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Effects of low-temperature long-time cooking conditions on the quality of sous-vide cooked pork loin and ham

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Abstract The results revealed that the pH, a*b*C* color, and browning index (BI) of the sous-vide cooked meat were low. The L*h* color, cooking loss (CL), and longitudinal shrinkage (LS) were more prominent in the pork loin (*longissimus lumborum*, LL) samples. When loin and ham (*semimembranosus*, SM) were cooked at 67 ℃, they had exhibited the highest values of b*C*h* compared to other temperatures. The samples cooked at 63-67 ℃ had a greater shear force (WBSF) and work of shear (WS), similar to traditionally-cooked (TC) meat, indicating tougher meat. Almost all textural profile analyses (TPA) showed an interaction between muscle type and cooking temperature. The lowest values of hardness, springiness, gumminess, and chewiness values were observed in SM samples cooked at 55 ℃. It was concluded that the SM meat looked darker, had higher moisture and lower shrinkage than the LL samples. Lower-temperature sous-vide cooking helped to retain water and tenderize the pork.

Keywords: Sous-vide, Meat quality, Tenderness, Pork

Introduction

Sous-vide cooking is a method widely used to improve consumer preference for various food products. It involves vacuum-sealed raw food cooking in an immersion circulator water bath at regulated temperatures and times (Baldwin, 2012). Several pantries and cooks have implemented this method over the years (Myhrvold *et al*., 2011). As compared to the conventional method, this method can improve the physicochemical characteristics of meat (Ayub and Ahmad, 2019; Baldwin, 2012; Sánchez Del Pulgar *et al*., 2012; Ruiz-Carrascal *et al*., 2019). The increased consumption of pork over the past few decades has been attributed to the belief that it can help

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people improve their diet and achieve a healthier lifestyle. This has prompted the food industry to continuously develop new meat products (Resurreccion, 2004). The sous-vide method can help to reduce the time, it takes to prepare food and increase its convenience. It also has various benefits, such as its palatability and tenderness. In addition, it can retain nutrients and increase microbiological safety (Ohlsson, 2003; Baldwin, 2012; Phoemchalard *et al.*, 2021a, b). Although thermal denaturation of structural and sarcoplasmic proteins occurs during heat treatment, the rates and temperatures of this process vary. Protein neutralization is generally attributed to softening or toughening of meat during cooking (Martens *et al*., 1982). On the other hand, the continued tenderness of the flesh is usually attributed to collagen solubilization (Tornberg, 2005; Christensen *et al*., 2011). Furthermore, heating reduces sarcoplasmic and myofibrillar protein levels while increasing connective tissue and myofibrillar protein levels. This process can result in muscle atrophy as well as water loss (Baldwin, 2012).

Pork is a widely eaten meat product. However, different pork slices have differed in nutrient profiles. Ham cut from pork is quite protein-rich with low-fat content. In contrast, pork loin has a lower protein and higher fat content. Moreover, cooking pork traditionally yields a tougher product and substandard meat due to the fact heat causes coagulation of proteins in muscle tissues and contraction of collagen (Tokifuji *et al.*, 2013). Although it is common knowledge that pork tastes better when cooked in sous vide machine (Christensen *et al.*, 2011); it is not yet clear if the physical, chemical, and structural attributes of pork from the other breeds are changed by this process. The study aimed to investigate the quality of three-way crossbred pork meat prepared through sous vide cooking at temperatures of 55, 59, 63, or 67℃ for 12 h and compare it to traditional cooking (80℃ for 20 min).

