Tenderness and flavor of leg cuts from meat goats influenced by calcium chloride injection

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ABSTRACT

This study was conducted to assess the potential of improving tenderness of chevon using calcium chloride (CaCl$_2$) injection and its effect on the palatability characteristics of chevon. Primal leg cuts from meat goats were allotted to one of four treatments: either no injection (control) or injection with water, CaCl$_2$ (food grade, 2.2% w/v), or CaCl$_2$ plus a spice mix. The CaCl$_2$ injection improved tenderness of goat leg cuts, proven by Warner–Bratzler shear force values and sensory panels. Furthermore, panelists were not able to detect off-flavor problems associated with CaCl$_2$ injection. When CaCl$_2$ was injected into goat leg cuts with the beef spice mixture, it resulted in a more desirable flavor. Calcium injection did not influence flavor volatile compounds in cooked chevon leg cuts. The results indicate that CaCl$_2$ plus spice mix injection can be applied to improve tenderness of goat meat without detrimental effects on other sensory characteristics.

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Introduction

Health concerns about the negative effects of high-fat diets in humans have increased the development of low-fat products in recent years. Since goat meat (chevon) has a relatively low fat content (3.5%) compared to other red meats, it is an excellent source for preparing low-fat meat entrees. Goat carcasses have low intramuscular fat with high levels of linoleic acid (C18:2n6) compared to lamb or beef. Despite these nutritional advantages, chevon is not widely consumed by mainstream Americans since it is considered to be lower in palatability than beef or lamb.

Meat tenderness may be considered as the most important eating quality attribute that determines consumer acceptability. Toughness in meat develops shortly after slaughter (0–24 h), primarily due to sacromere shortening during the process of rigor mortis. Subsequently, meat tenderizes if stored for prolonged periods at refrigerated temperatures. Kannan et al. reported that tenderness of chevon improved moderately by aging; however, the mechanical strength of intramuscular connective tissue remained unchanged even after 12 days of aging. There is overwhelming evidence that the calpain proteolytic system is responsible for postmortem tenderization of beef and lamb. The calcium chloride (CaCl$_2$) application was developed to enhance tenderization by stimulating proteolysis of muscle proteins by calpain enzymes. It has been demonstrated that infusion of carcasses or injecting cuts with CaCl$_2$ improves meat tenderness of young animals. The original procedure suggested for tenderizing meat with CaCl$_2$ was to infuse carcasses with 10% (wt/wt) of 0.3 M CaCl$_2$ solution. Since then numerous modifications have been proposed to the original procedure for reduced off-flavor and other palatability side effects. Injection of 0.2 M CaCl$_2$ solution at 5% (wt/wt) improved tenderness in retail cuts from lambs and beef cattle without affecting other palatability characteristics. However, the extent to which CaCl$_2$ injection can improve tenderness of chevon is unknown and needs to be

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determined. The objectives of this research were to assess the potential of improving tenderness of chevon using CaCl$_2$ injection and to evaluate the effect of CaCl$_2$ injection on the palatability characteristics of chevon.

**Materials and methods**

Intact male goats of Kiko × Spanish ($n = 16$) were raised on pasture with a grain supplement and harvested at approximately 8 months of age. After a 24-h chill period, each carcass was fabricated according to the procedures described by Olson et al.$^{[20]}$ Barbecue style was selected because carcasses were within the weight range of 9.0–13.5 kg. Primal leg cuts ($n = 32$) were collected from each carcass. Thirty-two leg cuts were randomly assigned to one of four injection treatments ($n = 8$ cuts/treatment): control (no injection), water injection, CaCl$_2$ (food grade, 2.2% w/v; Liquidow, The DOW Chemical Co., Midland, MI, USA) injection, or CaCl$_2$ plus spice mix (beef roast seasoning; A. C. Legg, Inc., Calera, AL, USA) injection. The injection was made by a multi-needle injector (Smart Tech model MN-10, Metalbud CO., Podlas 3, Poland) at a pump level to achieve a 5% (wt/wt) increase in weight. Immediately after injection, each leg was cut into 2.5-cm thick using a band saw with a bone-in blade, vacuum-packed (Vacuum Packaging Machine, Koch Supplies Inc., Kansas City, MO, USA) in a single-barrier plastic bag (Cryovac Inc., Duncan, SC, USA), and chilled at 2°C for 4 days. The chilled leg cuts were then stored at −28°C until analyzed.

