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ORIGINAL ARTICLE

Improving the quality of barbecued culled-dairy-goat meat by marination with plant juices and sodium bicarbonate

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Abstract Meat from dairy goats is less tender than that from meat goats since generally they are of an older age when culled. The objective of this study was to improve the quality of barbecued culled-dairy-goat by using juices (ginger and pineapple) and sodium bicarbonate (SB). The optimum time (30, 60, 90 min) for marinating the goat meat with ginger and pineapple juices was evaluated. Then, the optimum levels of SB (0, 1, 3, 5%) and the optimum marinating procedure for the application of SB was studied. The results showed that the ginger-marinated samples had a lower cooking loss than the pineapple-marinated samples. The optimum time for marinating the samples with plant juices was 60 min indicated by the lower hardness and chewiness as compared to those of the samples marinated with plant juices for 30 and 90 min. The cooking loss and L* values of the marinated samples significantly decreased with increasing concentrations of SB. The lowest hardness were observed in the samples marinated with pineapple juice containing 3% SB and ginger juice containing 5% SB. The samples marinated with pineapple juice for 60 min and then marinated with a barbecue sauce containing 3% SB for 60 min had a lower cooking loss and hardness as well as higher scores for all sensory attributes compared to the non-juice-marinated meat with SB and the ginger-marinated meat. The results indicate that pineapple juice and SB (3%) can improve the quality of culled dairy-goat-meat, and in particular its texture.

Keywords Dairy goat meat · Marinated meat · Ginger juice · Pineapple juice · Sodium bicarbonate

Introduction

The Department of Livestock Development of Thailand (2019) reported that the number of goats in Thailand increased from 374,029 in the year 2008 to 539,583 in the year 2015. Nowadays, goat meat is consumed not only by Muslims, but also by Buddhist and Chinese people in Thailand. Therefore, since the demand for goat meat has increased, the number of goats reared for their meat is insufficient to meet the demand for goat meat. Substituting meat from dairy goats for that of meat goats could help to respond to consumer needs. Moreover, whereas the Boer goat is the most popular meat goat with consumers, the Saanen breed is the most popular dairy-type goat in Thailand. This breed is normally reared and its milk collected up to the age of 5–7 years, after which its capacity for milk production becomes too low and it is then culled and sold to a commercial goat meat butchery. However, the tough texture and the flavor of culled dairy-goat meat are not acceptable to many consumers (Putra et al. 2017).

Nevertheless, the quality and yield of cooked meat can be improved by marinating the meat before cooking (Björkroth 2005) and previous researchers have studied improving the quality of meat by marination using plant juice, especially ginger juice (Naveena et al. 2004; Putra et al. 2017) and pineapple juice (Zochowska-Kujawska et al. 2013, 2017). Ginger (*Zingiber officinale*) is an

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important root spice that is widely used for culinary purposes (White 2007), especially in southern Asia (Pang et al. 2017). Further, ginger contains the proteolytic enzyme, *zingibain* which has the ability to tenderize tough meat (Naveena et al. 2004). Apart from meat tenderization, Putra et al. (2019) found that ginger juice also had the potential to decrease the gamey odor/flavor of refrigerated Saanen-crossbred-goat meat as well as decreasing lipid oxidation. In addition, pineapple is one of the most important fruits used for marinating meat products because it contains the proteolytic enzyme, *bromelain*. Zochowska-Kujawska et al. (2017) reported that marinating meat with pineapple increased the meat's sensory properties and decreased the shear force value of jerky meat.

Sodium bicarbonate (SB) can be used as a phosphate replacer in marinated meat, because SB has an effect on the quality (color, water-holding capacity, texture and yield) of meat similar with phosphate (Petracci et al. 2013). Although SB has an alkaline pH similar to that of phosphate, it has a greater capacity to raise the pH of meat compared to phosphate at the same level, probably due to its higher buffering capacity. Many researchers have observed a higher yield in marinated meat with SB compared to the marinated meat with phosphate (Sen et al. 2005; Petracci et al. 2013; Kaewthong and Wattanachant 2018). Moreover, SB has the ability to tenderize tough meat which contributes to the generation of carbon dioxide during cooking leading to a change of the meat's structure (Sheard and Tali 2004; Petracci et al. 2013).

The objective of this study was to improve the quality of barbecued culled-dairy-goat by using juices (ginger and pineapple) and sodium bicarbonate (SB). The marinated culled-dairy-goat was evaluated for marinade uptake, color, shear force and pH, whereas the cooked culled-dairy-goat was evaluated for cooking loss, texture profile analysis and sensory acceptability.

Materials and methods

Materials

Meat from culled 7-year-old dairy goats (Saanen crossbred, 87.5% Saanen × 12.5%) reared in Thailand was obtained from the Sittichai Dairy Goat Farm located in Sadao district, Songkhla Province, Thailand. The red meats from leg cut were collected from 20 dairy goats. Then, the samples were packed in polyethylene plastic bag and frozen at − 20 °C until used.

Pineapple and ginger were obtained from a fresh market in Songkhla Province and their plant juices were prepared by blending them in a blender (Panasonic, MK-5086 M, Malaysia) and filtering them through white cotton cheese cloth.

The ingredients used for barbecue sauce in experiment 2 and 3 for marinating 100 g goat meat was modified from the recipe of Choi et al. (2015) by using 0.7 g black pepper, 10 g butter, 6.2 g sugar, 1.4 g salt, 3.8 g oyster sauce, 8 g soya sauce, 4 g chili sauce, 7.8 g tomato sauce and 1.9 g chopped garlic. All ingredients were mixed before applying to marinate the goat meat.

