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Sous-vide meat properties as a function of physical and surface changes during processing

Natthaporn Chotigavin[1], William L Kerr[2], Wanwimol Klaypradit[3] and Soraya Kerdpiboon[1,*]

[1]Agro-Industry Division, School of Food Industry, Faculty of Food Industry, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
[2]Department of Food Science and Technology, University of Georgia, Georgia, USA
[3]Department of Fishery Products, Faculty of Fisheries, Kasetsart University, Bangkok, Thailand
[*]Corresponding author: soraya.ke@kmitl.ac.th

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Abstract

Sous-vide is a method of cooking of vacuum-packed samples at relatively low temperature for longer periods than practiced with conventional cooking. Sous-vide is applicable to a wide variety of foods, and optimized sous-vide processing of meat can result in more tender products with less cooking loss. In this study, chicken breast and Thai local beef round were compared under sous-vide (vacuum-packaged and cooked at 60 to 80 °C for 1 to 7.5 h) and traditional cooking temperatures. The physical properties and surface texture of meat during sous-vide cooking were determined. It was found that the L^* (lightness) and a^* (redness) of cooked chicken breast were not affected by cooking temperatures or times (p >0.05), while the color of cooked beef depended on both temperature and time (p ≤0.05). It was found that cooking at higher temperature and for longer time resulted in meat with lower cooking yield and higher sous-vide loss, but with less re-heating loss (p ≤0.05). These results were supplemented with surface texture images which showed that larger spaces developed between the fibers after cooking at higher temperatures for longer time than those for samples cooked by sous-vide. Sous-vide chicken breast cooked at 60 °C for 2 h and 80 °C for 0.5 h, as well as beef cooked at 60 °C for 2.5 h and 80 °C for 2 h, were the most tender as measured by the lowest shear force values.

Keywords: Cooking, Chicken breast, Local beef, Physical properties, Sous-vide

1. Introduction

The increase in consumer demand for high-quality foods, including a diversity of meat products, has contributed to the development of a variety of new technologies to improve meat quality [1]. Using low temperature cooking is one method to maintain juiciness, optimize flavor and color and maximize nutrient levels, while reducing the level of lipid deterioration and protein damage seen with traditional cooking methods [2-3]. Sous-vide cooking is one such approach in which food samples are heated at temperatures below 100 °C for relatively long times, typically in glass or plastic pouches under vacuum [3]. For sous-vide meat processing, the cooking temperature is typically in the range of 55-80 °C for a long time (up to 72 h) depending on the types and sizes of meat [2]. Vacuum-sealing the meat is beneficial as it helps promote efficient heat transfer from the water to the food. A vacuum environment also inhibits off-flavors from oxidation and prevents evaporative losses of flavor volatiles, nutrients and moisture during cooking and increases the food's shelf-life by eliminating the risk of recontamination during storage [4]. If not immediately consumed, the products may be stored for up to 10 days if pasteurized at 70 °C for 2 min which is sufficient to attain a 6 log reduction of *Listeria monocytogenes*. Overall, the low oxygen condition prevents the growth of aerobic spoilage micro-organisms. However, anaerobic bacteria in sous-vide packages, such as *Clostridium perfringens*, are a serious threat as they produce spores and are heat resistant psychrotolerant obligate anaerobes. However, sous-vide cooking at 55 °C for 300 min, as well as 60 °C and 70 °C for 60 min, can achieve 6 log reduction of *C. perfringens* in meat [5].

Consumers in Thailand consume a variety of meats, especially chicken, pork and beef. High-protein and low-fat local beef and skinless chicken provides consumers with a healthier choice compared to higher fat cuts of meat. Chicken breast in particular can provide a high amount of protein with low levels of fat, although beef can deliver high quality protein and other nutrients. Beef is also a major source of high-quality proteins for human. In addition to the B vitamins, especially B2 and B12, the heme protein prevalent in red meat myoglobin contains iron and serves as a major contributor to dietary requirements for iron in all age groups [6]. Locally produced beef is an attractive source for cooked and value-added meat products as it is rich in nutrients and lower in price compared to imported beef and cattle. However, the texture of local beef is often tough due to lower fat content [7]. Semitendinosus cuts have some 2-3% fat and are relatively tough compared to other beef muscles [8]. This might limit the consumption of local beef by children and elderly persons with chewing difficulties. Research has shown that sous-vide processing can improve the quality of local Thai beef by decreasing toughness, firmness and the amount of weight loss during cooking [9].