The Warner–Bratzler shear force (WBSF) values and cooking losses were determined according to the method of Lee et al.$^{[21]}$ Vacuum-packed frozen leg cuts were thawed at 4°C. Thawed leg cuts were cooked in a convection oven (Maytag Corporation, Model MER6550B, Newton, IA, USA) to the internal temperature of 71°C. After cooking, cooked leg cuts were weighed and wrapped in aluminum foil and cooled at 4°C overnight before core removal. The cuts were allowed to come to room temperature by removing them from the refrigerator and placing them on a laboratory countertop for 2 h, and then 1-cm-diameter cores were removed parallel to muscle fiber orientation.$^{[11]}$ Cores were taken from *Semimembranosus* muscle from individual cuts and WBSF values assessed using a TA-XT2 texture analyzer fitted with a Warner–Bratzler shear attachment (Texture Technologies Corp., Scarsdale, NY, USA). The instrument was set with a 25-kg load cell and a cross-head speed of 200 mm/min. The difference in weight of samples before and after cooking was expressed as a percentage cooking loss.

Leg cuts for sensory evaluation were also cooked in the same manner as those used to measure WBSF, which were cut into 1-cm$^3$ cubes and served warm to the panel. Panelists received two cubes per sample. An eight-member experienced sensory panel evaluated four samples per session (two sessions daily) for tenderness, juiciness, and overall flavor using 9-point scales (9 = extremely tender, juicy, and like flavor; 1 = extremely tough, dry, and dislike flavor).$^{[22]}$

The flavor volatiles of cooked leg cuts were extracted using a solid phase microextraction (SPME) method and analyzed using gas chromatography (GC).$^{[23]}$ One leg from each leg was cooked as described above. Each cooked cut was immersed into liquid nitrogen and homogenized with a Waring blender (Fisher Scientific, Pittsburgh, PA, USA). Five grams of the homogenized sample was transferred into a 20-mL vial. Each vial was sealed with a PTFE silicon septum (Supelco, Inc., Bellefonte, PA, USA). The vial was heated at 45°C on an SPME sampling stand, which fitted compactly on a Corning heat/stir plate (Model PC-400; Corning Inc., Corning, NY, USA). Subsequently, the volatiles in the headspace were collected for 15 min on a 50/30-mm divinylbenzene/carboxen/polydimethylsiloxane fiber (Supelco) inserted through the silicon septum. The volatiles were desorbed for 5 min by inserting the SPME needle and exposing the fiber directly into the injection port (220°C) of a TRACE GC Ultra (Thermo Electron Corp., Austin, TX, USA), separated on a Supelcowax column (60 m × 0.32 mm i.d.; Supelco), and detected in a flame ionization detector. Helium was used as a carrier gas with a flow rate of 1.6 mL/min. The injection port was in the splitless mode and the column temperature was programmed from 40°C to 230°C at a rate of 4°C/min and holding at 230°C for 10 min.
Volatile compounds were identified using GC-mass spectrometry (MS). Mass spectra were generated by a Thermo Electron GC (TRACE GC Ultra) interfaced to a mass spectrometer (Finnigan TRACE DSQ MS; Thermo Electron Corp.), operated in the electron impact mode with an electron energy of 70 eV, a multiplier voltage of 1100 V, and data collection rate of 1.5 scan/s over a range of m/z 40–450. Volatile compounds were tentatively identified by comparing their mass spectra with those contained in a mass spectra library (Thermo Electron Corp.). All data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Inst, Inc., Cary, NC, USA) with goat considered to be a random effect and injection treatment considered to be a fixed effect. Least-squares means were generated and separated statistically separated by pairwise t-test (PDIF option) protected by the ANOVA F test (P ≤ 0.05).