Experimental design

Experiment 1 Effect of plant juices and marinating times on the quality of dairy-goat meat

The frozen goat meats were thawed at 4 °C in a refrigerator until the core temperature reached 2 ± 2 °C and cut into 3 × 3 × 1.5 cm pieces. Thereafter, the samples (200 g/treatment) were marinated in the pineapple and ginger juices separately at a ratio of 4:1 (meat:plant juice) in plastic box (8 × 15 × 5 cm) with lid at 4 °C for 30, 60 and 90 min. Meat without marinade was used as a control sample. The control and marinated samples were measured for their marinade uptake, color and shear force. Thereafter, the control and marinated samples were heated in an oven at 180 °C until core temperature of sample reached 85 °C (approximately 6 min).The cooked samples were analyzed for cooking loss and color and also by texture profile analysis (TPA). The optimum time for marinating the dairy-goat meat with pineapple and ginger juices was evaluated. The optimum marinating time from this experiment could be applied to marinate the goat meat for studying the effect of sodium bicarbonate levels and marination process on the improving quality of barbecued dairy goat in experiment 2 and 3, respectively.

Experiment 2 Effect of sodium bicarbonate levels on the quality of barbecued dairy goat

The effect of the use of different levels of SB on the quality of barbecued goat meat was studied in two-step process of marination. For the first step, pieces of goat meat (size 3 × 3 × 1.5 cm) were marinated at 4 °C with pineapple juice, ginger juice and distilled water (control) separately with each liquid containing 0, 1, 3 and 5% SB at a ratio of 4:1 (meat:plant juice/water) for 60 min (the optimum marinating time obtained from the experiment 1). Thereafter, the samples were marinated in second step with a barbecue sauce at 4 °C for 60 min. The marinade uptake, color and shear force of the marinated samples were determined. Then, the marinated samples were grilled using an electric barbecue-grill machine (HSG-305, Hanabishi, Thailand) for 15 min. The cooking loss, color and

TPA of the cooked samples were determined. The optimum level of SB for marinating the goat meat was evaluated.

Experiment 3 Effect of marination process on the quality of barbecued dairy goat

The goat meat samples were marinated with the optimum level of SB in the different steps shown in Table 1. The optimum marinating procedure was studied. The marinade uptake, color and shear force of the marinated samples were determined. Thereafter, the marinated samples were grilled using an electric barbecue grill machine (HSG-305, Hanabishi, Thailand) for 15 min. The cooked samples were analyzed for cooking loss, color and TPA.

The preliminary sensory evaluation of barbecued goat meat marinated with plant juices and SB using various marination processes was conducted by untrained sensory panel composed of graduate students and academic staff using a 9-point hedonic scale (Stone and Sidel 2004; Watts et al. 1989).

Methods

Marinade uptake

Ten pieces of the dairy-goat meat were weighed before being marinated. After marination at 4 °C, the samples were drained for 2 min, then blotted with a paper towel and reweighed. The percentage of marinade uptake was calculated based on the difference in the sample weight before and after marination (Yusop et al. 2010).

Color

The color of the surface of the dairy goat meat samples was evaluated using a HunterLab colorimeter (C04-1005-631 ColorFlex, Reston, VA, USA).The result was presented according to the CIE color system (L*, a*, and b* values).

Shear force

The shear force was analyzed using a texture analyzer equipped with a Warner–Bratzler shear apparatus (TA-XTplus Stable Micro System Texture Analyzer, UK) and a 50 kg load cell was used. The cross head speed was set at 2 mm/s.

Cooking loss

The marinated dairy-goat meat was weighed before and after cooking. The cooked samples were blotted with a paper towel and reweighed. The percentage cooking loss was calculated based on the difference in the sample weight before and after cooking (Yusop et al. 2010).

The cooking of marinated goat meat in the first experiment was conducted by using an oven which was able to control the cooking temperature (at 180 °C for approximately 6 min until the core temperature of the sample reached 85 °C). For barbecue cooking condition in experiment 2 and 3, an electric barbecue-grill machine was applied for cooking the samples with the exact time (15 min).

Table 1 The marination process of culled-dairy-goat meat prior to being barbecued

Treatments	Marinating step at 4 °C	
	Step 1 (60 min)	Step 2 (60 min)
Non-marinated	Non-marinated goat meat	
Distilled water	Distilled water	Barbecue sauce
Barbecue sauce	Barbecue sauce for step 1 and 2 (total marinating time 120 min)	
Pineapple juice	Pineapple juice	Barbecue sauce
	Pineapple juice + SB	Barbecue sauce
	Pineapple juice	Barbecue sauce + SB
	Pineapple juice + Barbecue sauce + SB for step 1 and 2 (total marinating time 120 min)	
Ginger juice	Ginger juice	Barbecue sauce
	Ginger juice + SB	Barbecue sauce
	Ginger juice	Barbecue sauce + SB
	Ginger juice + Barbecue sauce + SB for step 1 and 2 (total marinating time 120 min)	

SB sodium bicarbonate

Texture profile analysis

The cooked samples were cut into size 2.0 × 2.0 × 1.0 cm pieces to conduct TPA in a texture analyzer (TA-XT plus Stable Micro System Texture Analyzer, UK) equipped with a cylinder probe (P35) and a 50 kg load cell. The TPA operating conditions were as follows: pre-test speed 2.00 mm/s, test speed 2.00 mm/s, post-test speed 10.00 mm/s and strain 50%. The result was presented based on hardness (kg), springiness (cm), cohesiveness, and chewiness (kg.cm).

pH value

The marinated goat meat was minced and blended using a blender (Panasonic, MK-5086 M, Malaysia) for 1 min. Thereafter, the blended marinated meat was homogenized with distilled water at the ratio of 1:5 (wt/vol) before the pH value was measured using a pH meter (SevenGo S62-FK2 Mettler Toledo, Switzerland).

