**SKINLESS AND SKIN-ON GOAT MEAT**

**Evaluation of Fabrication Efficiency, Meat Quality, and Microbiological Safety of Beef Steaks Prepared by a Wet-circular Cutting System**

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**ABSTRACT (need to update)**

This study investigated the effect of skin-on and skin-off processing methods on processing efficiency, product yield, and meat quality of goat carcasses. A total of 27 goats (9 goats/treatment, 6 months old) were processed by skin-on method for ethnic consumers with skin, skin-off method for traditional consumers without skin, and skin-off-late method (skin removed after chilling) for ethnic or traditional consumers with or without skin elimination.

Skin-on carcasses took 9.5 h to chill to the temperatures ≤ 4.4 oC that are significantly longer than skin-off carcasses (7 h) (P < 0.05), presumably due to the skin presence. There was no difference in total processing time from stun through fabrication regardless of skin treatment (P < 0.05) although fabrication time of the skin-on-late carcasses was longer than the skin-on and the skin-off carcasses due to the skin elimination step (P > 0.05). Dressing yield of the skin-off and fabrication yield of the skin-off-late were lower than other two methods due to the skin elimination (P < 0.05). The muscles of the skin-on and the skin-off-late showed longer sarcomere length and lower Warner Bratzler shear force than the muscle of skin-off carcasses (P < 0.05). Collagen content of the skin-on muscle was higher than the skin-off muscle (P < 0.05). Skin-on and skin-off-late muscles showed higher L\* values than the skin-off muscle (P < 0.05), with no difference observed for a\* and b\* regardless of skin processing method (P > 0.05). Based on these results, the skin-on-late method appears to improve dressing yield, meat tenderness, and visual appearance with an alternative option for skin-on meat for traditional consumers or skin-off meat for ethnic consumers.

**Key words**: Goat processing; processing efficiency, meat quality, muscle color, ethnic meat.

**1.** **Introduction**

The process of carcass fabrication involves converting whole carcasses into smaller, consumer-desired meat cuts. This process is critical in addressing market needs and enhancing consumer convenience. Given the variations in animal carcasses concerning size and muscle composition, the selection of appropriate cutting technologies and methods is crucial for the efficient separation of meat from bone and tendon, as well as the differentiation between tender and tough muscles, and between thinner and thicker cuts. Traditionally, this process involves the use of circular saw blades (named dry-circular cutting) for primary and intermediate cuts that are further fabricated into finish cuts with muscle trimming. However, this conventional method results in the accumulation of meat debris, bone dust/chips, and fat smearing on the muscle surface, which adversely impacts the cutting efficiency, product yield, visual appearance, and overall meat quality. As a result, an additional step is required for scrabbing the meat debris and smeared fat on meat surface this is labor-intensive, time-consuming, and costly (McGeough, 2016).

The meat industry has adopted waterjet cutting (WJC) technology to enhance cutting yield, cost-efficiency, and labor effectiveness while eliminating cross-contamination and bacterial transmission due to no blade contact (Alitavoli & McGeough, 1998; Malone et al., 1994; Wulfkuehler et al., 2014). This technology, originally developed in 1935, has progressively evolved to facilitate the cutting of diverse materials, including paper, stainless steel, stone, among others (Fourness et al., 1935; Rice, 1965; Guidorzi, 2022). Wang and Shanmugam (2009) demonstrated the capability of abrasive waterjet cutting (AWJC), utilizing salt as an abrasive, to cut meat along with bone. Despite its benefits, however, the AWJC system requires significantly higher cost for initial installation and equipment maintenance compared to the traditional blade cutting system. Additionally, waterjet cutting processes tend to be slower, generate wastewater, and require specialized training for operation (Liu et al., 2022).

Recently, an innovative cutting technology (Kleen KutTM ) named wet-circular cutting has been developed to effectively fabricate and simultaneously remove a band saw residue (meat debris, bone fragments, and blood) by placing water jet nozzles near a traditional circular saw blade (Chaffin and Jones, 2009). Within this system, dual water nozzle orifices are strategically positioned adjacent to the saw blade, delivering sufficient water to both sides of the blade. This setup allows the water to function as a lubricant, facilitating the removal of meat residues and inhibiting their adherence to the meat surfaces during the fabrication process. The primary objective of this study is to evaluate the quality, shelf-life, and visual appeal of beef steaks fabricated using this proprietary technology.

# **2. Materials and Methods**

# ***2.1. Muscle Selection and Fabrication into Steaks***

Six wholesale beef ribs at 48 h postmortem were purchased locally: Institutional Meat Purchases Specification (IMPS): Beef Loin, Short Loin, short-cut (IMPS # 174). The beef loins were fabricated into several steaks with the thickness of 2.54 cm, using a conventional bald saw (called dry cut) or an innovative blade saw (wet cut) at California Polytechnic State University (San Luis Obispo, CA).

