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Research Paper

Evaluation of goat meat product treated with apple cider vinegar alone and in combination with natural spices, cooked, vacuum packaged and stored at 4 ± 1°C for 42 days

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The objectives of this study were to manufacture a heat-and-serve precooked goat meat product, and to determine proximate, microbiology, Thiobarbituric acid reactive substances (TBARS), pH, sensory, and approximate cost of the finished packaged product. Goat meat was treated with water (Con), apple cider vinegar (ACV), spice rub (SRO) or combination of ACV-SRO, cooked to an internal temperature of 74°C, cooled, vacuum packaged and stored at 4 ± 1°C for 42 days. For all treatments, goat flavor intensity, and tenderness were rated slightly bland to slightly intense, and slightly to moderately tender, respectively, and no off-flavor was detected. Except for moisture, all proximate analyses were similar (P>0.05). Moisture was lower (P < 0.05) for SRO when compared to all other treatments. TBARS for ACV-SRO were lower (P < 0.05) than Con on 21 through 42 days. Except for day 14, all ACV and ACV-SRO treatments resulted in psychrotrophic and lactic acid bacteria counts at or below 5 log CFU/g through 42 days storage. The ACV and ACV-SRO treatments resulted in lower (P <0.05) pH values when compared to Con on all storage days. *Staphylococcus aureus*, *Salmonella* spp, *Escherichia coli* 0157:H7, fecal coliforms, and *Listeria monocytogenes* were not isolated in this study. Estimated cost of goat ribs ranged from $0.41 to $0.69 per 454 g higher than comparable commercially available pork ribs.

Key words: Goat meat, vacuum-package, apple cider vinegar, shelf life, microbiology

INTRODUCTION

Although goat meat inventory has remained essentially constant in the past 9 years, the demand for goat meat in the United States exists and is due mainly to the growth of ethnic populations, and others familiar with goat meat. All U.S. goat inventory on January 1, 2017 totaled 2.64 million head, up 1 percent from 2016, and meat and all other goats totaled 2.12 million head, up 1 percent from 2016 (USDA National Agricultural Statistics Service, 2017). In comparison, the U.S. cattle inventory for 2016 reached 93.5 million head, which was up 1.8% from January 2016 (National Cattlemen's Beef Association, 2017). Goat meat production represents approximately 2.82% of the cattle inventory for 2017. The disparity between cattle production and goat production suggests that meat goats should be considered as a niche market that produces products for its current audience (ethnic populations, and others familiar with goat meat) with the goal of educating and expanding to a larger audience.

Currently, goat meat products include primarily fresh wholesale and retail cuts. The limited availability suggests the need to add value to the current fresh goat meat products by employing product development research. Production of value added goat meat products would increase demand, consumption, acceptability, and marketability of goat meat (Cosenza et al., 2003a and 2003b). There would also be the added benefit of increasing the production of meat goats.

As part of adding value, there is a need to include functional ingredients that will extend shelf life and maintain freshness without affecting the acceptability of the product. The use of various antimicrobials alone or in combination in the meat and poultry industry have included acidified sodium chlorite, bromine, chlorine dioxide, cetyl pyridium chloride, organic acids, peracetic acid, trisodium phosphate, sodium metasilicate, monochloramine, electrolyzed water, and hypochlorous acid (Bilgili, 2009). These antimicrobials are used for the primary purpose of retarding and/or preventing the growth and survival of pathogenic and spoilage bacteria. For example, acetic acid is used in meat systems primarily in the forms of distilled white buffered liquid vinegar, and buffered powdered vinegar. Stelzleni et al. (2013) determined that white buffered vinegar imparted minimal anti-*Salmonella* properties, and significant reductions of 3 to 4 log CFU/g in psychrotrophic bacteria in beef trimmings used to manufacture ground beef. It was also determined that powdered vinegar exhibited stronger off-flavor (P-<-0.05) than all other treatments (liquid buffered vinegar, and a solution containing 1.0% levulinic acid plus 0.1% sodium dodecyl sulfate). No research was available on the use of apple cider vinegar in neither meat nor poultry products for antimicrobial or antioxidant properties. White vinegar and apple cider vinegar differ in the production process, pH, and flavor. White vinegar has a pH of 2.5, compared to a pH of 5.5 for apple cider vinegar (reddit.com, 2017). The ingredients, apple cider vinegar and natural spices, were selected to provide as many natural ingredients as possible, which would be very appealing to consumers. Researchers in this study manufactured a heat-and-serve precooked goat meat product using apple cider vinegar alone and in combination with natural spices, and determined storage stability, and approximate cost of the finished packaged product.