Materials and methods

Experimental design

Four loin (*longissimus lumborum*, LL) and four ham (*semimembranosus*, SM) muscles of three-way crossbred pigs (Duroc × Landrace × Large White) were purchased 24 h post-mortem from a market in Nakhon Phanom province, Thailand (Lat. 13.8140°N, Long. 100.0373°E) in January 2022. Upon acquisition, the samples were boxed up, stored inside an ice bucket around 4 ℃, and accompanied to the lab for further examination. Before analysis, the meat was thoroughly stripped of fat and other excessive tissue. After that, the meat samples (LL and SM) were cut (1-inch-thick steak) and allocated into five categories: 4 slices for sous-vide (SV) cooking at temperatures of 55, 59, 63, and 67 ℃ for 12 h, and another one for traditional cooking (TC) at a temperature of 80 ℃ for 20 min. The experiment was done according to a 2 × 5 factorial arrangement in a completely randomized design. The 10 treatment combinations (n = 4) were as follows: (T1-T4) LL meat SV cooked at 55, 59, 63 and 67 ℃ for 12 h, (T5) LL meat TC cooked at 80 ℃ for 20 min, (T6-T9) SM meat SV cooked at 55, 59, 63 and 67 ℃ for 12 h, and (T10) SM meat TC cooked at 80 ℃ for 20 min, respectively. They were firstly weighted and analyzed for pH levels and color properties. For SV cooking, they were initially placed in a laminated low-density polyethylene (LLDPE) bag, vacuumed, and sealed using a DZ-500 Vacuum Packaging Machine (Sammi Packing Machine Ltd., China). Everything was then prepared using an 800 W immersion cooker (SVJ-1000, Sous-vide Precision Cooker, China). The sous-vide steps were performed by preheating, initial weighing, bagging the meat, vacuuming, heating, removing, keeping cold, and weighing (Phoemchalard *et al.*, 2021a, b). Finally, a total of 40 packages were chilled at 4 ℃ overnight, and the quality characteristics were evaluated.

pH and color measurement

The pH of fresh and cooked loin and ham were evaluated in triplicate utilizing a handheld pH meter and an FC2323 sensor (HI99163, Hanna Instruments, USA). In order to ensure that the pH probe was functioning correctly, it was first calibrated against known pH values. Then, the CIELAB scoring system was used to determine the various color attributes of pork loin and ham in quintuplicate. After white calibration, the instrumental color (CR-400, Konica Minolta Sensing Inc., Japan) was used to measure the various values of the samples, such as lightness (L*), redness (a*), and yellowness (b*). Finally, the index of browning (BI) (Mohammadi *et al.*, 2008) and the total color difference (ΔE) (AMSA, 2012) across groups were calculated using L*a*b* values.

Measurement of cooking loss and muscle shrinkage

The percentage of cooking loss (CL) obtained after cooking was computed by considering the product's pre- and post-processing proportions (Honikel, 1998). For muscle shrinkage, longitudinal shrinkage (LS) was processed by the uncooked-to-cooked length difference. At the same time, transverse shrinkage (TS) was obtained from the circumference difference between the uncooked (C_1) and cooked (C_2) samples (Becker *et al.*, 2016). These parameters were measured in triplicates.

Shear force and texture profile analysis

The procedures used to assess the shear force were recommended by the American Meat Science Association (AMSA, 2016). Before the samples were analyzed, they were initially placed in the refrigerator and chilled at 4 ℃. The measurements were subsequently evaluated at standard room temperature. A coring device was used to remove the round core of the samples. A Warner Bratzler V-blade set attached to the TA-XT *plus* Texture Analyzer (Stable Micro System Ltd., Surrey, UK) was determined the core's diameter, which was 1.27 cm. The shear force was evaluated by applying a force sensor with a capacity of 50 kg at 240 mm/min speed. Six repetitions were used to assess the peak force in kg/cm^2 and work of shear in kg.s.

The machine was equipped with a P/50 cylindric probe, which allowed it to perform TPA. The meat was cut into 1 cm^3 and the characteristics of the finished product were analyzed in three replicates. The cooked meat was crushed twice at a pace of 60 mm/min, reducing its height by 75% following the technique developed by Bourne (1978). Hardness, stickiness, gumminess, cohesion, chewiness and springiness were determined by exponent software, version 6.1.16.0.

Statistical analysis

Data on the physicochemical properties of pork loin and ham cooked at different low temperatures (55, 59, 63, and 67 ℃) for a single longer duration (12 h) compared to the conventional method of cooking (80 ℃ for 20 min) were analyzed using two-way ANOVA using STAR 2.0.1 software (IRRI, Philippines) (Gulles *et al.*, 2014). Data were presented as least square means. Duncan's Multiple Range Test was determined whether the two groups had statistically significant differed ($P<0.05$). Free MetaboAnalyst version 5.0 web application interface (https://www.Metaboanalyst.ca) (Chong *et al.*, 2019) was transferred and evaluated the data. Pareto scaling, multivariate analysis of principal component (PCA), Venn diagram, and hierarchical clustering and heatmap visualization were employed.