Preliminary sensory evaluation

The preliminary sensory evaluation was performed using 30 untrained panelists who were familiar with goat meat product. The preference of the barbecued culled-dairy-goat meat was evaluated using a 9-point hedonic scale (1, dislike extremely and 9, like extremely) based on the appearance, color, texture, flavor and overall acceptance attributes of the samples (Stone and Sidel 2004; Watts et al. 1989).

Statistical analysis

A completely randomized design (CRD) was applied to the chemical and physical characteristics of the samples. The samples from each treatment replication were randomly subjected to chemical analysis in triplicate determinations and physical analysis in 10 replicate determinations. The statistical analysis of sensory analysis data used a randomized complete block design (RCBD). Data were analyzed using the SPSS statistical program, (SPSS Inc., Chicago, IL, USA) and significant differences between the means were analyzed by Duncan's multiple range test at a significance level of $\alpha = 0.05$.

Results and discussion

Effect of plant juices and marinating times on the quality of dairy-goat meat

The marinade uptake, color (L*, a*, b*) and shear force values of the goat-meat samples after marinating in pineapple and ginger juices at 4 °C for 30, 60 and 90 min are shown in Table 2. The marinade uptake of the pineapple-marinated and ginger-marinated goat meats increased slightly with increasing marinating time. The highest marinade uptake was observed in the sample marinated in pineapple juice for 90 min ($P < 0.05$). Although the ginger-marinated goat meat for 60 min had the highest marinade uptake, no significant difference in marinade uptake of the samples marinated in ginger juice for all marinating times were observed. In respect of color, the marinating time had no influence on the b* value of the pineapple-marinated and ginger-marinated goat-meat samples but the goat meat marinated in pineapple juice for 30 and 60 min had a significantly lower L* value and higher a* value than that of the non-marinated sample ($P < 0.05$). The goat meat marinated in both plant juices showed a significantly lower shear force value as compared to the non-marinated sample ($P < 0.05$). However, the marinating time had no effect on the shear force value of the pineapple-marinated and ginger-marinated goat-meat samples. The cooking loss of the marinated goat meat with pineapple juice increased as the marinating time increased especially, at 90 min (Table 2). The ginger-marinated sample showed a slight decrease in cooking loss with no significant differences. The pineapple-marinated goat meat showed a higher cooking loss than that of the ginger-marinated sample. Pineapple and ginger contain the proteolytic enzymes, *bromelain* and *zingibain*, respectively (Naveena et al. 2004; Putra et al. 2019). Ha et al. (2012) reported that commercial *zingibain* had a higher capacity to hydrolyze the collagen in meat than commercial *bromelain*. In the present study, goat meat was marinated directly in plant juice; therefore, the proteolysis in pineapple-marinated meat occurred by enhancing the proteolysis between the enzyme and the acid from the pineapple juice. For this reason, the structure of the pineapple-marinated meat had a lower ability to retain water during cooking.

Further, the cooked samples marinated with both plant juices had significantly lower a* value as compared to the non-marinated sample ($P < 0.05$). The results indicated that marinated goat meat with both plant juices had less red color than the non-marinated sample after cooking. As explained previously, the proteolysis enzyme and acidity in plant juices caused the high cooking loss of marinated goat meat leading to release the myoglobin from marinated goat

Table 2 The quality of marinated culled-dairy-goat meat samples with pineapple and ginger juices