MATERIALS AND METHODS

Sample preparation and treatment

Ten whole goat racks with longissimus dorsi intact, from approximately 6 to 7 month old Boer-Spanish crossbred goats were purchased from a local goat meat processing facility. Fat covering was visually similar among all racks. Excessive external fat was pretrimmed from the rib racks by processor, as requested by the researchers, prior to purchase. The meat color was cherry red (oxymyoglobin pigment), and the meat contained little or no visible marbling. The whole racks (33.1 kg total weight for ten racks) were split and cut according to the USDA Agricultural Marketing Service Institutional Meat Purchase Specifications (USDA AMS, 2006) for fresh goat, barbeque style. No distinctions were made between left and right sides of the racks. A cross sectional cut was made to remove the riblets, which were packaged and frozen. The remaining rib roasts were each cut longitudinal into approximately three 12 cm by 10 cm rib roast, bone-in samples with a Biro 44 Band Saw (The Biro Manufacturing Company), and divided into four groups. The meat was treated with (1) water only (Con), (2) apple cider vinegar (ACV, White House, Las Vegas, NV), (3) water plus Spice rub (SRO) and (4) water plus apple cider vinegar plus spice rub (ACV-SRO) (Table 1). The meat was placed into a vacuum tumbler (approximately 50 kPa, Lyco vacuum tumbler, model 40, Columbus, WI) along with water and the ingredients specific for each treatment, and tumbled for 25 min in processing room (10°C). Ingredients included water (10%), salt (1.0%), ACV (2.0%), and sodium tripolyphosphate (0.4% - dissolved first in the formula water, followed by formula salt). After vacuum tumbling, the meat in treatments SRO and ACV-SRO were coated with spice rub. Thermocouples (Extech 421307 Type K Dual Input by Extech Instrument Corporation, Waltham, MA, U.S.A.) were inserted into the geometric center of the ribs, to monitor internal temperature. The roasts from each treatment were baked on separate baking pans in a conventional General Electric® Built-in gas oven (Model JGRS14) at 163°C until the meat reached an internal temperature of 74°C. Following the cooking process, the meat was cooled to ambient temperature, and vacuum packaged with a FoodSaver® Pro Sport Model Vacuum Packager (Jarden Corporation. Rye, NY) equipped with FoodSaver® packaging material (oxygen transmission rate: 164.232 cc/m^2/24 h at 23°C on the rough side, and 0.334 cc/m^2/24 h at 23°C on the smooth side, as determined by the University of Florida Agriculture Engineering packaging experts).The roasts were packaged in a single layer at approximately 300 g per bag, sealed and stored at 4 ± 1°C for 42 days.

According to the manufacturer, the FoodSaver® packaging material was designed for use in refrigerator, freezer, microwave, boiling water, and reuse after proper cleaning. FoodSaver® packaging roll stock film was used to make 112 30.48 cm X 27.94 cm custom-sized bags with the aid of FoodSaver® Store ‹n Cut device. The study was repeated two times, and in each trial, goat meat was purchased from the same supplier.

Proximate analysis

Duplicate samples of each rib formulation were analyzed

Table 1. Formulations and margination yields for goat ribs formulated with apple cider vinegar, and a topical spice rub blend.

Parameters	Treatments*			
Ingredients	**Con**	**ACV**	**SRO**	**ACV-SRO**
			Percent	
Goat Meat	90.00	86.60	90.00	86.60
Water	10.00	10.00	10.00	10.00
Salt	-	1.00	-	1.00
Apple Cider Vinegar	-	2.00	-	2.00
Sodium tripolyphosphate	-	0.40	-	0.40
Spice rub Blend (.575kg/45.5 kg meat)	-	-	+	+
Marinate Weight increase (%)	5.25	10.31	5.82	20.61

*CON – control, water only, no additives; ACV – Apple cider vinegar; SRO- Spice rub only; ACV-SRO – apple cider vinegar plus spice rub.

for moisture using the oven drying technique (method 985.14, AOAC, 2000), ash using the muffle oven technique (method 920.153, AOAC, 2000), fat (method 960.39, AOAC, 2000), and protein following the Kjeldahl procedure (method 928.08, AOAC, 2000).