Results

The changes in the pH, color, color differences, and browning index of pork loin and ham following conventional cooking (80 ℃ for 20 minutes) were shown in Table 1. The results revealed no interactions between muscle type and the cooking temperature (P>0.05). In comparison to fresh meat, the pH levels of all cooked treatments were found to be high (P<0.05), with SM exhibiting a higher pH than LL. However, the cooking conditions did not have any impact on the pH levels of the treatments. Both fresh pork colors (a* and C*) and cooked pork colors (a*, b*, C*, and BI) were observed to be higher SM than in LL meat. The L* values were found to be higher in fresh and cooked LL meat compared to SM meat (P<0.05). All cooking treatments had significantly higher b*C*h* values than the control (P<0.05), with the highest values observed when cooked at 67 ℃. However, no discernible differences in total color differences were observed when the sous-vide cooking method was employed.

The cooking loss, muscle shrinkage, and shear values of sous-vide ham and pork loin was displayed in Table 2. There was no significant interaction between any of the parameters. The cooking loss and longitudinal shrinkage were higher in LL compared to SM meat (31.60 vs 26.14%) and (28.35 vs 14.76%) respectively (P<0.05). The percentages of water loss at 63 ℃ (30.72) and 67 ℃ (32.89) were higher than at 55 ℃ (22.41) and 59 ℃ (26.98) and similar to TC (31.35%). The water evaporation rate significantly increased (R^2 = 0.79, P<0.01) with an increase in the temperature (Figure 1A). Transverse shrinkage, shear force, and shear work had no effect on muscle; however, cooking at 67 ℃ resulted to higher shear force (5.84 kg/cm^2) and shear work (13.16 kg.s) compared to traditional cooking (6.13 kg/cm^2 and 13.21 kg.s, P<0.05). When pork was sous-vide cooked at 55, 59, 63 and 67 ℃ for 12 h, the shear force reduced by 44.94, 38.44, 26.80 and 4.78%, and shear work was reduced by 45.68, 38.04, 25.99 and 0.38%, respectively as compared to TC.

The majority of textural indices were significantly lower in the samples cooked at 55 ℃ for 12 h (P<0.05) as shown in Table 3. In addition, interaction effects of muscles and temperature on hardness, adhesiveness, springiness, gumminess and chewiness were found (P<0.05). The cooked SM samples at 55 ℃ were shown to be the most tender compared to other treatments due to the lower textural profile parameters (P<0.05). On the other hand, the toughness of the meat significantly increased (R^2 = 0.95, P<0.001) with an increase in temperature (Figure 1B).

The PCA results of sous-vide pork loin and ham cooked at 55, 59, 63, and 67 ℃ for 12 h compared to the traditional cooking (80 ℃ for 20 min) was shown in Figure 2. According to the 3D PCA analysis, the first two PCs accounted for approximately 94% of the standard variation. The PCA results exhibited that SM meat (upper green) was considered independently of LL meat (lower red) after sous-vide cooking. However, PCA was unable to effectively differentiate the unique cooking temperatures.

A venn diagram of a two-way ANOVA results of sous-vide prepared pork loin and ham at the various temperatures for 12 h compared to the traditional cooking was explained in Figure 3. A venn diagram is a visual portrayal that utilizes circles to demonstrate relationships between various items or restricted sets of things. Circles overlap share specific qualities, while circles that do not overlap do not share those qualities. Out of the 26 elements in the present work, either muscle, cooking temperature, or both at the same time caused an overlap of 17 highlights. The following 6 parameters were measured at several locations: cooking loss was measured on the plane for muscle and temperature, springiness was measured on the plane for muscle and interaction, and other four parameters (adhesiveness, gumminess, hardness, and chewiness) were measured on each of the three platforms. As a result, 11 distinct variables were quantified on at least one platform. Muscle included springiness, longitudinal shrinkage, browning index, a*, L* and pH, while temperature covered C*, b*, shear work, resilience, and shear force.