**Results and discussion**

Cooking losses and WBSF values of goat leg cuts from different injection treatments are presented in Table 1. The percentage loss from cooking was higher (P < 0.05) in the leg cuts injected with CaCl₂ plus a spice mix than in uninjected cuts (control). However, no differences (P > 0.05) were found in cooking losses in leg cuts from control and H₂O- or CaCl₂-injected groups. Cooking loss traits in the present study are not in agreement with the results of Pringle et al. [16] and Wheeler et al. [18]. They reported greater cooking loss with calcium injected beef, whereas Koohmaraie et al. [14] reported similar cooking loss with calcium-injected lamb. This inconsistency may be attributed to the species and maturity difference in animals used in these studies, as well as using different retail cuts (muscles). Differences in the percentage loss from cooking were not detected in the cuts among three different injection groups (H₂O, CaCl₂, and CaCl₂ plus spice mix). Increased percentage cooking loss was expected in leg cuts from the injected groups compared with uninjected group because of the added water through the injection. Similar findings have been reported by Wheeler et al. [24] when the same level of CaCl₂ was injected into sub-primal cuts of crossbred heifers after 2 days postmortem. However, other researchers have reported that CaCl₂ injection of sub-primal cuts from other breeds of beef cattle did not increase their cooking losses. [16,17] The reason for this discrepancy is not known. All three injected treatments (H₂O, CaCl₂, and CaCl₂ plus a spice mix) caused significant reduction in WBSF values of leg cuts from meat goats in the present study. The cuts from CaCl₂- or CaCl₂ with spice mix-injected groups had lower (P < 0.05) WBSF values than those from H₂O-injected or uninjected groups; however, the WBSF values were not different (P > 0.05) between CaCl₂ and CaCl₂ plus spice mix-injected groups. These results are consistent with previous findings in beef cattle and lambs. [10,16,24] Although the H₂O injection improved tenderness of leg cuts from goats, the cuts from H₂O-injected groups were tougher than either of the calcium-injected groups. Improving meat tenderness of H₂O-injected cuts might be due to the penetration of needles into the cuts when H₂O was applied through a multi-needle injector. Calcium-injected cuts improved in meat tenderness due to increased activity of the calpain proteinase systems. [16,17]

| Item           | Control | H₂O  | CaCl₂ | CaCl₂ + SM | SEM  |
|----------------|---------|------|-------|------------|------|
| **Cooking loss, %** | 27.0<sup>d</sup> | 30.6<sup>cd</sup> | 30.5<sup>cd</sup> | 33.0<sup>c</sup> | 1.58 |
| **WBSF, kg**    | 3.5<sup>c</sup> | 2.8<sup>d</sup> | 1.9<sup>e</sup> | 1.9<sup>e</sup> | 0.170 |
| **Sensory**     |         |      |       |            |      |
| Tenderness      | 5.7<sup>d</sup> | 6.2<sup>cd</sup> | 6.1<sup>cd</sup> | 6.4<sup>c</sup> | 0.19 |
| Juiciness       | 5.6<sup>d</sup> | 5.9<sup>cd</sup> | 6.0<sup>cd</sup> | 6.3<sup>c</sup> | 0.23 |
| Overall flavor  | 5.1<sup>d</sup> | 5.4<sup>d</sup> | 5.6<sup>d</sup> | 6.3<sup>c</sup> | 0.23 |

<sup>a</sup>Control: no injection; H₂O: water injected; CaCl₂: 2.2% (w/v) food-grade CaCl₂ injected; CaCl₂ + SM: CaCl₂ plus spice mix (commercial beef roast seasoning) injected.

<sup>b</sup><sup>c</sup>-<sup>e</sup>Within a row, least-squares means that do not have a common superscript letter differ (P < 0.05).
Sensory evaluation scores of the treated goat leg cuts by an experienced panel are also presented in Table 1. Based on the finding of WBSF values, tenderness scores of calcium-injected goat leg cuts from experienced sensory panel were expected to be higher ($P < 0.05$) than those from control or water-injected groups. As reported by other researchers, tenderness and juiciness scores of sub-primal beef cuts improved due to the calcium injection. However, outcomes of sensory evaluation are not always consistent with the findings of physicochemical properties. The cuts from CaCl$_2$ plus spice mix-injected groups had higher ($P < 0.05$) tenderness and juiciness scores than those from uninjected groups (control). Those from H$_2$O- or CaCl$_2$-injected groups had intermediate scores and were not different ($P > 0.05$) from either control or CaCl$_2$ plus spice mix-injected groups. No significant differences were found in tenderness and juiciness scores in the cuts among the three injection groups (H$_2$O, CaCl$_2$, and CaCl$_2$ plus spice mix). Injection of CaCl$_2$ plus spice mix increased sensory scores for overall flavor compared to any of the other treatments; however, differences were not detected in the cuts among control, H$_2$O- and CaCl$_2$-injected groups. This indicated that panelists did not find off-flavor problems associated with CaCl$_2$ injection such as metallic, bitter, or livery taste. Wheeler et al. reported similar results for sensory tenderness and off-flavor scores of calcium-injected (5% (wt/wt) of 0.2 M CaCl$_2$ solution) sub-primal cuts of crossbred steers. However, Morgan et al. reported that the 10% (wt/wt) of 0.3 M CaCl$_2$ injection of sub-primal cuts from mature cows resulted in enhanced sensory tenderness, but also in bitterness and metallic flavors. The reason for this off-flavor problem might be due to the higher concentration and/or injection volume of CaCl$_2$ used.