Microbiological analysis

Duplicate goat meat samples per treatment were analyzed for, total psychrotrophs, lactic acid bacteria, *Staphylococcus aureus, Salmonella,* fecal coliforms, *Escherichia coli* 0157:H7, and *Listeria monocytogenes.* All media (Difco Laboratories) and materials used for the cultivation and maintenance of the bacteria were purchased from Fisher Scientific. Microbiological analyses were conducted as outlined in the Bacteriological Analytical Manual (BAM) (U.S. Food and Drug Administration, 2017). Twenty-five grams of goat meat from each treatment were placed in sterile 18 x30 cm Fisherbrand stomacher bags (400 ml, Fisher Scientific) along with 225 ml of sterile 0.1% peptone water (Cat. No. DF01897-17-4). The stomacher bags were massaged by hand (because use of the stomacher spilled the mixture) for two min to loosen any surface bacteria. Serial dilutions of 10^{-1} to 10^{-6} were prepared by transferring 1.0 ml of the sample homogenate to 9 ml of sterile 0.1% peptone water.

One hundred µl of the dilutions were pipette in duplicate and spread (using a sterile glass hockey stick) onto Xylose Lysine Desoxycholate Agar (XLD, Cat. No. DF0788-17-9) for *Salmonella* spp., Plate Count Agar (PCA, Cat. No. DF0479-17-3) for total psychrotroph counts, mFC Agar (Cat. No. DF0677-17-3) for total coliforms, Oxford Agar (Cat. No. DF0225-17-0) with Oxford media Supplement (Cat. No. DF0214-60-9) for *Listeria monocytogenes*, Remel Mannitol Salt Agar (Cat. No. 453902) for *Staphylococcus aureus*, MacConkey Sorbitol Agar (Cat. No. DF0075-17-1) for *Escherichia coli* 0157:H7, and APT Agar (Cat. No. DF0654-17-0) for lactic acid bacteria. All plates were prepared in duplicate and incubated for 18 to 24 h at 44 ± 1°C for mFC plates, 25 ± 1°C for 5 days for PCA plates, and 24 ± 2 h at 37 ± 1°C for Mannitol Salt, Modified Oxford, MacConkey Sorbitol, APT, and XLD plates.

After incubation, colony forming units (CFU) from each plate were counted, recorded, averaged and reported as colony forming units per gram (CFU/gram).

Thiobarbituric acid reactive substances analysis

Thiobarbituric acid reactive substances (TBARS) distillation procedure for meat and poultry was adapted using procedures from Tarladgis et al. (1960), Rhee, (1978) and Ke et al. (1984). In the adapted procedure, the sample was read against the blank at the optical wavelength of 535 nm in an effort to increase recovery of malonaldehyde. TBARS values were reported as mg malonaldehyde per kg of sample.

pH measurements

Immediately after the microbiological analyses were completed, pH values were recorded for each sample homogenate using an Accumet AB15 pH meter (Fisher Scientific). The pH probe was placed into the sample homogenate and allowed to equilibrate for one min before the reading was taken. All pH readings were performed in duplicate and averaged.

Trained sensory panel analysis

The University of Florida Institutional Review Board preapproved all sensory evaluations. Training for the goat meat sensory panels was conducted in a one-hour session. Panelists were selected who were familiar with goat meat and had previously participated in trained goat meat panels. However, all panelists were required to participate in the training session. Goat meat was purchased from a local supermarket, and utilized in the training session. Panelists were trained to identify goat meat flavor and overall tenderness. The panelists were presented with roasted goat meat 1) without additives, 2) treated with apple cider vinegar, and 3) without additives,

reheated, held at refrigeration temperature and reheated again to create a rancid oxidized flavor. The panelists were trained to detect the characteristic goat flavor in goat meat with and without apple cider vinegar added. Prior to the training session, researchers and assistants conducted a preliminary evaluation of the treated goat meat samples to verify that rancid flavor, and differences between all treatments could be detected.

During training and the actual sensory panels, goat flavor intensity was evaluated using an 8 - point scale, where 8 = extremely intense, 7 = very intense, 6 = moderately intense, 5 = slightly intense, 4 = slightly bland, 3 = moderately bland, 2 = very bland, 1 = extremely bland. Overall tenderness was evaluated using an 8 - point scale, where 8 = extremely tender, 7 = very tender, 6 = moderately tender, 5 = slightly tender, 4 = slightly tough, 3 = moderately tough, 2 = very tough, 1 = extremely tough. Off-flavor was evaluated using a 6 - point scale, where 6 = none detected, 5 = threshold; barely detected, 4 = slight off-flavor, 3 = moderate off-flavor, 2 = strong off-flavor, 1 = extreme off-flavor. The panelists were asked to describe any off-flavor detected. Panelist were given a list of descriptions (sour, bitter, sweet, grassy, musty, metallic, stale, cardboard-like, and painty) to assist in their identification of the off-flavor detected. They were also requested to describe the flavor using other terms, if the listed descriptors were not adequate. The descriptors bitter, metallic, stale, cardboard-like and painty were emphasized as descriptions that were associated with rancidity.