The hierarchical clustering and heatmap display of a two-way ANOVA findings of pork loin and ham SV-cooked at various temperatures for 12 h compared to traditional cooking (80 ℃ for 20 min) was presented in Figure 4. Muscle types exhibited positive relationship with pH (r = 0.72), a* (r = 0.67), b* (r = 0.47), C*(r = 0.58), and browning index (r = 0.66), while L* (r = -0.68), h* (r = 0.-0.54), cooking loss (r = -0.49), and longitudinal shrinkage (r = -0.56) showed opposite results ($P<0.05$). Cooking loss (r = 0.50), shear force (r = 0.63), shear work (r = 0.58), hardness (r = 0.55), springiness (r = 0.45), gumminess (r = 0.59), chewiness (r = 0.57), and resilience (r = 0.65) were positively correlated with cooking temperatures ($P<0.05$). Additionally, pH was correlated with all color parameter (r = -0.49-0.70), cooking loss (r = -0.58), and longitudinal shrinkage (r = 0.-0.37). The cooking loss was positively associated with shear force (r = 0.52), shear work (r = 0.43), hardness (r = 0.65), springiness (r = 0.50), gumminess (r = 0.0.63) and chewiness (r = 0.57).

Table 1. pH, color, and color index of sous-vide cooked pork loin and ham

Items	*Muscle types (M)*		*Cooking temperature (T)*					*Significance*		
	LL	SM	55 ℃	59 ℃	63 ℃	67 ℃	TC	M	T	M×T
Fresh pork (24 h p.m.)										
pH_{24}	5.33[b]	5.74[a]	5.52	5.53	5.52	5.54	5.56	<0.001	0.997	0.999
L*	54.18[a]	46.55[b]	49.03	50.40	50.94	50.97	50.48	<0.001	0.945	0.932
a*	4.51[b]	7.46[a]	6.37	5.77	5.40	5.67	6.74	<0.001	0.661	0.841
b*	4.77	5.01	4.89	4.75	4.79	4.76	5.24	0.605	0.955	0.973
C*	6.68[b]	8.63[a]	8.18	7.59	7.38	7.57	7.55	0.019	0.973	0.871
h*	49.14[a]	33.63[b]	39.85	41.48	42.52	42.47	40.61	0.001	0.990	0.976
SV-cooked pork										
pH_{cooked}	5.71[b]	6.13[a]	5.89	5.91	5.93	5.96	5.91	<0.001	0.988	0.979
L*	71.44[a]	64.95[b]	68.51	68.29	68.81	67.28	68.07	<0.001	0.944	0.168
a*	6.77[b]	9.60[a]	9.03	8.57	7.87	8.39	7.07	<0.001	0.198	0.562
b*	15.19[b]	17.35[a]	15.39[b]	16.37[b]	16.69[b]	18.94[a]	13.95[c]	<0.001	<0.001	0.151
C*	16.66[b]	19.87[a]	17.88[b]	18.49[b]	18.48[b]	20.79[a]	15.68[c]	<0.001	<0.001	0.386
h*	65.89[a]	61.15[b]	59.84[c]	62.53[bc]	65.00[ab]	66.54[a]	63.68[ab]	<0.001	0.006	0.318
ΔE	20.58	22.50	22.05	19.92	21.64	21.67	22.42	0.256	0.896	0.912
BI	15.15[b]	22.75[a]	17.82	21.12	17.47	18.19	20.13	<0.001	0.496	0.563

[a–c] Means with various superscripts are different (P<0.05), LL: *Longissimus lumborum*; SM: *Semimembranosus*; TC: traditional cooking; ΔE: total color differences; BI: browning index.

Table 2. Cooking loss, meat shrinkage, shear force, and shear work of sous-vide cooked pork loin and ham

Items	*Muscle types (M)*		*Cooking temperature (T)*					*Significance*		
	LL	SM	55 ℃	59 ℃	63 ℃	67 ℃	TC	M	T	M×T
Cooking loss (%)	31.60[a]	26.14[b]	22.41[c]	26.98[b]	30.72[a]	32.89[a]	31.35[a]	<0.001	<0.001	0.081
Transversal shrinkage (%)	19.74	17.53	19.92	14.93	17.54	23.16	17.64	0.539	0.662	0.911
Longitudinal shrinkage (%)	28.35[a]	14.76[b]	26.67	21.26	16.18	20.77	22.90	0.000	0.404	0.129
Shear force (kg/cm^2)	4.52	4.92	3.37[c]	3.77[c]	4.49[bc]	5.84[ab]	6.13[a]	0.344	0.001	0.545
Shear work (kg.s)	9.40	11.19	7.17[b]	8.18[b]	9.77[ab]	13.16[a]	13.21[a]	0.090	0.002	0.531

[a–c] Means with various superscripts are different (P<0.05), LL: *Longissimus lumborum*; SM: *Semimembranosus*; TC: traditional cooking.