Parameters	Non-marinated	Pineapple juice			Ginger juice		
		Marinating time (min)			Marinating time (min)		
		30	60	90	30	60	90
After marinating							
Marinade uptake (%)	–	1.16 ± 0.46^{b}	1.33 ± 0.61^{b}	2.25 ± 0.84^{a}	1.65 ± 0.57^{ab}	2.00 ± 0.55^{a}	1.92 ± 0.58^{a}
Color L*	40.97 ± 2.83^{a}	35.04 ± 2.93^{b}	35.29 ± 3.09^{b}	39.54 ± 3.86^{a}	38.52 ± 2.12^{a}	39.66 ± 3.59^{a}	40.82 ± 2.89^{a}
a*	9.55 ± 2.14^{b}	11.37 ± 1.67^{a}	11.71 ± 1.59^{a}	9.37 ± 1.80^{b}	8.77 ± 1.62^{b}	8.47 ± 1.95^{b}	9.07 ± 1.60^{b}
b*	12.40 ± 1.96^{ns}	12.99 ± 2.51^{ns}	12.70 ± 2.33^{ns}	14.09 ± 2.59^{ns}	14.27 ± 1.61^{ns}	13.80 ± 1.96^{ns}	13.42 ± 1.24^{ns}
Shear force (kg)	6.46 ± 1.74^{a}	3.23 ± 1.12^{bc}	3.07 ± 1.04^{c}	3.80 ± 1.09^{bc}	4.68 ± 1.61^{b}	3.97 ± 1.31^{bc}	3.72 ± 1.22^{bc}
After cooking							
Cooking loss (%)	29.99 ± 2.43^{d}	43.63 ± 3.23^{b}	42.04 ± 4.24^{b}	49.57 ± 3.74^{a}	34.94 ± 3.59^{c}	34.84 ± 3.03^{c}	30.81 ± 2.20^{cd}
Color L*	49.75 ± 1.50^{b}	50.50 ± 2.80^{ab}	48.65 ± 1.36^{b}	48.10 ± 1.42^{b}	50.18 ± 3.02^{b}	52.66 ± 2.18^{a}	50.09 ± 2.87^{b}
a*	8.27 ± 1.65^{a}	6.54 ± 0.86^{b}	6.24 ± 0.31^{b}	6.31 ± 0.53^{b}	7.09 ± 1.05^{b}	7.30 ± 1.36^{ab}	6.76 ± 0.88^{b}
b*	17.61 ± 1.03^{a}	16.21 ± 1.49^{b}	15.29 ± 0.99^{b}	15.41 ± 0.91^{b}	16.50 ± 1.02^{ab}	17.49 ± 1.40^{a}	16.49 ± 0.53^{ab}
Texture profile analysis							
Hardness (kg)	6.75 ± 1.43^{a}	6.06 ± 1.33^{a}	4.70 ± 1.12^{ab}	5.76 ± 1.52^{a}	6.30 ± 1.63^{a}	3.53 ± 1.07^{b}	5.10 ± 1.46^{ab}
Springiness (cm)	0.67 ± 0.09^{ab}	0.58 ± 0.04^{b}	0.67 ± 0.07^{ab}	0.73 ± 0.08^{a}	0.57 ± 0.03^{b}	0.60 ± 0.16^{b}	0.63 ± 0.07^{ab}
Cohesiveness	0.63 ± 0.03^{a}	0.55 ± 0.04^{b}	0.57 ± 0.05^{b}	0.54 ± 0.06^{b}	0.59 ± 0.03^{ab}	0.63 ± 0.06^{a}	0.59 ± 0.03^{ab}
Chewiness (kg.cm)	2.98 ± 0.57^{ab}	2.32 ± 0.73^{ab}	1.43 ± 0.67^{ab}	2.35 ± 1.08^{a}	2.38 ± 0.98^{a}	1.21 ± 0.45^{b}	1.96 ± 0.92^{ab}

[a–d]Mean ± SD Different superscripts within the same row indicate a significant difference ($P < 0.05$)

[ns]Mean ± SD Different superscripts within the same row indicate a non-significant difference ($P \geq 0.05$)

meat during cooking. The denaturation of myoglobin also affected the color of cooked meat. The less brown color of pineapple juice marinated goat meat after cooking has been reported by Putra et al. (2019). This might be associated with the denaturation of myofibril protein by the acids of pineapple juice concomitant with the normal denaturation of globin protein induced by heat during heating. The discoloration attributes have been observed using organic acid in marinades, turning the meat a dark grey or grey-brown color (Burke and Monahan 2003; Sawyer et al. 2008).

The TPA results of the pineapple- and ginger-marinated goat meat samples after cooking are presented in Table 2. No significant differences in hardness and chewiness between the non-marinated sample and the samples marinated in ginger and pineapple juices for all marinating times were observed, with the exception of hardness of the ginger-marinated goat meat for 60 min. However, the data showed that the hardness and chewiness of cooked goat meat trended to decrease when the sample was marinated in both plant juices for 60 min. Pineapple and ginger contain the proteolytic enzymes, which have been noted in previous studies to have the ability to tenderize tough meat by hydrolyzing tissue fibers (Naveena et al. 2004; Putra et al. 2019). In the present study, the marinated goat meat with both plant juices had a significantly lower shear force value ($P < 0.05$) compared to those of the non-marinated sample. The results revealed that the plant juices had a capacity to tenderize the texture of goat meat. However, the less effect of marinating time on the texture of cooked goat meat was observed. This was probably due to the high cooking loss of all marinated sample after cooking which might contribute to the increase in toughness of the meat sample (Liu et al. 2013). The proteolytic enzymes from both pineapple and ginger juices could denature the muscle proteins leading to lower water holding capacity of the marinated meat sample and to higher cooking loss. The results indicated that the lowest shear force, hardness, and chewiness of marinated dairy-goat meat was obtained at the optimum marinating time at 60 min with both pineapple and ginger juices.

Effect of sodium bicarbonate levels on the quality of barbecued dairy goat

The marinade uptake, color (L*, a*, b*) and shear force value of the marinated goat meat with pineapple juice, ginger juice and distilled water (control) containing 0, 1, 3 and 5% SB for 60 min are shown in Table 3. The marinade uptake of the ginger- marinated samples increased with

Table 3 Marinade uptake, color (L*, a*, b*) and shear force value after marinating of culled-dairy-goat meat samples marinated with plant juices and sodium bicarbonate for 60 min