***2.2. Fabrication Time, Fabrication Yield, and Color Evaluation***

Fabrication time and fabrication yield were recorded during and after the processing, and their values were calculated as below:

Fabrication tine (second): End cutting/scrabbing time – Initial cutting tine.

Fabrication yield (%): End cut weight of steaks/Initial weight of beef rib x 100.

For color evaluation, Commission Internationale de l’Éclairage (CIE) L\*, a\*, and b\* values (where L\* refers to light- ness, a\* to redness, and b\* to yellowness) were measured on the surface of steaks after 30 minute of blooming, using a chromameter (8-mm aperture, illuminant C; CR-400, Konika Minolta Sensing Inc., Osaka, Japan) that was calibrated with a white plate (L\*, 97.28; a\*, −0.23; b\*, 2.43). Areas were selected that were free of any obvious blood-related defects, such as bruises, hemorrhages, or full blood vessels (Fletcher et al., 2000). Three readings/steak were obtained for CIE L\*, a\*, and b\* using two from longissimus dorsi muscle and one from Psoas major muscle. each part (3 readings/side) of semimembranosus and longissimus lumborum.

# ***2.3. Steak Preparation for Displaying in a Display Case***

Six steaks were cut and taken from the sirloin to the rib end, placed on retail trays having a pad, and displayed on shelves in a coffin-style retail case at 4 – 5 oC (Howard-McCray, Model SC-CMS 35-6, HMC Enterprises LLC, Philadelphia, PA) under continuous fluorescent (34 W Warm White light; F40/Spec./RS/EW/Alto, Philips Lighting Company, Somerset, Versailles, KY) (**Figure 1**). The steaks were then evaluated for physicochemical and microbiological changes during the storage of 0, 3, 6, 9, and 12 days.

***2.3.1 pH measurement***

For pH, each sample (5g with duplication) of steaks was homogenized in 50 ml of deionized water using a homogenizer (Brinkmann Homogenizer, Wesbury, NY) to the pH value, using a pH electrode (Accumet AB 15, Fisher Scientific, Pittsburgh, PA).

***2.3.2 Purge loss***

For purge loss, samples were individually weighed prior to placing on a case. The purge was calculated using the equation of (stored steak weight)/(initial steak weight)\*100.

***2.3.3 Lipid oxidation (TBARS value)***

For oxidative stability, thiobarbituric acid was evaluated using the procedure described by Pikul et al. (1989). On each sampling day, a 10-g sample in duplicate was taken from the surface (2 mm thick) and results was reported as thiobarbituric reactive substances (TBARS) representing mg malondialdehyde (MDA) equivalents per kg of steak.

***2.3.4 Microbiological analysis***

On each sampling day, each stake was randomly taken and opened aseptically after wiping the package surface with 70% (vol/vol) ethanol. Using a sterile scalpel, meat (25 g) was taken, diluted 1:10 (wt/vol) in phosphate-buffered saline (PBS) and homogenized in a Stomacher 4000 (Seward, Norfolk, England) for 1 min. For bacterial enumeration, serial 10-fold dilutions of stomached samples were plated (0.1 ml) in duplicates on standard method agar (Acumedia, Lansing, MI) for mesophilic aerobic bacteria (MAB) and on 3M petrifilms (3M Microbiology Products, St. Paul, MN) for Coliform/*Escherichia coli* (*E. coli*). Red and blue colonies with associated gas bubbles were confirmed Coliforms and blue colonies with associated gas bubbles were confirmed *E. coli*.

***2.4 Scanning electron microscope (SEM) imaging (Dr. Lily to edit)***

After cutting steaks, muscle samples (3 mm x 3 mm?) were removed from the center of the steak and fixed at 4 oC for 12 h in 4% glutaraldehyde buffered at pH 7.4 with 0.1 M sodium phosphate. The samples were then rinsed for 4 h in the buffer followed by post-fixation for 12 h in 1% osmium tetraoxide buffered with 0.1 M sodium phosphate. After fixation, the samples were rinsed again in the buffer for 4 h followed by dehydration by exchanging with graded ethanol series (25%, 50%, 75%, 95%) for 2 h at each gradation followed by three 2 h changes in 100% ethanol. The samples were critically point dried in a Leica Microsystems model EM CPD300 critical point dryer (Leica Microsystems, Vienna, Austria) using liquid carbon dioxide as the transitional fluid. The samples were then mounted on aluminum stubs using carbon suspension cement (SPI Supplies, West Chester, PA) and coated with gold (~20 nm thick) in an Emscope Sputter Coater model SC 500 (Ashford, Kent, England) purged with argon gas. Samples, mounted on the stubs, were examined at 10,000 x magnification in a JEOL 6610LV SEM (tungsten hairpin emitter) scanning electron microscope (JEOL Ltd., Tokyo, Japan). Total of 30 microscopic fields (6 fields/sample) were observed for each treatment.