Sensory panels were conducted in a taste panel facility equipped with 11 private booths,that were each equipped with seating and the appropriate lighting for the specific food being evaluated. In this study, the booths were illuminated with red filtered lights to enhance objectivity. In preparation of taste panels, four 300g packages of goat meat were placed in a 1.5-L stainless steel kettle filled to approximately ¾ of its capacity with cold tap water and heated to boiling on a conventional Magic Chef® electric range. The packaged meat remained in the boiling water for 20 min and reached internal temperature of 71°C. The meat was allowed to cool at room temperature. After cooling, the meat was removed from the package, and separated from the bones and connective tissue as suggested by American Meat Science Association (1995). Four Separate cutting boards and knives were used to prepare each treatment for sensory evaluation in an effort to avoid any crossover in flavor. The boneless meat was cut into 1cm x 1cm pieces and served in a five-jar capacity thermal controlled yogurt warmer (Salton Inc., Bronx, NY). Each jar was labeled with a code that corresponded to the codes on the sensory scoring sheet. Prior to placing the samples into the jars, the jars were pre-heated at 135°C for 1 h in a conventional electric oven. The samples were served at ambient temperature with tap water and crackers. Panelists were instructed to drink water and eat crackers to cleanse their palates, and pause for 20 sec between samples.

Statistical analysis

A complete randomized block design, with four formulations, seven sampling intervals over a period of 42 storage days, duplicate sample replications and two trials, was used in this study. A total of 112 samples were analyzed. The analysis of variance of General Linear Model (PROC GLM) and LSMEANS procedures for generating standard errors of the mean (SEM) were used to analyze trial, day, treatment, and treatment by day interaction (SAS Institute, 2002). The effects of trial, treatment, day, and treatment*day accounted for variations in the data. Significant differences among means were determined using the multiple comparison procedure of Duncan's Multiple range test, at a level of alpha = 0.05 significance. Statistical analyses revealed no significant differences between trials ($P > 0.05$). Therefore, trials were combined into a single statistical analysis.

RESULTS AND DISCUSSION

Proximate composition

Protein, fat, and ash values were similar ($P > 0.05$) for all treatments (Table 2). Except for the spice rub only treatment, moisture content was similar ($P > 0.05$) for all treatments. The spice only treatment had lower ($P < 0.05$) moisture than all other treatments. The lower moisture in the spice only treatment was attributed to the loss of surface moisture when the dry spice rub was applied. Although the same spice rub was applied to the ACV-SR treatment, the moisture content was not affected because of the added moisture of the vinegar. The researchers speculated that ACV did not produce protein denaturation, which would have resulted in excessive loss of moisture in samples treated with ACV. USDA Agricultural Research Service (2017) reported higher moisture (68.21%) and protein (27.16%), and lower fat (3.04%) and ash (1.46%) for 'Game Meat, goat, cooked, roasted "than the products produced in this study.

Microbiological analyses

Except for ACV-SRO, psychrotrophic counts increased ($P < 0.05$) as storage time increased for all treatments (Table 3). ACV-SRO resulted in similar counts ($P > 0.05$) on days 35 and 42 when compared to day 0. Psychrotrophic counts for Con reached 6 log CFU/g on day 42, while the SRO had 6 log CFU/g on days 14 through 42 The data suggested that the microbial population of the spice rub might have contributed to the

Table 2. Proximate composition (%) for vacuum packaged precooked goat ribs stored at 4 ± 1°C

Treatments*	Moisture	Protein	Fat	Ash
Con	57.83[a]	22.27	16.25	3.65
ACV	57.36[a]	22.66	16.60	3.38
SRO	54.79[b]	23.95	17.74	3.52
ACV-SRO	57.60[a]	22.37	16.75	3.28

*Con –control, water only, no additives; ACV – Apple cider vinegar; SRO- Spice rub only; ACV-SRO – apple cider vinegar plus spice rub. [a-b] means in same column with different superscripts are significantly different (P < 0.05). Each mean value represents four measurements.

Table 3. Mean total psychrotrophic bacteria counts for refrigerated vacuum-packaged precooked goat ribs stored at 4 ± 1°C for 42 days.