Table 3. Texture profile analysis (TPA) of sous-vide cooked pork loin and ham

Items	Hardness (g)	Adhesiveness (g.s)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
LL*55 ℃	753.33[cd]	-29.93[b]	0.11[ab]	0.70	523.07[cd]	57.26[cd]	0.24[cd]
LL*59 ℃	777.81[cd]	-6.19[a]	0.10[ab]	0.65	516.55[cd]	58.06[cd]	0.23[d]
LL*63 ℃	1,015.98[bc]	-6.59[a]	0.11[ab]	0.66	668.79[bc]	74.13[bc]	0.24[cd]
LL*67 ℃	1,623.65[a]	-4.53[a]	0.12[a]	0.64	1,040.16[a]	127.91[a]	0.23[d]
LL*TC	991.81[bc]	-6.69[a]	0.10[ab]	0.74	721.00[bc]	79.33[bc]	0.29[ab]
SM*55 ℃	253.76[e]	-8.05[a]	0.08[c]	0.68	170.78[e]	13.84[e]	0.24[cd]
SM*59 ℃	602.12[d]	-9.23[a]	0.09[b]	0.69	412.66[d]	38.57[de]	0.26[cd]
SM*63 ℃	1,248.96[b]	-4.734[a]	0.11[a]	0.70	874.05[ab]	99.19[ab]	0.27[bc]
SM*67 ℃	1,231.34[b]	-5.320[a]	0.11[a]	0.65	792.55[b]	90.33[bc]	0.24[cd]
SM*TC	1,258.68[b]	-13.33[a]	0.12[a]	0.69	863.50[ab]	102.48[ab]	0.31[a]
Significance							
M	0.117	0.262	0.055	0.945	0.146	0.146	0.007
T	<0.001	0.005	0.001	0.064	<0.001	<0.001	<0.001
M*T	0.004	0.006	0.009	0.214	0.004	0.008	0.401

[a–d] Means with various superscripts are different ($P<0.05$), LL: *Longissimus lumborum*; SM: *Semimembranosus*; TC: traditional cooking.

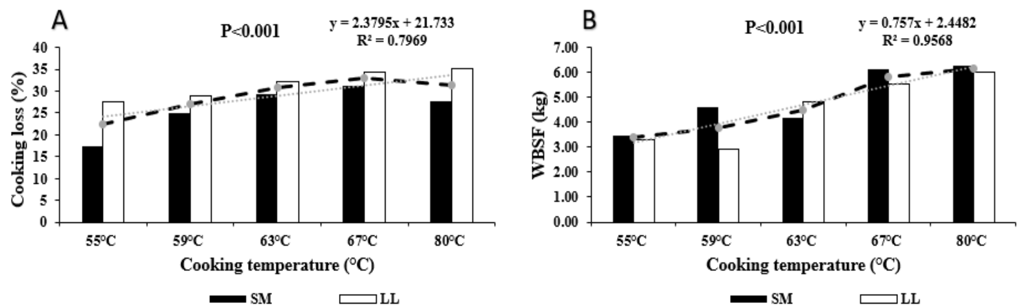

Figure 1. Graph plots of cooking loss (A) and shear force (B) of sous-vide cooked pork loin and ham