***2.9. Statistical analysis (need to update)***

Data with three replications were statistically analyzed using one-way analysis of variance (ANOVA) that was performed by Proc MIXED procedure of SAS (SAS Institute, 2022) in a completely randomized design. If significance was determined (*P* < 0.05) in the model, dependent variable means were separated using the least significant difference procedure of SAS (*P* < 0.05; SAS Institute 2022).

# **3. Results and Discussion**

# ***3.1. Steak appearance and fabrication time of conventional and nozzle cuts***

A conventional band saw is a powerful tool that can fabricate carcasses into wholesale cuts, retail cuts, and individual steaks by cutting through muscle and bones. However, it provides the steaks with saw residue such as protein, fat, blood, and bone fragments. Figure 1 shows the steak fabricated with a conventional cut (**Figure 1a, 1b**) that requires an additional step of scrap off (**Figure 1c**), whereas the steak fabricated with a nozzle cut (**Figure 1a, 2b**) appears clean with almost no meat and bone dusts for no necessary of additional scrap. The fabrication time for steaks was significantly lower in the nozzle cut over the conventional cut due to the additional step of scrapping off (*P* < 0.05) (**Figure 1, 2**).

***3.2. SEM image of beef steaks***

The scanning electron microscope (SEM) image shows that the surface of steak edge (**Figture 1a, 1b**) had a rough appearance compared to the steak center (**Figure 2a, 2b**), regardless of cutting method. It is predicted that more physical vibration occurred at the moment of initial cutting than the continuous cutting between the two surfaces, providing a gentle pressure and bade stability. The surface of conventional cuts (**Figure 1a, 2a**) also showed a rough surface over the wet cuts (**Figure 1b, 2b**). The wet cut system has two waterjet nozzles, one on each side of blade saw and provides a film of water on the blade that serves as a lubricant during cutting (Chaffin et al., 2009). The smooth surface in wet cutting is expected by the combined effects of lubricant smoothness and less bone fragments after washing off.

***3.3. Steak yield, pH, and TBARS during storage***

During storage, the steak yield showed a stepwise reduction from 100% to 97.2%, with a significant reduction observed at 9 and 12 days compared to the control (P < 0.05). The weight loss is attributed to the dehydration of meat during storage that is affected by the difference between the water vapor pressure on food surface and that in the air bulk (Campanone et al., 2002). Weight loss is also affected by muscle size (or surface/volume ration) as well as fat and skin covering (Bustabad, 1999; Cutting and Malton, 1973).

The muscle having pH values of 5.4 – 5.8 at approximately 24 h postmortem is considered normal while the muscle with pH 6.1 or higher is defined as dark, firm, and dry (DFD) meat (Zhang et al, 2009). At 0-day storage (or 48 h postmortem), the muscle pH values of 5.59 for loin and pH 5.51 for tenderloin appear to be normal, which remained in the range of 5.41 – 5.45 at the 12-day storage. The initial pH (5.59) of loin continuously reduced to 5.45 as the storage extended to 12 days, and a significant reduction was observed in 9 and 12 days (P < 0.05). A pH reduction trend was seen for tenderloin within the normal pH range (5.51 – 5.41). In comparison of combined pH values, the conventional cut showed a higher pH value (5.52) for tenderloin than the wet cut (5.42), while no difference was observed for loin (**Table 1**).

***3.3. TBARS during storage for 12 days***

Prevention of lipid oxidation in muscle foods is very important because it affects the sensory attributes, purchasing behavior of consumers, and economic losses (Barden and Decker, 2016; Dirinck et al., 1996; Liu et al., 1995). It has been suggested that more oxidations occur when meat is physically damaged during mincing and emulsion compared to simple chopping or steak cutting (Shimizu, H. and Iwamoto, S., 2022; Hosseini et al., 2020).

The TBARS scores of loin and tenderloin cuts in 0 day significantly increased in the day 6 of storage and continued increased to reach 1.02 and 1.18, respectively, which was 0.83 – 0.91 units more than the initial.