Twenty-seven volatile compounds were isolated and identified from cooked goat leg cuts (Table 2). The compounds were grouped based on their chemical functional groups such as aldehydes, Table 2. Injection treatment effects on volatile flavors of cooked leg cuts.

| Flavor volatiles, % | Treatment$^a$ | Control | H$_2$O | CaCl$_2$ | CaCl$_2$ + SM | SEM |
|--------------------|----------------|---------|--------|----------|---------------|-----|
| **Aldehydes**      |                |         |        |          |               |     |
| Hexanal            | 41.40$^{b}$    | 32.62$^c$ | 38.07$^{bc}$ | 37.90$^{bc}$ | 2.339 |
| Heptanal           | 4.26           | 4.31    | 5.45   | 4.81     | 0.675 |
| Octanal            | 3.18           | 2.36    | 2.62   | 0.483    |       |
| Nonanal            | 10.88          | 17.07   | 11.84  | 12.79    | 2.900 |
| 2-Octenal          | 0.34           | 0.47    | 0.45   | 0.76     | 0.212 |
| 2,4-Decenal        | 0.26           | 0.27    | 0.21   | 0.34     | 0.034 |
| 2,4-Nonadienal     | 1.36           | 1.33    | 1.26   | 1.33     | 0.134 |
| 2,4-Decadienal     | 0.47           | 0.61    | 0.48   | 0.66     | 0.136 |
| Benzaldehyde       | 1.53           | 0.62    | 0.78   | 1.15     | 0.262 |
| **Hydrocarbons**   |                |         |        |          |               |     |
| Heptane            | 3.59           | 3.57    | 5.83   | 3.05     | 1.081 |
| Octane             | 0.97           | 0.54    | 0.72   | 0.44     | 0.381 |
| Tridecane          | 0.91           | 0.55    | 1.29   | 1.45     | 0.380 |
| Tetradecane        | 0.40           | 0.56    | 0.24   | 0.42     | 0.156 |
| Pentadecane        | 2.92           | 2.03    | 3.52   | 2.12     | 0.550 |
| Hexadecane         | 0.65           | 0.70    | 0.41   | 0.59     | 0.153 |
| Nonadecane         | 0.24           | 0.41    | 0.47   | 0.29     | 0.122 |
| Cyclopropane, pentyl | 1.12$^{a}$     | 1.82$^{b}$ | 0.95$^c$ | 1.03$^c$ | 0.150 |
| **Ketones**        |                |         |        |          |               |     |
| 2-Octanone         | 0.41           | 0.42    | 0.32   | 0.37     | 0.054 |
| 2-Decanone         | 0.94           | 1.27    | 0.91   | 0.79     | 0.144 |
| 2-Undecanone       | 2.44           | 3.71    | 2.80   | 2.00     | 1.105 |
| 2-Pentadecanone    | 0.26           | 0.43    | 0.29   | 0.46     | 0.150 |
| 2,3-Octanedione    | 5.25           | 5.52    | 6.18   | 6.69     | 0.723 |
| **Other compounds**|                |         |        |          |               |     |
| Carbon disulfide   | 6.94           | 5.16    | 9.12   | 5.33     | 1.260 |
| Furan, 2-pentyl    | 0.58           | 0.57    | 0.51   | 0.63     | 0.101 |
| 1-Octanol          | 0.12           | 0.13    | 0.11   | 0.61     | 0.219 |
| 1-Decanol          | 0.31           | 0.37    | 0.33   | 0.52     | 0.079 |
| 2-Methyl cyclohexanol | 3.36           | 2.92    | 3.75   | 3.67     | 0.601 |

$^a$Control: no injection; H$_2$O: water injected; CaCl$_2$: 2.2% (w/v) food-grade CaCl$_2$ injected; CaCl$_2$ + SM: CaCl$_2$ plus spice mix (commercial beef roast seasoning) injected.