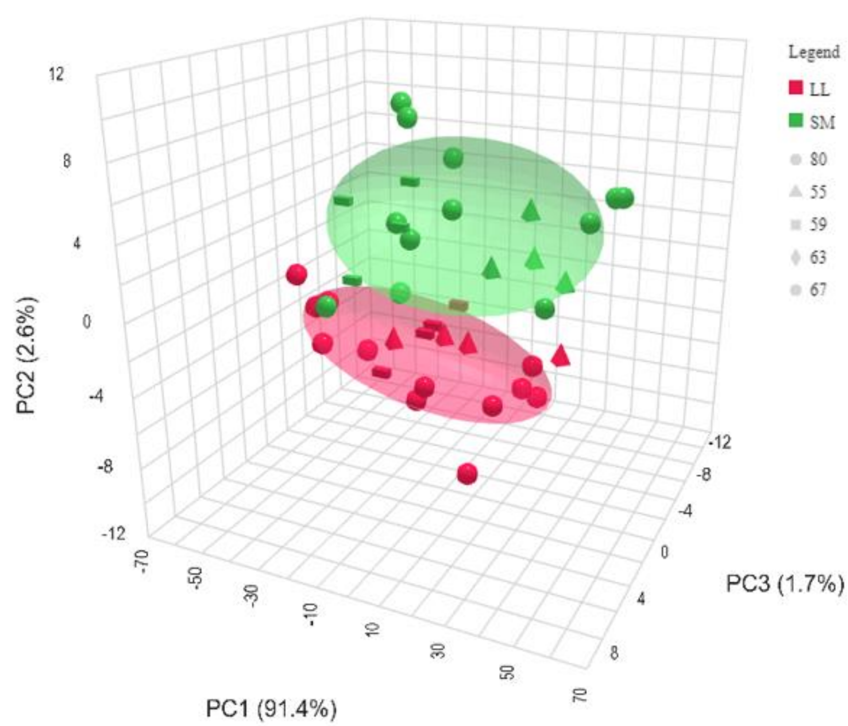

Figure 2. Principal component analysis (PCA) of sous-vide cooked pork loin and ham at 55, 59, 63, and 67 ℃ for 12 h compared to the traditional cooking (80 ℃ for 20 min)

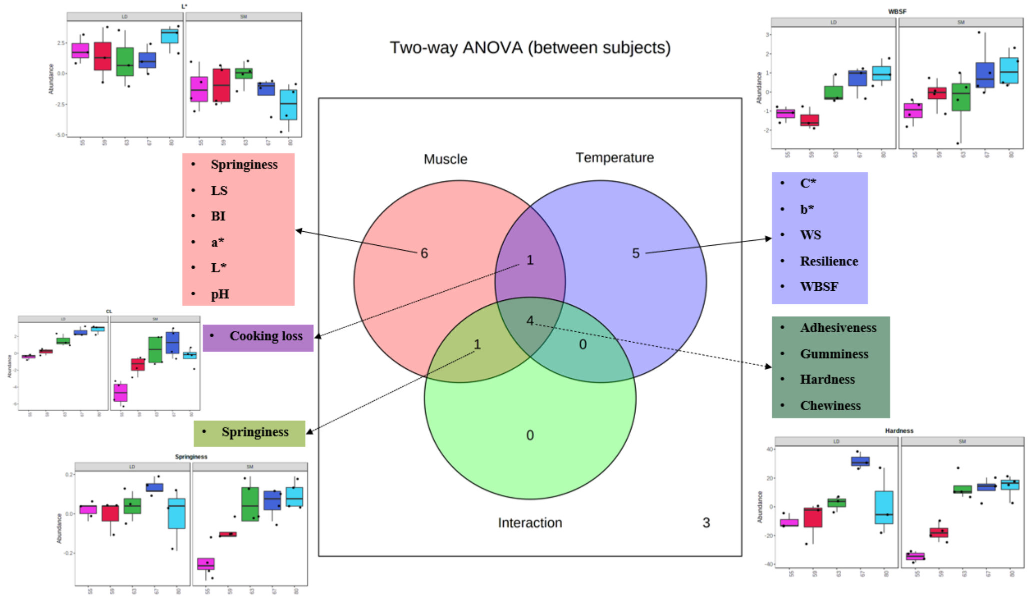

Figure 3. Venn diagram summary of two-way ANOVA results of sous-vide cooked pork loin and ham at 55, 59, 63, and 67 ℃ for 12 h compared to traditional cooking (80 ℃ for 20 min)