Treatments		Marinade uptake (%)	L*	a*	b*	Shear force (kg)
Juice	SB (%)					
Non-marinated		–	37.69 ± 1.81^{a}	10.92 ± 1.40^{a}	11.84 ± 1.27^{a}	3.53 ± 0.44^{a}
Distilled water	0	6.75 ± 0.36^{de}	32.34 ± 1.43^{c}	7.34 ± 0.35^{cd}	11.94 ± 1.18^{a}	2.28 ± 0.50^{b}
	1	8.45 ± 0.93^{c}	30.63 ± 1.01^{d}	6.52 ± 0.91^{cdef}	8.83 ± 0.70^{bc}	2.02 ± 1.00^{bc}
	3	8.19 ± 0.98^{cd}	27.76 ± 0.47^{f}	7.20 ± 0.88^{cde}	8.58 ± 0.74^{bcd}	1.38 ± 0.10^{d}
	5	8.34 ± 1.22^{c}	28.82 ± 1.19^{ef}	6.05 ± 0.62^{ef}	7.18 ± 0.79^{e}	1.70 ± 0.48^{cd}
Pineapple juice	0	2.43 ± 0.92^{f}	37.35 ± 1.26^{a}	9.30 ± 1.25^{b}	12.36 ± 1.62^{a}	1.63 ± 0.35^{cd}
	1	7.58 ± 1.41^{cde}	29.95 ± 0.94^{de}	7.54 ± 0.45^{c}	9.03 ± 0.73^{bc}	1.42 ± 0.26^{d}
	3	7.85 ± 0.82^{cd}	30.51 ± 0.37^{de}	5.55 ± 1.14^{f}	8.14 ± 1.43^{de}	1.25 ± 0.17^{d}
	5	7.96 ± 1.82^{cd}	29.15 ± 1.65^{def}	6.88 ± 1.35^{cde}	8.84 ± 1.78^{bc}	1.41 ± 0.25^{d}
Ginger juice	0	6.13 ± 1.41^{e}	34.24 ± 1.59^{b}	9.27 ± 1.05^{b}	12.57 ± 1.75^{a}	1.58 ± 0.11^{cd}
	1	8.95 ± 0.84^{bc}	32.75 ± 1.57^{bc}	7.61 ± 1.02^{c}	10.07 ± 0.89^{b}	1.60 ± 0.32^{cd}
	3	10.31 ± 1.47^{ab}	29.86 ± 1.52^{de}	6.29 ± 0.50^{def}	8.98 ± 0.98^{bc}	1.36 ± 0.41^{d}
	5	10.59 ± 1.66^{a}	29.80 ± 1.50^{de}	6.05 ± 0.76^{ef}	7.52 ± 1.70^{de}	1.33 ± 0.16^{d}

[a–f]Mean ± SD Different superscripts within the same column indicate a significant difference ($P < 0.05$), *SB* sodium bicarbonate

increasing concentrations of SB, whereas no significant differences in marinade uptake of distilled water- and pineapple-marinated goat meat with increasing concentrations of SB were observed. The lightness of the marinated goat meat was decreased with increasing the concentration of SB as indicated by a decrease in the L* value. Moreover, the a* and b* values were also decreased with increasing the concentration of SB. The results revealed that the marinade solution containing SB caused the dark-brown color of marinated goat meat. The shear force value of the marinated goat meat was slightly decreased with increasing concentrations of SB. The cooking loss and L* values of the cooked marinated goat meat in all the marinade solutions were significantly decreased ($P < 0.05$) when the concentration of SB was increased (Table 4). The highest cooking loss was observed in non-marinated sample, followed by the sample marinated in all the marinade solutions containing 0% SB. Cooking loss of marinated samples decreased with SB ($P < 0.05$). The lowest cooking loss was found in the sample marinated in ginger juice containing 5% SB. No significant differences in cooking loss were observed between the samples marinated in pineapple juice containing 3% and 5% SB. The goat meat marinated in ginger juice containing 5% SB had a significantly lower cooking loss ($P < 0.05$) compared to those of the samples marinated in ginger juice containing 1% and 3% SB.

The TPA of the cooked marinated goat meat is presented in Table 4. Marinating with all solutions decreased hardness and chewiness of cooked goat meat as compared to the non-marinated control sample ($P < 0.05$). The level of SB only in distilled water showed significantly effect on hardness and chewiness of cooked marinated goat meat. However, the lowest hardness and chewiness was observed in the sample marinated in both plant juices containing 5% SB when compared with the sample marinated in both plant juices containing 1% and 3% SB. This was probably because SB was able to maintain the water content of the marinated goat meat as indicated by the increase in marinade uptake after marination and the decrease in the cooking loss after cooking. The HCO^{3-} ions from SB might have been able to interact with the protein side chains of the meat muscle, leading to increases in the repulsive force among the meat proteins.The alkaline pH of SB can raise the pH away from the isoelectric point (pI) of the meat proteins thus increasing the negative charge of the protein, leading to an improved water-holding capacity in the marinated meat (Xiong 2012). The pI is defined as the pH where the net charge of the protein is zero (Yao et al. 1994). Moreover, SB has the ability to tenderize tough meat by generating carbon dioxide during cooking, which changes the meat structure and holds water by physical entrapment (Mudalal et al. 2014). In the present study, no significant differences in hardness or chewiness were observed between the cooked samples marinated in pineapple juice containing 5% and 3% SB. The lowest hardness was observed in the cooked samples marinated in pineapple and ginger juices containing 5% SB. The results indicate that SB has the potential to improve the texture of dairy-goat meat. However, the optimum levels of SB for pineapple-marinated goat meat and ginger-marinated goat

Table 4 Cooking loss, color (L*, a*, b*) and texture profile analysis after cooking of culled-dairy-goat meat samples marinated with plant juices and sodium bicarbonate for 60 min