	Storage (Days)						
Treatments*	**0**	**7**	**14**	**21**	**28**	**35**	**42**
Psychrotrophic bacteria (log CFU/g)							
Con	3.00[b,y]	3.76[b,x,y]	3.95[b,x,y]	3.70[b,x,y]	4.00[b,x]	5.60[b,w]	6.53[a,w]
ACV	3.00[b,y]	3.50[b,x,y]	3.56[b,x,y]	4.28[b,w,x]	4.20[b,w,x]	4.34[c,w,x]	4.80[b,w]
SRO	4.72[a,,x]	3.38[b,y]	6.67[a,w]	6.61[a,w]	6.00[a,w]	6.86[a,w]	6.91[a,w]
ACV-SRO	4.07[a,x]	5.30[a,w]	6.16[a,w]	2.00[c,y]	2.00[c,y]	4.39[c, x]	3.84[,b,x]
Lactic acid bacteria count (log CFU/g)							
Con	3.07[a,y]	3.60[b,y]	5.06[a,x]	6.29[a,w]	6.13[a,w]	6.71[a,w]	6.00[a,x,w]
ACV	3.00[a,x]	4.91[a,w]	4.18[b,w]	3.00[bx]	4.75[b,w]	4.00[b,w]	4.00[b,w]
SRO	3.00[a,x]	3.00[b,x]	5.26[a,w]	5.71[a,w]	5.78[a,w]	5.90[a,w]	6.00[a,w]
ACV-SRO	3.00[a,y]	3.84[b,x,y]	4.13[b,x]	5.40[a,w]	4.80[b,w,x]	4.25[b,w,x]	3.00[c,y]

*Con – control, water only, no additives; ACV – Apple cider vinegar; SRO- Spice rub only; ACV-SRO – apple cider vinegar plus spice rub.
[a-c] means in same column with different superscripts are significantly different (P < 0.05).
[w-y] means in same row with different superscripts are significantly different (P < 0.05). Each mean value represents four measurements.

higher (P < 0.05) microbial counts reported on days 0, and 14 through 35 for SRO when compared to Con. However, the spice rub was not analyzed for microbial counts in this study. The ACV-SRO treatment resulted in lower (P < 0.05) psychrotrophic counts on days 21 through 42 when compared to Con and SRO treatments. On days 35 and 42, ACV and ACV-SRO had similar (P > 0.05) psychrotrophic counts. A synergistic effect for ACV-SRO was revealed on days 21 and 28 where the combination of ACV-SRO resulted in lower (P < 0.05) counts than ACV or SRO alone. Further research is necessary to reduce or eliminate the high bacteria counts contributed by the spice rub, as speculated by the researchers. Psychrotrophic organisms are the primary spoilage bacteria for fresh meat, poultry and seafood (Jackson et al., 1997). In general, spoilage defects in meat become evident when the number of bacteria at the surface reaches 7 log CFU/g (Jackson et al., 1997). It has been determined that when microbial counts reach 8 log CFU/g, decomposition of the muscle tissue begins and is evident by surface slime formation (Ayres, 1960). Psychrotrophic counts in this study remained less than 7 log CFU/g through 42 days storage for all treatments, and less than 5 log CFU/g for meat treated with ACV and ACV-SRO after 42 days storage.

Lactic acid bacteria (LAB) increased as storage time increased (P < 0.05) for CON, ACV and SRO (Table 3).LAB counts reached 6 log CFU/g on day 21 for Con, and day 42 for SRO. LAB counts remained less than 5 log CFU/g for ACV and ACV-SRO on all days except 21, where ACV-SRO had LAB counts of 5.40 log CFU/g. ACV and ACV-SRO resulted in lower (P < 0.05) LAB counts than Con and SRO on days 14-42 (except day 21 for ACV-SRO).As was revealed for psychrotrophs, LAB counts for SRO were similar (P > 0.05) to Con on all storage days, which revealed no antimicrobial effects due to SRO. A synergistic effect for ACV-SRO was revealed on day 42 where the combination of ACV-SRO resulted in counts lower than ACV or SRO. LAB usually result in spoilage of vacuum packaged cooked meat at counts of 10^7 to 10^8 CFU/g (Egan, 1983, Chenoll et al., 2006). All treatments in this study resulted in LAB counts that were less than 7 log CFU/g through 42 days. No fecal coliforms nor pathogenic bacteria (i.e., *Staphylococcus*

aureus, *Salmonella* spp. *Escherichia coli* 0157:H7, and *Listeria monocytogenes*) was isolated on the goat meat samples in any of the treatments in this study. The absence of pathogenic bacteria revealed that the precooked products were safe and cooked properly.

pH measurements

In general, the pH values for all meat treated with ACV and ACV-SRO were lower ($P < 0.05$) than Con and SRO (except for day 42) on all storage days (Table 4). pH values were similar ($P > 0.05$) among days for Con and SRO when day 0 was compared to day 42. pH for ACV and ACV-SRO was similar ($P > 0.05$) through 28 days. On days 35 through 42, the pH values for ACV-SRO were lower ($P < 0.05$) than all other treatments. Except for days 0, 7 and 35, SRO also resulted in lower ($P < 0.05$) pH than Conon all storage days. The data suggested that the decrease in pH was due largely to the addition of the apple cider vinegar and not production of

Table 4. Mean pH and TBARS for refrigerated vacuum-packaged heat and serve goat ribs stored at 4 ± 1°C for 42 days.