The interest in and consumption of poultry, including chicken breast with low fat but high protein content, has increased. However, comparison of quality changes in different meat materials is still limited. While a few studies exist on changes in red meats, there has been limited work on sous-vide cooking of poultry. It has been shown that sous-vide cooking results in soft and moist chicken breast [10]. Thus, it would be interesting to compare meat and poultry products to understand if similar mechanisms are behind the changes witnessed during high-temperature or sous vide cooking.

One of the critical quality attributes in muscle foods is texture, and modifications in texture during heating are a result of complex physical and structural changes. The texture of meat can be related to the structuring of myofibrillar (50-55%), sarcoplasmic (30-34%) and connective tissue (10-15%) proteins. The relative amounts and interconnectivity of these components depends on the animal species, age and sex [3,11]. Moreover, heat treatments induce changes in meat texture. During cooking, heat causes denaturation and shrinkage of myofibrillar proteins associated with meat toughness and gel formation of sarcoplasmic proteins. In addition, shrinkage and solubilization of connective tissue, especially the collagen component, helps increase meat tenderness [12-13]. Even if the content and cross linking of collagen is relatively low, as in chicken breast, it can still have a significant effect on meat tenderness [14]. Moreover, low temperature cooking, as used in sous-vide, can help extend the action of proteolytic enzymes and cause a synergistic effect on tenderness [11,15]. Studies on meat proteins have shown that at 65 °C, sarcoplasmic proteins form a gel which makes the meat more tender. However, at temperatures above 65 °C changes in elasticity cause the meat to become tougher [13]. In addition, it has been found that at 50 to 60 °C, there is a critical reduction in muscle fiber diameter [16]. Transversal shrinkage of the myofibrils relates to the water lost during cooking. At temperatures above 60 °C, shrinkage occurred both in diameter and in the longitudinal axis. This indicates that the denaturation of myofibrillar proteins and connective tissue upon cooking largely affects the changes in meat texture [17].

The temperature and duration of cooking largely determines the quality and physical properties of meat [18]. While many consumers prefer more tender meat, the ability to create more tender muscle food products may be of great benefit for elderly populations in upcoming Thai society. Thus, production of soft texture meat from chicken and local beef using sous vide processing could be very beneficial, particularly as it does not require salt, phosphates or other additives. However, the properties of meat that are most changed during cooking often include cooking yield, weight loss, color, and texture. To better study the textural and surface characteristics of meat, digital imaging was used to follow changes in the muscle fiber surface. This research was conducted to study meat and poultry properties in terms of physical and structural characteristics during different sous-vide cooking times.

2. Materials and methods

2.1 Meat preparation

Local beef and chicken breast were used as raw materials. Beef round muscle was attained at 24 h postmortem from 18 month old Thai local beef animals (*Bos indicus*) weighing 200-250 kg, and purchased from Huatakhe market in Bangkok province, Thailand. Samples that retained blood were blotted dry with tissue paper before being trimmed of excess fat and connective tissue. Cuts of meat were sliced into $2\times4\times2$ cm^3 pieces weighing ~15-20 g, while carefully noting the fiber direction. The pH value of the raw samples at 24 h postmortem was 5.38 ± 0.07. The chicken breast fillets were purchased from the factory at 24 h postmortem. The fillets were skinless and cut into the same size as the beef pieces. Samples were vacuum-packed in laminated low density polyethylene (LLDPE) pouches by using a vacuum packaging machine (DZQ-500B, China) and cooked under various conditions.

2.2 *Sous-vide cooking process*

Sous-vide cooking was carried out in a WNB14 water bath (Memmert, Germany) at temperatures of 60 or 80 °C from 0 to 7.5 h. Heat was supplied such that the cold point of the sample reached 60 °C for 15 min or 80 °C for 11 min. Samples were taken every 30 min so as to measure various physical properties. After cooking, the samples were rapidly cooled in ice water to below 4 °C for 1 h and then kept at room temperature (28 °C) for 30 min until property measurements. Each treatment was replicated three times.