Treatments		Cooking loss (%)	L*	a*	b*	Texture profile analysis			
Juice	SB (%)					Hardness (kg)	Springiness (cm)	Cohesiveness	Chewiness (kg cm)
Non-marinated		33.17 ± 1.88^{a}	60.21 ± 1.84^{a}	3.75 ± 0.40^{e}	16.78 ± 0.39^{bc}	17.32 ± 1.06^{a}	0.80 ± 0.05^{ab}	0.76 ± 0.02^{a}	9.64 ± 1.23^{a}
Distilled water	0	23.24 ± 0.88^{c}	52.99 ± 1.74^{c}	7.40 ± 0.90^{a}	19.07 ± 0.71^{a}	13.90 ± 2.01^{b}	0.79 ± 0.07^{ab}	0.77 ± 0.02^{a}	8.23 ± 1.35^{b}
	1	12.44 ± 1.61^{e}	49.51 ± 1.88^{e}	5.38 ± 1.15^{bcde}	14.69 ± 0.78^{d}	10.97 ± 1.52^{c}	0.83 ± 0.05^{ab}	0.77 ± 0.03^{a}	7.50 ± 1.40^{bc}
	3	8.78 ± 0.85^{fg}	46.82 ± 1.79^{fg}	7.34 ± 1.80^{a}	15.66 ± 0.75^{cd}	9.65 ± 1.13^{cd}	0.85 ± 0.06^{a}	0.77 ± 0.03^{a}	6.69 ± 1.77^{cd}
	5	8.06 ± 0.90^{fg}	49.16 ± 1.76^{e}	6.67 ± 1.67^{abc}	16.76 ± 0.80^{bc}	10.21 ± 0.71^{c}	0.88 ± 0.04^{a}	0.770.03^{a}	7.76 ± 1.21^{bc}
Pineapple juice	0	26.59 ± 1.20^{b}	55.84 ± 1.34^{b}	4.43 ± 0.21^{de}	15.24 ± 0.62^{d}	7.16 ± 2.67^{fg}	0.68 ± 0.15^{cd}	0.58 ± 0.06^{c}	3.03 ± 1.82^{gh}
	1	12.21 ± 0.60^{e}	51.59 ± 0.68^{cd}	4.17 ± 1.52^{e}	13.28 ± 1.61^{e}	6.87 ± 0.92^{fg}	0.66 ± 0.10^{cd}	0.55 ± 0.06^{c}	2.42 ± 0.90^{gh}
	3	7.73 ± 1.17^{g}	48.87 ± 1.54^{e}	6.61 ± 1.71^{abc}	14.95 ± 1.17^{d}	6.43 ± 0.52^{fg}	0.64 ± 0.16^{d}	0.56 ± 0.09^{c}	2.94 ± 1.60^{gh}
	5	7.38 ± 1.55^{g}	48.36 ± 0.46^{ef}	6.61 ± 1.21^{abc}	14.65 ± 1.12^{d}	5.54 ± 1.13^{g}	0.66 ± 0.18^{cd}	0.56 ± 0.09^{c}	2.08 ± 1.29^{h}
Ginger juice	0	20.39 ± 1.49^{d}	56.95 ± 1.95^{b}	5.12 ± 1.43^{cde}	17.80 ± 1.69^{ab}	7.70 ± 1.63^{ef}	0.74 ± 0.07^{bc}	0.65 ± 0.06^{c}	3.53 ± 1.04^{fg}
	1	9.72 ± 1.92^{f}	50.11 ± 1.75^{de}	6.07 ± 1.74^{abcd}	16.11 ± 1.66^{cd}	8.17 ± 0.56^{def}	0.80 ± 0.04^{ab}	0.70 ± 0.03^{b}	4.89 ± 1.27^{ef}
	3	7.53 ± 1.13^{g}	46.27 ± 0.96^{g}	5.16 ± 1.49^{cde}	15.25 ± 1.18^{d}	9.30 ± 1.32^{cde}	0.85 ± 0.08^{a}	0.69 ± 0.04^{bc}	5.43 ± 1.27^{de}
	5	4.03 ± 1.88^{h}	45.85 ± 1.19^{g}	7.09 ± 1.44^{ab}	15.49 ± 1.31^{cd}	7.61 ± 1.86^{ef}	0.88 ± 0.08^{a}	0.71 ± 0.03^{b}	4.76 ± 1.58^{ef}

$^{a–h}$Mean ± SD Different superscripts within the same column indicate a significant difference (P <0.05), *SB* sodium bicarbonate

meat were 3% and 5%, respectively, as indicated by the lowest hardness, chewiness and cooking loss.

Goat meat marinated in ginger juice containing SB at the same concentrations showed the higher marinade uptakes and lower cooking losses than goat meat marinated in pineapple juice. This was probably because the ginger juice had a higher pH (6.31 ± 0.01) than that of the pineapple juice (3.96 ± 0.01). The higher pH of ginger juice containing SB (pH of juice containing 0–5% SB = 6.31–8.04, pH of marinated meat = 5.63–8.12) was able to raise the pH away from the pI of the meat proteins more than the pineapple juice containing SB (pH of juice containing 0–5% SB = 3.96–7.56, pH of marinated meat = 5.34–7.39) leading to an increase in the ability of the ginger-marinated meat to retain water during cooking. Although the meat marinated in ginger juice containing SB had a high water-holding capacity, the meat marinated in pineapple juice containing SB showed lower hardness and chewiness than that of the meat marinated with ginger juice containing SB. As explained previously, the proteolysis in pineapple-marinated meat in the present study occurred by enhancing the proteolysis between the enzyme and the acid from the pineapple juice. For this reason, the structure of the pineapple-marinated meat had a lower ability to retain water during cooking. According to the results of Zochowska-Kujawska et al. (2013) dried wild boar meat sausage produced with pineapple juice presented a higher proteolysis index as compared to dried sausage produced with ginger juice leading to a decrease in the hardness and chewiness of the former sample during storage.