Treatments*	Storage (day)						
pH	**0**	**7**	**14**	**21**	**28**	**35**	**42**
Con	$6.70^{a,w}$	$6.63^{a,w,x}$	$6.63^{a,w,x}$	$6.38^{a,x}$	$6.70^{a,w}$	$6.46^{a,x}$	$6.78^{a,w}$
ACV	$6.17^{b,x}$	$6.10^{b,x}$	$6.05^{c,x}$	$5.89^{c,x}$	$6.20^{c,w}$	$6.24^{b,v,w}$	$6.36^{b,w}$
SRO	$6.59^{a,w}$	$6.50^{a,w}$	$6.42^{b,w}$	$6.25^{b,x}$	$6.33^{b,x}$	$6.43^{a,w}$	$6.44^{b,w}$
ACV-SRO	$6.20^{b,w}$	$6.16^{b,w}$	$5.95^{c,x}$	$5.95^{c,x}$	$6.14^{c,w}$	$5.81^{c,x}$	$5.99^{c,x}$
mg of malonaldehyde/ kg sample							
Con	$0.68^{a,y}$	$0.82^{a,y}$	$0.84^{a,y}$	$2.00^{a,x}$	$4.10^{a,w}$	$2.74^{a\ x}$	$2.19^{a,\ x}$
ACV	$0.29^{\ a,z}$	$0.81^{a,y,\ z,}$	$0.70^{\ a,y,z}$	$1.46^{\ a,b,y}$	$4.79^{a,w}$	$3.73^{a,x}$	$1.25^{b,y}$
SRO	$0.34^{\ a,y}$	$.25^{a,y}$	$0.66^{\ a,x,y}$	$0.90^{\ b,,x,y}$	$4.58^{a,w}$	$1.42^{b,x}$	$2.30^{a,x}$
ACV-SRO	$0.78^{\ a,x}$	$0.79^{a,x}$	$1.41^{a,x}$	$0.81^{b,x}$	$2.52^{b,w}$	$1.70^{b,w}$	$0.86^{b,x}$

*Con – control, water only, no additives; ACV – Apple cider vinegar; SRO- Spice rub only; ACV-SRO – apple cider vinegar plus spice rub.
$^{a-c}$ means in same column with different superscripts are significantly different ($P < 0.05$).
$^{w-z}$ means in same row with different superscripts are significantly different ($P < 0.05$). Each mean value represents four measurements.

lactic acid by LAB. The data also suggested that the spices had an effect on lowering the pH of the goat meat.

Thiobarbituric acid reactive substances

TBARS increased as storage time increased up to 28 days (Table 4). After 28 days, TBARS decreased ($P < 0.05$) on days 35 (except for ACV-SRO) through 42 for all treatments. On days 21through 42, the ACV-SRO treatment resulted in lower TBARS ($P < 0.05$) than Con, and ranged from 0.81 to 2.52 mg malonaldehyde/kg. Goat meat treated with SRO, and ACV had lower ($P< 0.05$) TBARS than Conon days 21 and 35, and day 42, respectively. The results for ACV-SRO and SRO suggested that spices used to prepare the rub (Ingredient statement: salt, black pepper, cayenne pepper, garlic powder, onion powder) might have imparted antioxidant properties in the goat meat. Spices such as rosemary, garlic, onion, and cloves have antioxidant properties (Bishov et al., 1977; Chang et al., 1977; Houlihan et al., 1984, 1985; Barbut et al., 1985). The presence of spices also might have counteracted the pro-oxidant effect of the salt. The phenolic compounds of natural spices are responsible for their antioxidant properties (St. Angelo et al., 1990; Wong et al., 1995). Widayaka et al. (2001) reported 0.50 mg and 1.0 mg malonaldehyde/kg for cooked goat meat on day 0, and 1, respectively, which is in the range of values in this study. Watts (1962) reported that TBARS values increased to 1.5 mg malonaldehyde/kg, and 4.0 after 12 days for raw and cooked goat meat stored at -18°C, respectively. Xiong et al. (2015) developed an analytical method for Non-destructive prediction of TBARS for freshness evaluation of chicken meat using hyperspectral imaging (HSI). The researchers used the spectral data and the reference values of TBARS to establish a partial least square regression model that yielded acceptable results with regression coefficients in prediction of 0.944 and root mean squared errors estimated by prediction of 0.081. Finally, an image algorithm was developed to achieve image visualization of TBARS values in some representative samples. The results of the study demonstrated that HSI is suitable for determination of TBARS values for freshness evaluation in chicken meat.