2.3 *Color measurement*

The color was measured across the cut surface of the sous-vide cooked samples at room temperature (25 °C). L^* value (lightness), a^* value (redness) and b^* value (yellowness) were measured using a Minolta Colorimeter (CR400, Japan) equipped with a standard illuminant D65. The mean values from readings at three locations in each sample were determined. The colorimeter was standardized before use with a white ceramic tile. In each condition, the meat was a longitudinal section and the color of each side of meat was measured at 3 positions. Experiments were done in 2 replicates. The data were expressed in terms of L^*, a^* and b^*.

2.4 *Cooking yield and loss*

The cooking yield was calculated from the mass difference before and after sous-vide cooking. The percent cooking yield was calculated using:

$$\%\ Cooking\ yield = \frac{(w_2)}{w_1} \times 100 \tag{1}$$

where w_1 is the mass (g) of the sample before and w_2 is the mass of the sample after sous-vide cooking (g). The percentage of sous-vide cooking loss was calculated using equation (2):

$$\%\ Cooking\ loss = \frac{(w_1 - w_2)}{w_1} \times 100 \tag{2}$$

where w_1 is the weight of the sample before sous-vide cooking (g) and w_2 is the weight of the sample after sous-vide cooking (g).

2.5 *Reheating loss*

Sous-vide foods are also useful for the large-scale commercial food industry, where they can be precooked then quickly reheated for immediate service. The method described by [19] for process simulation. Sous-vide cooked samples were packed in polyethylene bags and heated at 75 °C for 30 min in a water bath. Samples were then removed from the water-bath and rapidly cooled in ice water to below 4 °C for 30 min until the temperature was ~28 °C. Reheating loss was determined by weighing the sample before and after reheating:

$$\%\ Reheating\ loss = \frac{(w_c - w_r)}{w_c} \times 100 \tag{3}$$

where w_c is weight of sample sous-vide cooking (g) and w_r is the weight of the sample after reheating (g).

2.6 *Shear force*

Sample tenderness was assessed by shear force measurements using a texture analyzer (TA-XT plus, England). Cooked muscles were cut into 3×1×1 cm^3 pieces and shear force was performed using a Warner-Bratzler blade [19]. The blade cut the sample at 1 mm/s and the force recorded with a 50 kg load cell. The shear force was determined as the maximum force (N) required to slice perpendicularly across the muscle fibers. Three replicates were performed for each cooking condition.

2.7 *Surface texture imaging*

To examine surface characteristics, meat samples were placed in a black box (61×61×61 cm) and imaged with a camera place at 30 cm distance. The sample was illuminated by three light-emitting diodes (LED) lamps. Sous-vide cooked samples were cut in parallel to the muscle fiber direction. Images of the muscle surface from each side were acquired in triplicate with an Olympus E-M10Mark camera operating at F 5.6. Data were collected at 4608×3456 pixel size in the RGB (red-green-blue) format.

2.8 Statistical analyses

The effects of cooking temperature and cooking time were analyzed by one-way analysis of variance (ANOVA). Mean and standard deviations (SD) were calculated with SPSS software. A significant difference test at 95% confidence level (p <0.05) was applied to test differences of evaluated parameters.

3. Results and discussion

3.1 Color parameters

Changes in the color values of beef round and chicken breast undergoing sous-vide cooking are shown in Figure 1 with (A) the lightness L^* on a scale of 0 (black) to 100 (white), (B) a^* the color on the green (-100) to red (+100) axis, and (C) b^* the color along the blue (-100) to yellow (+100) axis. Initially, the raw beef was primarily red due to myoglobin content and darker after cooking, while the raw chicken was lighter and became pale after cooking. The L^* increased from 44.31 to 68.67 for the beef, and from 48.55 to 82.22 for the chicken breast. After cooking at 60°C and 80°C, the L^* of chicken and round beef was slightly different. Most changes in lightness occurred early in cooking and after 30 min there were only slight differences in lightness at either 60 or 80°C. Cooking meat under lower temperature has been shown to result in less moisture loss and lighter samples. The samples cooked at 60°C retained greater water content in the meat and when sliced before measurement, and retained more surface water that caused greater light scattering [20].

