cores from each cut. The LM cross sectional area of goat carcasses is considerably smaller than carcasses of other traditional red meat animals.

Scanning electron microscopic observations revealed that the cross sections of NaOH-treated LM contained intact honeycomb structures of endomysium with no muscle fiber elements (Figure 3A and B). Nishimura et al. (1998) reported that embedding NaOH-treated muscle samples in acrylamide gel did not alter the structures of IMCT. In the current experiment, PM or ST did not influence the mechanical strength of IMCT preparations as measured by texture analyzer (Figure 4), indicating that there was no weakening of the IMCT of goat LM during storage for up to 12 d. This result is in agreement with that of Nishimura et al. (1998), who reported that the mechanical strength of IMCT of beef semitendinosus muscle decreased only after 14 d of postmortem aging. The authors further confirmed that after 14 d of aging, the mechanical strength of endomysium and perimysium kept decreasing with increasing aging time.

In the present study, scanning electron micrographs also did not show any visible structural changes due to ST or PM. The structure of intramuscular connective tissue of bovine semitendinosus muscle remains unchanged up to 10 d postmortem, but structural changes became clearly visible after 14 d of aging (Nishimura et al., 1995; Takahashi, 1996), based on scanning electron microscopic observations. Similar structural changes and weakening of intramuscular connective tissue were reported in chicken semitendinosus muscle after 12 h of postmortem aging (Liu et al., 1995). They suggested that the weakening mechanism of endomysium and perimysium were the same in beef and chicken muscles, but the time of onset of these changes were considerably different (Liu et al., 1995).

Uncooked LM shear values decreased (P < 0.05) over ST, with the overall WBS means highest on d 0 and lowest on d 8 and d 12 (Figure 5). The trend of shear values over ST was similar for both vacuum-packed and overwrapped LM samples, indicating virtually identical improvement in tenderness during storage. The difference in the shear values noted at d 0 of aging was probably due to random animal variations and small sample size. Shear force values of uncooked LM decreased significantly up to 8 d postmortem. In contrast, the shear value of uncooked beef semitendinosus muscle has been reported to decrease with increasing aging time up to about 28 d postmortem (Nishimura et al., 1998).
Figure 3. Scanning electron micrographs of NaOH-treated longissimus muscle (LM) samples under two different magnifications showing honeycomb structure of endomysium with no muscle fiber elements.

The structural weakening of goat LM myofibrils, however, continued throughout the aging time periods studied. Aging time had a significant effect on MFI values of goat LM ($P < 0.05$). Myofibril fragmentation steadily increased throughout the aging time periods, although the increase after 8 d was not statistically significant (Figure 6). The MFI estimation procedure described by Takahashi et al. (1967) was used in this experiment to directly observe the myofibril fragments under a phase contrast microscope and to avoid possible contribution of intramuscular connective tissue fragments to the MFI estimates. Structural weakening of goat LM myo-
Effect of packaging on Warner-Bratzler shear force values of intramuscular connective tissue preparations from longissimus muscle. Time main effect probability value is for the data pooled across both packaging methods (n = 6/time period/packaging method).

Figure 4.

Effect of packaging on Warner-Bratzler shear force values of uncooked longissimus muscles (LM). Time main effect probability value is for the data pooled across both packaging methods (n = 6/time period/packaging method). Time means lacking a common letter differ (P < 0.05).

Figure 5.

fibrils continued to progress throughout the time periods studied, but the shear values of cooked meat did not decrease significantly during aging.

The average collagen content of the LM was 5.96 mg/g dry muscle. Collagen solubility of LD muscles was not significantly (P > 0.05) influenced by aging time (collagen solubility percentages of LM aged for 0, 4, 8, and 12 d were 16.8, 11.4, 9.6, and 11.6, respectively. Schönfeldt et al. (1993) reported that collagen content was lower, and solubility greater, in sheep LM than that of Angora and Boer goats. Furthermore, Pierson and Fox (1976) and Harris et al. (1992) demonstrated that collagen solubility of bovine muscles was not affected by duration of postmortem aging, whereas Pommer (1992) observed that collagen solubility of bovine LM increased after 7 d of aging. Nishimura et al. (1998) showed that structural weakening of beef intramuscular connective tissue takes place during extended aging, based on decreases in mechanical strengths as well as increases in yield of perimysial fractions. It is not known if a similar weakening of IMCT takes place in chevon during extended aging beyond 12 d postmortem.

Chevon is known to be less tender than beef, lamb, and pork. It is important to improve the palatability and perception of chevon to widen its already existing market in the United States. Results indicated that packaging method did not notably interfere with the normal postmortem tenderization process in chevon. Aging chevon for more than 4 d may not result in sig-
nificant additional improvement in tenderness of semimembranosus muscle. While myofibril weakening increased with aging time, intramuscular connective tissue strength did not change for up to 12 d postmortem. However, it is not known if extended aging beyond 12 d will weaken the intramuscular connective tissue in chevon.

Implications

Significant improvement in chevon tenderness occurs within the first 4 d of refrigerated storage and further improvements in Warner-Bratzler shear force were not as evident thereafter. Packaging method did not appear to adversely affect the postmortem tenderization process. Maximum tenderization of chevon occurs within the first 4 d of aging, although myofibril weakening and fragmentation continue to increase even after 8 d of aging. The endomysium and perimysium of chevon did not weaken up to 12 d of aging as evidenced by shear force values and collagen solubility of intramuscular connective tissue. The results suggest that extended aging of meat from Spanish goats may not be of added advantage since tenderness does not improve markedly beyond 4 d.

Literature Cited