Based on the researchers' findings, the increase in TBARS reported in this study followed by a decline on days 35 and 42 was attributed to the variations of physical characteristics and chemical components of the goat meat induced possibly by microbial spoilage, enzyme

Table 5. Mean trained sensory panel responses for refrigerated vacuum-packaged precooked goat ribs stored at 4 ± 1°C for 42 days.

		Storage (day)						
Parameter	**Treatment**	**0**	**7**	**14**	**21**	**28**	**35**	**42**
Goat flavor intensity[1]	Con	4.5^{x}	4.6^{x}	5.7^{w}	4.0^{x}	5.3^{w}	DP	DP
	ACV	4.6	4.8	5.2	4.7	5.2	5.3	5.5
	SRO	4.5	5.2	4.9	4.7	4.7	5.2	4.0
	ACV-SRO	4.0	4.8	4.9	4.7	5.2	4.9	4.6
Overall tenderness[2]	Con	5.3	6.5	6.5^{a}	5.8	6.0	DP	DP
	ACV	4.9	5.9	5.9^{ab}	5.7	5.2	5.5	5.0
	SRO	5.5	5.6	6.1^{a}	6.0	6.2	5.6	6.0
	ACV-SRO	5.3	5.6	4.9^{b}	5.5	6.0	6.0	6.0

*Con – control, water only, no additives; ACV – Apple cider vinegar; SRO- Spice rub only; ACV-SRO – apple cider vinegar plus spice rub.
[a-b] means in same column with different superscripts are significantly different ($P < 0.05$).
[w-x] means in same row with different superscripts are significantly different ($P < 0.05$). Each mean value represents four measurements.
DP: Discontinued Panel
[1]Goat flavor intensity Score Scale: 8 = extremely intense, 7 = very intense, 6 = moderately intense, 5 = slightly intense, 4 = slightly bland, 3 = moderately bland, 2 = very bland, 1 = extremely bland
[2] Overall tenderness Score Scale: 8 = extremely tender, 7 = very tender, 6 = moderately tender, 5 = slightly tender, 4 = slightly tough, 3 = moderately tough, 2 = very tough, 1 = extremely tough.

Table 6. Comparative cost analysis for 100 kg batches of vacuum packaged precooked goat ribs.

Ingredients	**Ingredient, Packaging, and Mark-up Expenses ($)**			
	Control	**Marinade Only**	**Spice rub Only**	**Marinade and spice rub**
Meat	1007.60	1007.60	1007.60	1007.60
Water	0.03	0.03	0.03	0.03
Salt	-	0.72	-	0.72
Apple Cider Vinegar	-	13.00	-	13.00
Sodium tripolyphosphate	-	2.48	-	2.48
Spice Rub	-	-	21.48	21.48
Packaging Material:				
Vacuum pouches	173.00	173.00	173.00	173.00
Mark-up Cost ($)*				
Total cost/ 100 kg batch	1180.63	1196.83	1202.11	1218.31
Mark up (40%)	787.09	797.89	801.41	812.20
Total cost/ 100 kg batch	1967.72	1994.72	2003.52	2030.52
Total cost/ kg	19.68	19.95	20.04	20.31
Total cost/ 454g	8.95	9.07	9.11	9.23

* A mark up of 40% was used which includes 10% for estimated cost for electricity, labeling, transportation and advertising. Labor cost is not included.

activity and storage time. The maximum formation of malonaldehyde at day 28 was attributed to the additional absorption of the un-decomposed chemical components. When the storage time increased, the TBARS contents were slowly accumulated and their corresponding lipid oxidation products, to some extent, may have caused the cross linking of myofibrillar proteins and the structural and functional changes of these proteins (de Abreu et al., 2011; Yanishlieva and Marinova, 2001).

Sensory evaluation

Except for Con, the panelists rated goat flavor intensity similar ($P > 0.05$) for all samples through 42 days storage (Table 5). The detection of intense “bitter” and “chemical” off-flavors resulted in discontinuation of evaluation of the Con samples after 28 days storage. The panelists rated goat flavor intensity for all samples slightly bland (4.0) to slightly intense (5.7).