Effect of marination process on the quality of barbecued dairy goat

The different processes used in marinating the goat meat with SB before barbecuing it are shown in Table 1. The marinade uptake, color (L*, a*, b*) and shear force values of the marinated goat meat with the different processes are shown in Table 5. The results showed that marinating the goat meat with plant juices containing SB for 60 min then marinating it with a barbecue sauce for 60 min (P + SB3:BQ and G + SB5:BQ) produced a greater improvement in the marinade uptake than those in the other treatments (Table 5). The different processes used for marinating the goat meat with SB had no effect on the shear force value. Moreover, the samples marinated in plant juices containing SB for 60 min then marinated with a barbecue sauce for 60 min (P + SB3:BQ and G + SB5:BQ) had the lowest L* and b* values and thus a darker color as compared to the other samples. The lowest cooking loss was observed in the cooked goat meat marinated in plant juices for 60 min then marinated with a barbecue sauce containing SB for 60 min (P:BQ + SB3 and G:BQ + SB5) (Table 5). The lowest hardness was found in the cooked dairy-goat meat marinated in pineapple for 60 min and then marinated with a barbecue sauce containing 3% SB for 60 min (P:BQ + SB3) (Table 5).

The preliminary sensory evaluation results of the barbecued goat meat marinated with plant juices and SB are shown in Table 6. The barbecued pineapple-marinated goat meat scored higher on all the sensory attributes compared to those of the barbecued control and ginger-marinated goat meat. The pineapple juice and SB were able to improve the textural quality of the barbecued marinated goat meat. In particular, the barbecued pineapple-marinated goat meat was given the highest textural sensory score which was significantly higher ($P < 0.05$) than those of the barbecued non-marinated sample with SB (control) and the barbecued ginger-marinated goat meat sample. However, no significant differences were revealed in the textural sensory score between the barbecued ginger-marinated goat-meat sample and the control. Moreover, the barbecued ginger-marinated goat-meat sample obtained the lowest sensory score for flavor and overall preference when compared to those of the control and pineapple-marinated goat-meat samples. This was probably due to the unsuitably strong odor and flavor of the ginger juice in the final barbecued product. Nevertheless, the result of sensory score in this study obtained from only 30 untrained panelists, the consumer test with higher amount of panelists should be further evaluated to confirm the sensory result.

Conclusion

Plant juices and SB can be used to improve the textural quality and yield of dairy-goat meat. The dairy-goat meat marinated with pineapple juice for 60 min and then marinated with barbecue sauce containing 3% SB for 60 min had the lowest cooking loss and the highest sensory score for all attributes compared to those of the sample not marinated with plant juice and SB (control) and the ginger-marinated sample. Ginger juice was found to be unsuitable for marinating barbecued goat meat because of its strong odor and taste as witnessed by the barbecued ginger-marinated goat meat obtaining a lower consumer preference score when compared to the barbecued pineapple-marinated goat. Overall, however, the present study revealed that meat from culled dairy goats could be used as a meat raw material to produce marinated meat which would be acceptable to consumers and marination with pineapple juice and SB could lead to an increase in the value of meat from dairy goats. However, the sensory evaluation with more consumers should be further studied to confirm the utilization of barbecued culled-dairy-goat meat.

Table 5 The quality of marinated culled-dairy-goat meat samples with different processes