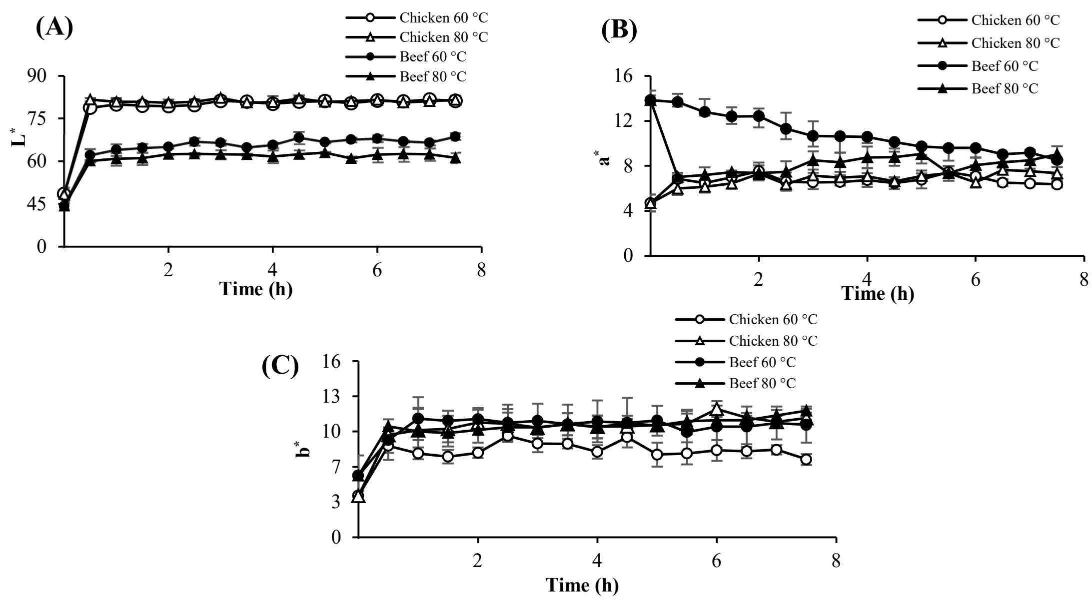

Figure 1 Effect of sous-vide cooking on color: (A) L^* - lightness along the black (0) to white (100) axis, (B) a^* - color value on the green (negative) to red (positive) axis, and (C) b^*- color value along the blue (negative) to yellow (positive) axis.

The initial a^* values were greater for the beef than the chicken breast as the beef has a higher myoglobin content [2]. In general, chicken redness remained lower than that for beef throughout cooking, although the differences diminished at longer cooking times. For chicken breast, cooked samples were somewhat redder than the raw chicken, but a^* values did not change after ~30 min of cooking. For the local beef, samples were redder when cooked at 60 °C as compared to those at 80 °C. Cooking time was also a significant factor, particularly for samples cooked at 60 °C for which a^* decreased steadily from 14.0 to 8.51. Similar results were observed by Roldan et al [25] who studied sous-vide cooked lamb loin at different temperature (60, 70 and 80 °C) and time (6, 12 and 24 h). They found that samples had the greatest redness when cooked at 60 °C and lowest at 80 °C. The results [20,21] also showed a decrease in redness when meat was cooked at higher temperatures.

The decrease in a^* could be related to protein aggregation and loss of myoglobin with the drip solution released from the meat [10]. According to Florek et al. [22], the denaturation of myoglobin starts between 55 °C and 65°C and becomes more extensive between 75 °C and 80 °C. Cooking at higher temperature denatures globin and results in oxidation of Fe^{2+} to the Fe^{3+} state. This produces denatured globin hemochrome that gives a brown-gray color to the meat [23].

After cooking for 1 h, b^* values became relatively constant. However, the chicken cooked at 60 °C had lower values than the others. The b^* values for beef cooked at 80 °C was slightly higher than that cooked at 60 °C. The greater b^* may be due to denaturation of myoglobin, causing an increase in the brown color associated with metmyoglobin. Meat browning can also be attributed to Maillard reactions but are less likely in a sous-vide process as these reactions usually only occur above 110 °C [13].

3.2 Cooking yield, cooking loss, and re-heating loss

Moisture content of raw chicken breast and local Thai beef were about 74.0% and 75.5% respectively [24]. Water loss is a natural process in the meat system [15]. Figure 2 shows (A) the cooking yield, (B) the sous-vide cooking loss and (C) the reheating loss at various temperatures for different times. Cooking yield was lower for samples cooked at lower temperature and longer time.