$^b$Within a row, least-squares means that do not have a common superscript letter differ ($P < 0.05$).
hydrocarbons (alkanes and alkenes), ketones, and others. The meaty flavor of red meat develops during cooking through degradation and reactions of water-soluble compounds.\(^{25}\) Meat lipids also act as a solvent for the volatile compounds that accumulate during cooking of meat. Among the volatile compounds, carbonyl compounds such as aldehydes and ketones are mainly responsible for oxidized flavor deriving from lipid oxidation; however, less responsibility is ascribed to hydrocarbons (alkanes, alkenes, and alkylfurans) and alcohols.\(^{26}\) In the present study, nine aldehydes were presented in the cooked leg cuts, which consisted of 5-alkanals, 1-alkenal, 2-alkadienals, and benzaldehyde. Most of these compounds are derived from the oxidation of C18 and C20 unsaturated fatty acids.\(^{27}\) Of the aldehyde groups, hexanal and nonanal were the most relevant aldehydes presented in the cooked leg cuts. Lamikanra and Dupuy\(^{28}\) reported that pentenal, hexanal, heptanal, 2,3-octanedione, and nonanal were identified as warmed over flavor markers in cooked goat meat. Furthermore, hexanal was considered a principal marker of cooked goat meat warmed over flavor development. No differences (\(P > 0.05\)) were found in any of the aldehyde compounds present in the cooked leg cuts in the current study, except hexanal. Only the percentage of hexanal was lower (\(P < 0.05\)) in the cuts injected with H\(_2\)O than in control groups (no injection), yet there was no difference in the concentration of hexanal in the cooked cuts from the two calcium injected groups and H\(_2\)O-injected or control groups. Volatile aldehyde compounds such as hexanal, heptanal, octanal, nonanal, 2-octenal, 2-decanal, 2,4-nonadienal, and 2,4 decadienal are derived from the oxidation of C18 unsaturated fatty acids.\(^{26,29}\) From the degradation of either oleic or linoleic acid, heptanal, octanal, and nonanal are produced. Hexanal, 2-octenal, 2,4 decadienal, and 2,4-nonadienal are generated by the oxidation of linoleic acid, whereas decanal is formed by the oxidation of oleic acid.\(^{26,29}\)

Of eight hydrocarbon compounds, no differences were found in any of the hydrocarbons present in cooked leg cuts in the current study, except pentylcyclopropane. Only the concentration of pentylcyclopropane was higher in the cuts injected with H\(_2\)O than in other groups, yet there was no difference in the level of pentylcyclopropane in the cooked cuts from the two calcium-injected groups and control groups. In general, hydrocarbons may not be important contributors to meat flavor compared to other carbonyl compounds, which can be formed via either lipid oxidation or degradation of carotenoids.\(^{30}\)

There were no significant differences in the concentrations of ketone volatile compounds isolated in the cooked leg cuts. Ketone flavor compounds might be generated by either oxidation or thermal degradation of fatty acids or by the degradation of amino acids.\(^{26,31}\) One furan, three alcohols, and one sulfur-derived flavor compounds were isolated in the cooked leg cuts; however, no differences were found in those flavor compounds among treatment groups in the present study. The 2-pentylfurane is produced by the oxidation of linolenic acid (C18:3n3).\(^{26,34}\) Fatty acids and amino acids are precursors of variable volatile compounds. Alcohols are generally derived from oxidative degradation by lipoxygenase alone or in combination with a hydroperoxide lyase of precursors of volatile compounds.\(^{26}\) However, alcohols may not be important contributors to meat flavor compared to other carbonyl compounds. Carbon disulfide is a sulfur-containing volatile compound. Most of the sulfur compounds had low-odor threshold and were considered as major contributors to meat flavor.\(^{32}\) In early studies, H\(_2\)S has been identified to characterize the volatile components of cooked red meat.\(^{30}\) However, H\(_2\)S was not detected in the present study because of the limited molecular scan range (40–450). Since all meat products containing protein probably emanate H\(_2\)S upon heating, the amount of H\(_2\)S and its reaction with other compounds should highly impact cooked meat flavor.\(^{30,32}\) Carbon disulfide may be formed from sulfur-containing amino acids (cysteine, cystine, and methionine) via reaction with free radicals.

**Conclusion**

The effect of CaCl\(_2\) injection on leg cuts from meat goats at 24 h postmortem was consistent with results from studies with other red meats using 0.2 M CaCl\(_2\) injection. While CaCl\(_2\) injection improved tenderness of goat leg cuts according to WBSF values, it was not perceived by the sensory panel. Furthermore, panelists were not able to detect off-flavor problems associated with CaCl\(_2\) injection. When CaCl\(_2\) was injected into goat leg cuts with the beef spice mixture, it resulted in a
more desirable flavor. Calcium injection did not influence flavor volatile compounds in cooked chevon leg cuts. Results show that either CaCl₂ or CaCl₂ plus spice mix injection can be applied to improve tenderness of chevon without detrimental effects on palatability characteristics and flavor volatile compounds.

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