Degner and Locascio, (1988) reported that market development for goat meat is confronted with an uphill battle in trying to convince mainstream American consumers to purchase goat meat. Goat meat is low in fat but has an intense and characteristic aroma and taste that may be uninviting to many consumers. The scores of slightly bland to slightly intense recorded by the panelists revealed no intense or undesirable goat flavor in the goat meat utilized in this study.

The intense aroma and taste of goat meat discussed by Degner and Locascio (1988) was due largely to the age of the goat. Madruga et al. (2000) determined that organoleptic properties of tenderness, appearance, aroma, flavor, juiciness and overall palatability decreased with goat age from 175 to 310 days. The researchers reported that meat from goats slaughtered at 175 days of age had a lower number of volatile compounds and intensity, as measured by total relative abundance, and was preferred bysemi-trained sensory panelists over meat from older animals.

The goats used in this study were between 168 to 196 days old. Except for Day 14, overall tenderness was rated similar ($P > 0.05$) for all samples, and scored slightly (5.3) to moderately tender (6.5). On Day 14, overall tenderness of ribs treated with ACV-SRO was rated slightly tough (4.9), and lower ($P < 0.05$) than Con ribs (6.5, moderately tender), and ribs treated with SRO (6.1, moderately tender). ACV ribs were rated similar ($P > 0.05$) to all treatments (5.9). The 'slightly tough' ribs reported for Day 14 might have been due to the presence of connective tissue that was not completely removed. On all other days, the ribs in ACV-SRO were rated slightly tender (5.3) to moderately tender (6.0). It is also important to mention that the score of '4.9 for slightly tough' is very close to '5' which was indicative of 'slightly tender' meat.

Cost analysis

A cost analysis of the four goat rib treatments was performed in order to determine the production cost and the approximate end price. The information was used to determine the economic feasibility of production of the different formulations of goat ribs. Cost analysis consisted of expenses for goat meat, nonmeat ingredients, packaging, processing of the goat carcasses, and labor. The cost of three commercially available retail precooked vacuum packaged products were compared to the goat meat products. The estimated retail cost per 454 g for goat ribs manufactured in this study containing water, apple cider vinegar, spice rub only, and apple cider vinegar plus spice rub were $8.95, $9.07, $9.11 and $9.23, respectively (Table 6). The three commercially available heat and serve vacuum packaged marinated pork products that were purchased from a local supermarket included Tony Roma's Baby Back Ribs ($5.89/454 g), Lloyds Barbeque Seasoned & Smoked Baby Back Pork ribs ($7.66/454 g) and Chili's Mesquite Smoked and Seasoned Baby Back Pork Ribs ($8.54/454 g). All commercial products were vacuum packaged in a barbecue sauce. Comparison of the price of commercially available precooked Chili's Mesquite Smoked and Seasoned Baby Back Pork Ribs to heat and serve product produced in this study, revealed that the cost of a similar goat meat product would be at least U.S. $0.41 (Con), $0.53 (ACV), $0.57 (SRO), and $0.69 (ACV-SRO) per 454 g higher. In conclusion, an acceptable value-added goat meat product was produced. The ACV and ACV-SRO treatments were effective in reducing psychrotrophic and lactic acid bacteria, which remained at or below 6 log CFU/gram through 42 days storage. The data also suggested that the combination of ACV-SRO might have synergistic effects on microbial growth. TBARS for ACV-SRO, and SRO suggested that spices used to prepare the rub might have imparted antioxidant properties to the goat meat. The ACV, ACV-SRO and SRO treatments resulted in lower ($P < 0.05$) pH values when compared to Con. For all treatments, goat flavor intensity and tenderness were rated acceptable with scores of 5 or below for goat flavor intensity, which indicated that there was no moderate to extremely intense flavor, and 5 or above to denote slightly to extremely tender. The panelists detected no off-flavor. Except for moisture, all proximates (protein, fat and ash) were similar. Estimated cost of goat ribs ranged from U.S. $0.41 to $0.69 per 454 g higher than comparable commercially available pork ribs.

A desirable feature of the product packaging system is the FoodSaver® bags, which have the versatility of allowing the product to be stored in the bags refrigerated or frozen, and prepared by cooking or microwaving in the bag, or removing the bag and cooking in a conventional oven. The heat and serve goat meat product should have significant economic impact on the goat industry by increasing profitability of meat goats, and increasing consumer awareness and purchasing of goat meat products. In addition, a new product is also being provided for the consumer.

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