The greatest cooking yield and lowest sous-vide cooking loss were observed at 60 °C. At 60 °C, the cooking yield was 74.53 - 83.18% for chicken and 63.59 - 78.99% for beef. At 80 °C, the cooking yield was from 58.12 - 69.84% and 52.93 - 60.04% in chicken and beef, respectively. Thus, chicken had greater cooking yield than beef at a given temperature. This may indicate that the beef experienced greater shrinkage and expellation of juices containing soluble protein and fat. This has been attributed to collagen denaturation and subsequent shrinkage, particularly at elevated temperatures [20]. Cooking yield normally correlates with cooking loss, that is samples with high sous-vide cooking loss have lower cooking yield. Sous-vide cooking loss significantly increased when temperature and cooking time increased, again indicating greater loss of juices in these conditions. Other researchers have also noted increased juice loss at higher cooking temperatures for various meats [19-20]. Moisture losses in cooked meat are caused by three main factors [20]. First, water is lost by evaporation with the increased temperature. Second, temperatures above 40°C cause denaturation and shrinkage of myofibrillar protein. Myofibrillar proteins hold most of the water retained within the muscle [25]. These denatured proteins are less able to bind water, so that the water (with dissolved substances) is released causing shrinkage and reduction in weight [2,13]. Finally, shrinkage of collagen occurs at temperatures between 56 and 62 °C [13]. Up to 60 °C the muscle fibers shrink transversely and widen the gap between fibers, but above 60 °C the muscle fibers shrink longitudinally and cause more water loss [25]. Moreover, there are other water soluble components that are also lost with the water, as has been observed in beef at 60 °C with longer cooking time [20]. Similar results have been reported by Kerdpiboon et al [10] who studied how chicken breast properties changed during sous-vide cooking. They found that longer sous-vide cooking times resulted in lower yield and a greater cooking loss percentage. Higher yield and reduced cooking loss is of course attractive to the food industry, and it has been stated that the lower temperatures and vacuum packaging associated with sous-vide cooking promotes both [20].

Sous-vide foods are also useful for large catering events, where individual portions can be precooked then quickly re-heated for serving [26]. The reheating loss is shown in Figure 2. While samples cooked at high temperature had greater cooking loss, those samples also had the lowest reheating loss. Thus the reheating loss for both beef and chicken cooked at 80 °C was lower than for those cooked at 60 °C. As previously noted, decreased yield and cooking loss are related to protein denaturation and shrinkage of myofibrillar and sarcoplasmic proteins, along with shrinkage and solubilization of the connective tissue, all of which contribute to decreased water holding capacity [13,21]. When the samples are reheated, those cooked at higher temperature will already have lost more of the juices and hold on more tenaciously to the remaining juices than those cooked at lower temperature. In terms of time-dependence, samples cooked at 60 °C showed a continuing decrease in reheating loss over time. At 80 °C, however, there as no change in reheating loss as a function of cooking time.

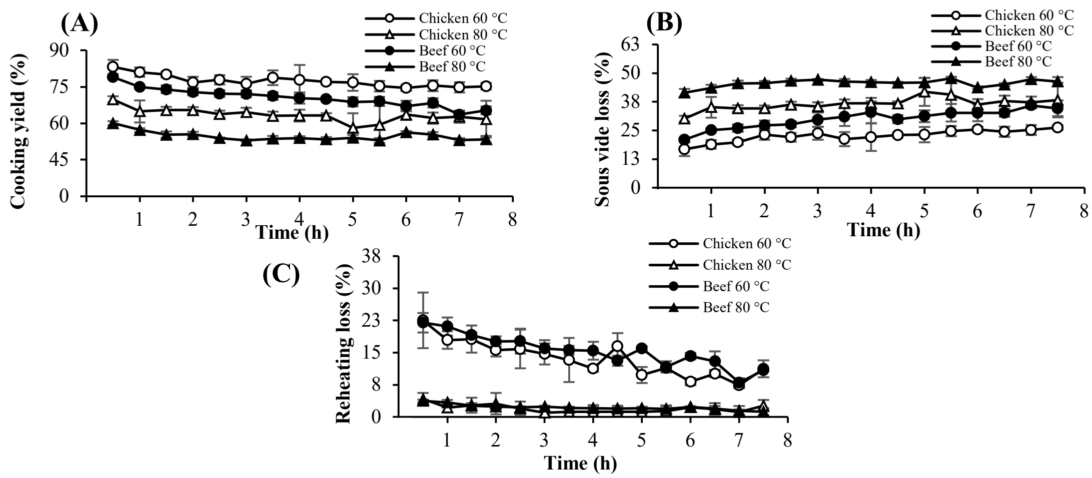

Figure 2 Effect of sous-vide cooking on (A) the cooking yield, (B) the sous-vide cooking loss and (C) the reheating loss of local Thai beef and chicken breast.