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of carcasses declined from ~ 6.9 to ~ 5.9 during chilling, regardless of muscle type, with no significant difference between the SM and LL muscles at 0.75 and 25 h postmortem (P > 0.05). However, a lower pH value was observed for the SM muscle than the LL muscle in the mid-chilling at 2 and 9.5 h postmortem (P < 0.05) (**Figure 5**). A similar pattern of pH reduction was reported for 6 to 9-month goats, showing that the pH was reduced from 6.9 to 6.0 during 24 h postmortem (Abhijith, 2021). Unlike other red meat species, goat meat pH has been known to slowly decline with no rapid reduction in the early chilling. In addition, most goat carcasses have higher end-chill pH values (5.7 - 5.9) over other species (Webb et al., 2005; Atti et al., 2006; Mushi et al., 2009; Ding et al., 2010; Shija et al., 2013; Abhijith et al., 2021) although some carcasses show normal pH (5.4 - 5.7) (Madruga et al., 2008, Arsenos et al., 2009; Astruc, 2014).

In comparison of pH values during chilling, the skin-off-late carcasses showed a higher initial-chill pH (6.95) and lower end-chill pH (5.87) than those (6.87 to 6.01) of skin-on carcasses, while no difference was found in the mid-chilling, regardless of the skin treatment (P < 0.05) (**Figure 6**). The relatively high pH in goats is associated with the tendency of premortem stress and low glycogen storage (Webb, 2014; Abhijith et al., 2021; Simela & Frylinck, 2004). LaRoche et al. (2022) reported even higher pH values (6.14 - 6.36) at 24 h than normal, which was explained by high parasitic infections resulting in lower glycogen content (Simela et al., 2004; Warren et al., 2010).

***3.4. Sarcomere length (µm) and WBSF (kg)***

In the muscle at 24 h postmortem, the sarcomere length of SM was longer than LL (P < 0.05) although no WBSF difference was observed between the two muscles (P > 0.05) (**Table 3**). In case of carcass, the skin-on and skin-off-late carcasses showed longer sarcomere lengths and lower WBSF values than skin-off carcasses, regardless of muscle type (P < 0.05). These results indicate that the skin-on carcasses showed less muscle shrinkage and more meat tenderness during chilling than the skin-off carcasses. One of main concerns of goat meat is its toughness that is expected from low fat over high fat in carcasses (Kannan et al., 2014; Shija et al., 2013). In our study, the carcasses covered with skin might have less cold shortening than the carcasses with no skin although fat content was not evaluated. A positive relationship between sarcomere length and meat tenderness has been reported in animal muscles from rigor onset to rigor completion (Wheeler et al., 2000; Hamm, 1981; Honikel et al., 1981). In accordance with the meat tenderness, LaRoche et al. (2022) reported that overall juiciness of skin-on goat meat was higher than skin-off goat meat.

***3.5. Collagen content and cooking yield***

Collagen exists in mammalian skin in addition to other carcass parts of tendons, ligaments, cartilage, and bones (Jongjareonrak et al., 2005; Nalinanon et al., 2011). Collagen has many functional properties including hydration that improves sensory attributes and versatile functionality that improves protein intaking, bioavailability, and antioxidant (Cao et al., 2022; Gómez-Guillén et al., 2011; León-López et al., 2020; Schrieber & Gareis, 2007). The LL showed higher collagen content than the SM, with the highest value and the least value observed for the skin-on LL and the skin-off-late SM, respectively (P < 0.05). A similar trend was seen for cooking yield, showing the higher cooking yield with the LL than the SM, except the skin-on SM, regardless of skin treatment (P < 0.05) (**Table 4**).

***3.6. Color***

Muscle color and visual appearance are very important because they have a substantial effect on consumers who often decide to buy the products based on the initial appearance (Northcutt, 1997). Immediately after fabrication, the color values of SM and LL were evaluated. There was no significant difference for lightness (L\*) between the two muscles (P > 0.05), while both redness (a\*) and yellowness (b\*) of SM were higher than LL (P < 0.05) (**Table 5**). In evaluating three carcasses using the two muscles, higher L\* values were observed in the skin-off-later muscle than the skin-off muscle, and intermediate values were noticed for the skin-on muscle (P < 0.05). It may be possible that the freshly deskinned muscle might have less dry property than the previously skinned muscle. Although not goat, it is well documented that the water-chilled chicken skin (less dry) has higher L\* value than air-chilled skin (dryer) largely because the dehydration of surface reduced lightness on the muscle (Mielnik et al., 1999; Huezo et al., 2007). There was no significant difference for a\* and b\* values, regardless of skin treatment.

**4. Conclusions**

This study compared the physicochemical and quality characteristics of skin-on, skin-off, skin-off-late muscles. Conventionally, goats have been processed with skin off for traditional consumers and skin on for ethnic consumers. The major advantages of skin-on goats are higher dressing yield, fabrication yield, meat tenderness, and collagen content than skin-off goats. An additional advantage of the skin-off-late processing is the flexibility in meat processing that allows skin-on and skin-off products with and without skin elimination during fabrication. Additional research for meat safety and sensory attributes is required.

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