Parameters	Non-marinated	Distilled water	Pineapple juice				Ginger juice			
			Marinating process (Step1:Step2)				Marinating process (Step1:Step2)			
			P : BQ	P + SB3: BQ	P : BQ + SB3	P+BQ + SB3	G : BQ	G + SB5: BQ	G : BQ + SB5	G + BQ + SB5
After marinating										
Marinade uptake (%)	-	10.65 ± 1.10^{b}	8.08 ± 1.26^{d}	9.99 ± 1.99^{bc}	8.58 ± 1.11^{cd}	8.00 ± 0.74^{d}	10.11 ± 1.67^{b}	12.58 ± 1.78^{a}	11.51 ± 1.53^{ab}	8.29 ± 0.92^{d}
Color L*	40.94 ± 2.02^{b}	38.44 ± 1.46^{c}	38.09 ± 1.45^{c}	33.81 ± 1.60^{e}	35.69 ± 1.27^{d}	42.82 ± 1.62^{a}	40.95 ± 1.63^{b}	33.97 ± 1.96^{e}	36.74 ± 1.99^{cd}	41.96 ± 1.20^{ab}
a*	10.22 ± 1.62^{a}	8.20 ± 1.24^{b}	8.16 ± 1.13^{b}	8.10 ± 0.94^{b}	7.49 ± 1.92^{b}	7.87 ± 1.84^{b}	8.00 ± 0.94^{b}	7.96 ± 0.69^{b}	8.25 ± 1.27^{b}	7.32 ± 2.46^{b}
b*	13.15 ± 1.09^{bc}	14.39 ± 1.18^{ab}	14.42 ± 2.06^{ab}	12.61 ± 1.80^{c}	13.48 ± 1.05^{bc}	13.04 ± 0.84^{bc}	15.84 ± 1.53^{a}	12.31 ± 0.97^{c}	15.60 ± 1.23^{a}	12.84 ± 1.18^{c}
Shear force (kg)	5.97 ± 0.97^{abc}	4.70 ± 1.37^{bcd}	7.02 ± 2.35^{a}	3.59 ± 1.22^{d}	4.69 ± 1.92^{bcd}	4.23 ± 1.11^{cd}	6.45 ± 2.03^{ab}	4.34 ± 1.07^{bcd}	3.70 ± 2.66^{d}	3.49 ± 0.29^{d}
After cooking										
Cooking loss (%)	35.12 ± 2.25^{a}	24.26 ± 2.72^{b}	22.75 ± 1.22^{b}	11.37 ± 2.10^{d}	8.56 ± 1.87^{e}	13.36 ± 1.04^{d}	19.05 ± 2.70^{c}	6.63 ± 1.53^{e}	8.70 ± 1.47^{e}	13.21 ± 0.95^{d}
Color L*	53.16 ± 1.55^{a}	49.52 ± 2.88^{b}	54.54 ± 0.75^{a}	46.29 ± 1.20^{c}	49.07 ± 2.51^{b}	44.73 ± 1.74^{cd}	50.09 ± 2.69^{b}	43.45 ± 1.76^{de}	44.57 ± 1.39^{cd}	42.41 ± 1.42^{e}
a*	6.04 ± 1.24^{bc}	5.33 ± 0.52^{cde}	4.21 ± 0.48^{e}	4.25 ± 1.34^{e}	4.53 ± 2.02^{de}	6.88 ± 0.86^{ab}	5.96 ± 1.42^{bc}	5.51 ± 0.46^{cd}	4.54 ± 0.85^{de}	7.66 ± 0.95^{a}
b*	16.91 ± 1.36^{a}	16.14 ± 1.61^{ab}	14.67 ± 0.64^{c}	14.46 ± 1.35^{c}	13.87 ± 0.88^{cd}	14.26 ± ± ± 1.10^{c}	16.55 ± 0.96^{a}	16.02 ± 1.05^{ab}	15.00 ± 0.92^{bc}	13.10 ± 1.71^{d}
Texture profile analysis										
Hardness (kg)	11.75 ± 2.80^{a}	5.98 ± 2.19^{bcd}	5.26 ± 1.33^{bcd}	4.53 ± 0.78^{cd}	4.10 ± 0.96^{d}	5.30 ± 0.84^{bcd}	5.80 ± 1.17^{b}	6.80 ± 1.64^{bc}	6.33 ± 1.32^{bcd}	6.04 ± 0.94^{bcd}
Springiness (cm)	0.81 ± 0.07^{de}	0.81 ± 0.14^{bcd}	0.68 ± 0.11^{de}	0.75 ± 0.17^{cde}	0.64 ± 0.10^{e}	0.89 ± 0.07^{bcd}	0.79 ± 0.11^{abc}	0.87 ± 0.05^{ab}	0.89 ± 0.07^{ab}	0.96 ± 0.09^{a}
Cohesiveness	0.70 ± 0.05^{bcd}	0.68 ± 0.04^{abc}	0.55 ± 0.04^{d}	0.61 ± 0.07^{cd}	0.56 ± 0.07^{d}	0.67 ± 0.04^{abc}	0.67 ± 0.04^{ab}	0.71 ± 0.02^{ab}	0.70 ± 0.02^{abc}	0.74 ± 0.02^{a}
Chewiness (kg.cm)	5.39 ± 1.67^{a}	3.29 ± 1.20^{bcd}	1.99 ± 0.58^{ef}	2.06 ± 0.66^{ef}	1.53 ± ± ± 0.64^{f}	2.54 ± 0.75^{cde}	3.04 ± 0.76^{ab}	4.23 ± 1.30^{abc}	3.92 ± 0.94^{def}	3.31 ± 1.06^{bcd}

P pineapple juice, *G* ginger juice, *BQ* barbecue sauce, *SB3* 3% sodium bicarbonate, *SB5* 5% sodium bicarbonate

[a–f]Mean ± SD Different superscripts within the same row indicate a significant difference ($P < 0.05$)

Table 6 Sensory attributes of barbecued culled-dairy-goat meat

Treatments	Attributes				
(Step1:Step2)	Appearance	Color	Texture	Flavor	Overall acceptance
BQ (Control)	7.27 ± 1.10^{ab}	6.87 ± 1.30^{ab}	6.53 ± 1.30^{b}	7.33 ± 1.40^{a}	7.27 ± 1.10^{a}
P: BQ + SB3	7.33 ± 1.29^{a}	7.07 ± 1.58^{a}	7.87 ± 1.19^{a}	7.80 ± 1.15^{a}	7.80 ± 1.32^{a}
G: BQ + SB5	6.67 ± 1.18^{b}	6.20 ± 1.70^{b}	6.93 ± 1.16^{b}	4.93 ± 2.15^{b}	5.60 ± 1.88^{b}

BQ barbecue sauce, *P* pineapple juice, *G* ginger juice, *SB3* 3% sodium bicarbonate, *SB5* 5% sodium bicarbonate

[a-b]Mean ± SD Different superscripts within the same column indicate a significant difference ($P < 0.05$)

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Compliance with ethical standards

Conflict of interest We confirm that the manuscript has been read and approved by all the named authors. The authors declare that they have no conflicts of interest.

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