3.3 Shear force

The Warner-Bratzler shear force is a common technique for toughness and tenderness measurement in raw or cooked meat. The effects of low and high temperature cooking on the shear force are shown in Figures 3 and 4, for chicken and beef, respectively. The shear force of raw chicken breast (11.57 N) was lower than the local beef (30.20 N). In the case of chicken breast, cooking at 60 °C resulted in greater shear force values than those measured for samples cooked at 80 °C for the first 1.5 h. However, after cooking for 1.5 h the shear force values were not much different between those cooked at 60 °C and 80 °C. A cooking temperature of 60 °C resulted in chicken breast with the lowest shear force at 2 h, while cooking at 80 °C was found to have the lowest shear force at 4 h.

The results were different for the local beef in that samples cooked at 60 °C had lower shear values than those cooked at 80 °C at all cooking times. Lowest shear values were observed at 2.5 h for samples cooked at 60°C, and at 2 h for those cooked at 80 °C. Optimization of meat texture must be considered in conjunction with food safety concerns. The pathogenic bacteria of concern for cook-hold or cook-serve sous vide are *Salmonella spp.* and pathogenic *E. coli* as they are relatively heat resistant and the vegetative bacteria causes illness in the consumers, especially if the person is immunocompromised [3]. To ensure public health, FSIS [28] recommends that establishments achieve a 6.5D reduction of *Salmonella spp.* in cooked beef and a 7D reduction in poultry [27]. Heating chicken to 60 °C and holding for 3 min could sufficiently reduce *Salmonella spp* [29].

The most important factor causing changes in meat texture during cooking is the effect of heat on heme proteins. Researchers have found that the dense packing of myofibrillar proteins provides much of the structure and resistance to compressive and shear forces. The protein myosin begins denaturing at 40 to 50 °C while actin denatures at 70 °C. Thus, at the higher temperature, actin denaturation causes a reduction in fiber diameter associated with increased meat toughness [2,13,18].

Connective tissue, especially collagen, also impacts meat texture but the amount and overall structuring of this tissue varies with animal species, type of muscle, gender and age of the animal [30-31]. The beef cuts used in this research were beef round. This is a long primal cut in the rear leg and rump and the density of myofibrils in this region along with connective tissue can cause greater toughness. In contrast with beef, chicken breast has much lower fat content (~1%) and connective tissue. While lower fat can lead to a reduced sensation of juiciness, smaller amounts of connective tissue generally results in lower measured shear values and easier chewing of the meat [32]. During cooking, denaturation of connective tissue starts at 53 to 63°C, causing shrinkage of the muscle. This is followed by solubilization of collagen to form gelatin at around 80°C which can improve the tenderness of meat [13]. However, reduced tenderness related to collagen solubilization is most pronounced in older animals, tough cuts of meat and meat with relatively high collagen content (such as in beef brisket) [33]. As the local beef used in this study was from only young animals (<18 months old), the toughness from connective tissue would be less important than with cuts from older animals.

Several studies have shown that low-temperature cooking can improve meat texture as proteolytic enzymes are more active. These include enzymes such as calpain, cathepsin B, and cathepsin L that degrade myofibrillar proteins as well as collagenase that breaks down connective tissue [33]. Research has shown that cathepsin B and L activity is higher in pork and beef when cooked by sous-vide at 45-55 °C then when cooked at 70 °C [11].