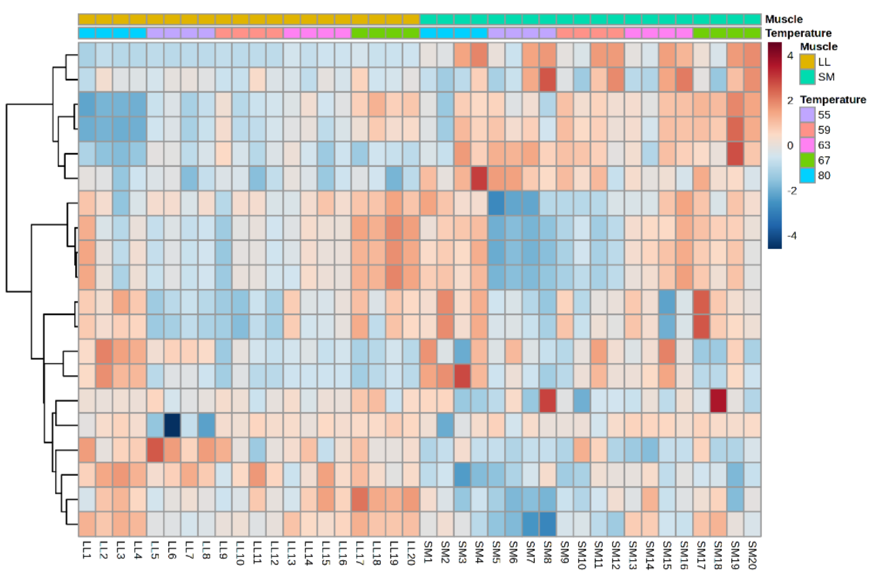

Figure 4. Hierarchical clustering and heatmap visualization of two-way ANOVA results of pork loin and ham SV-cooked at 55, 59, 63, and 67 ℃ for 12 h compared to traditional cooking (80 ℃ for 20 min)

Discussion

Generally, heating raises the pH of meat as a result of structural changes in the proteins (Hamm and Deatherage, 1960). According to a study (Lawrie, 1998), the pH of cooked red meat increased as a result of the loss of acidic amino groups and protein denaturation. In comparison to the present results, only the pH of muscles was affected. The pH of pork loin and ham cooked at different temperatures was not statistically different. This result was different to a previous research which found that the pH of cooked treatment was altered by cooking conditions (Hwang *et al.*, 2019).

Sous-vide cooking usually has a larger L* and a smaller a* as temperature increases (Sánchez del Pulgar *et al.*, 2012; Hwang *et al.*, 2019). However, all the cooked samples in the present work exhibited higher L*, a*, b*, C*, and h* compared to fresh pork. Heating and time did not affect L* and BI values among all treatments. It was shown that LL meat had a higher L* but a lower BI than SM meat. As a result, the SM meat reached a darker color faster than the LL meat. The high BI caused by the oxidation of myoglobin during cooking may be explained by the significantly higher heme iron content of SM meat compared to LD meat (Hunt *et al.*, 1999). The results of this experiment agreed with those of Christensen *et al.* (2011), who discovered that increasing cooking temperature yielded higher L* values. In terms of the "cooking factor", the L* colors in this study were very similar. Cooking causes myoglobin to denature, resulting in a loss of a* at temperatures above 60 ℃. This study found similar a* values throughout all the temperatures, with LL and SM a* values differing slightly. Changes in a* and b* colors can be explained by the heat denaturation of metmyoglobin, which also leads to an increase in the production of the dark brown color (Roldán *et al.*, 2013). The concentration of myoglobin is associated with C* or meat shade saturation. Cooking traditionally produced lower C* values compared to sous-vide cooking, which had higher C* values. Possible explanations include different lengths of time involved. In this investigation, samples cooked at 67 ℃ had the most intense color hue; however, the values were comparable to those at cooked at 63 and 80 ℃. There has been some debate about whether or not the color changes that occur as a result of prolonged heating or cooking using a sous-vide method are helpful (Becker *et al.*, 2015).

Heating meat reduces its water content because muscle fiber bundles contract, allowing the water to drain from the meat (Sims and Bailey, 1992). Moreover, three fundamental approaches result in water loss in cooked meat, an increase in temperature causes water to evaporate, myofibrillar proteins decreasing as cooking temperatures rise impacts the myofibril's potential to save water, and the perimysium contraction facilitates water loss from the cuts (Martens *et al.*, 1982). In this study, loin cooking loss was higher than ham, and it increased with an increase in temperature. Cooking at 63 and 67 ℃ resulted in the same cooking loss as traditional cooking. Compared to samples cooked at higher temperatures, Phoemchalard *et al.* (2021a, b) and Becker *et al.* (2015) found that meats were slow-cooked at moderate temperatures exhibited less cooking loss. However, at higher temperatures, the cooking loss was similar to that of traditional cooking. Other results of higher cooking loss are described by Supaphon *et al.* (2021), who found that sous-vide cooking meat samples damaged some mitochondria, leading to hypercontraction and myofiber rumpling and musculature size reduction.

Longitudinal shrinkage in this study was affected by muscles rather than cooking temperatures. This was contrary to earlier research where the LS of TC-cooked meat decreased after heating (Becker *et al.*, 2016; Phoemchalard *et al.*, 2021b). The result contradicted the findings in buffalo meats, where LS remained constant with an increase in temperature (Phoemchalard *et al.*, 2021b). Becker noted that the TS content of muscle fiber was highest at temperatures below 60 ℃, while heat between 60 ℃ and 90 ℃ affected the LS of muscle fiber. However, neither muscles nor cooking temperatures affected the TS in this study. This finding contradicted with that of Becker and colleagues who observed that TS of pork increased with an increase the temperature (Becker *et al.*, 2016). The slightly higher TS was particularly noticeable in samples subjected to two temperatures and traditional cooking (Phoemchalard *et al*., 2021a).

Shear force is an important indicator and potentially one of the essential qualities of meat products, with small shear force scores in meat being preferred. This study observed an increase in shear force values when cooking temperatures were raised from 55 to 67 ℃. It was found that the samples cooked at 67 ℃ and TC treatments had the highest values. This was similar to the results of buffalo meat, in which an increase in cooking heat increased the shear force (Phoemchalard *et al.*, 2021b). Moreover, pigs and sows exposed to temperatures between 48 and 63 ℃ for 0 to 17 hours had lower shear force (Christensen *et al*., 2011). Previous studies of shear force in pigs showed that Pakchong 5 and their crossbreds had significantly greater average shear forces (6.35 kg/cm^2) (Lertpatarakomol *et al.*, 2019) than those seen in the present study, while crossbred Landrace × Large White pigs had significantly lower average shear forces (2.4 kg/cm^2) (Pornanek and Phoemchalard, 2020). A study by Lertpatarakomol *et al*. (2019) found that meat tenderness may be impacted by underlying differences in muscle ultrastructure. Their findings suggested that longer sarcomeres and larger fiber diameter could contribute to greater toughness in pork meat.

On the other hand, the temperature dependence of shear force was actually caused by heating and breakdown of the formation of connective tissues (Tornberg, 2005; Baldwin, 2012) and myofibrillar arrangement (Palka and Daun, 1999; Vaudagna *et al*., 2002). The findings of Ismail and his colleagues were compared to the shear force value of the sample cooked at 45 ℃ which was much lower than cooked at 65 ℃ or by traditional cooking (Ismail *et al.*, 2019).

Toughness (shear work) in meat is measured by how well the meat can withstand an external force being applied to it. It was found that samples cooked at 55 ℃ and 59 ℃ had lower toughness values than those cooked at 63 ℃, 67 ℃, and traditional cooking. These findings were in line with those of Phoemchalard *et al*. (2019) and Phoemchalard *et al*. (2021a), in that the 55 ℃ and 59 ℃ treatments were tougher than the ones cooked at higher-temperatures or traditionally.

Most textural parameters, particularly hardness, had lower values for the 55 ℃/12h cooked samples compared to the other samples. Sous-vide cooked pork results agreed with this assessment compared to traditionally cooked samples (Jeong *et al*., 2018). The tenderness and moisture of sous vide cooked meat is affected by how much protein is broken down, how the structure of myofibrils and connective tissue changes, and how active enzymes are (Hwang *et al*., 2019).

The PCA reduces the dimensionality of feature sets, thereby improving readability while lowering data loss. In addition, it creates nonstationary factors that optimize variability (Jolliffe, 2002). The recent study found that PCA differentiated two muscles (SM and LL) after cooking sous-vide. However, PCA could not distinguish pork samples cooked at slightly varied temperatures. In contrast, PCA of cooked sous-vide mackerel revealed temperature-dependent clustering, indicating that cooking temperature was a major factor influencing quality changes (Cropotova *et al*., 2019). Together, the PCA applications demonstrated the technique's utility for elucidating how sous-vide cooking influenced quality attributes in different meats.

In conclusion, the comparison to conventional cooking method, sous-vide cooking pork loin and ham for 12 hours at 55, 59, 63, and 67 ℃ affected the quality of the meat. Almost all texture measures were enhanced by the combination of low heat and extended time, but hardness, gumminess, and chewiness values stood out as the most notable changes. The L*, h*, cooking loss, and longitudinal shrinkage values of SM meat were lower than those of LL meat. All values of cooking loss, shear force, b* C*, and h* colors increased with an increase in temperature. As a result, it suggested that cooking pork at 55 or 59 ℃ would be reached high quality of the meat. Therefore, this study indicated that sous-vide was the best cooking method for tenderizing pork loin and ham.

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