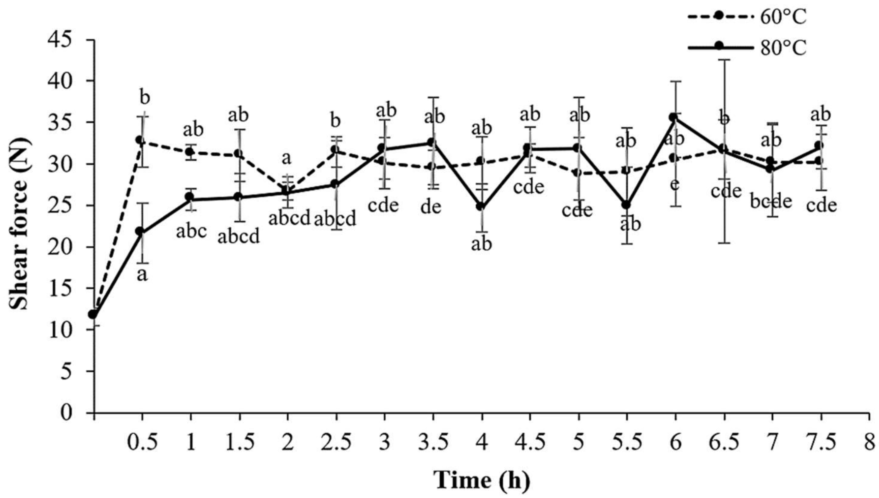

Figure 3 Effect of sous-vide cooking on shear force of chicken breast. Lowercase indicates a significant difference (p <0.05) in cooking time (same cooking temperature).

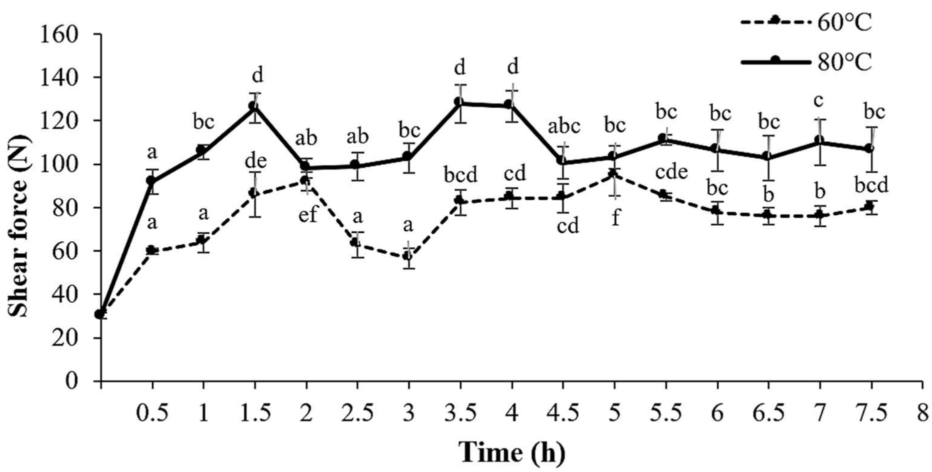

Figure 4 Effect of sous-vide cooking on shear force of local Thai beef. Lowercase indicates a significant difference (p <0.05) in cooking time (same cooking temperature).

3.4 Surface texture imaging

Qualitative changes in the structure of raw and cooked beef and chicken are shown in the surface texture images for beef (Figure 5) and chicken (Figure 6). The images show longitudinal cuts of the muscle during the course of cooking at the two temperatures. Both cooking temperature and time had a large effect on physical properties of the meat. Several studies have shown that the perimysium layer in intramuscular connective tissue is the most important constituent that determines the surface texture of meat [11-12]. For both of raw chicken and beef, the surface of the meat looked denser than the sous-vide cooked samples. Thus, this shows that the intramuscular connective tissue was still perfectly wrapped around the myofibrils [11]. During heating, for beef longitudinal sections, there was little change in the surface texture when cooking at 60 °C for 0.5 - 3 h. From 4 to 7.5 h, there was an increase in the spaces between muscle fibers. When beef *semitendinosus* muscle was cooked at 50 °C there was no significant change in the structure, but when cooked at 60 °C had large spaces [16]. Moreover, transverse shrinkage in the fibers occurs at 40 – 60 °C, while at 60 – 70 °C the connective tissue and muscle fibers shrink longitudinally which further widens the gap [34]. The physical shrinkage in cooked meat creates forces that further the release of liquid from the muscle [19]. When cooking at 80 °C at 1 - 7.5 h there were large gaps appearing between fibers, and even wider spaces developing at more than 3.5 h.

For chicken breast sections, cooking at 60°C for 0.5 to 6 h caused only slight changes in the textural appearance of the surface, and the surface retained a moist appearance. At cooking times beyond 7 h large spaces developed between the fibers. When cooking was done at 80°C inter-fiber gaps were observed particularly at 5 to 7.5 h of cooking. These results coincide with previous observations that low-temperature cooking leads to shrinkage of muscle fibers in the transverse direction. In contrast, cooking at high temperature causes contraction of sarcomeres along their length along with longitudinal shrinkage, both which positively correlate with meat toughness [16,31].

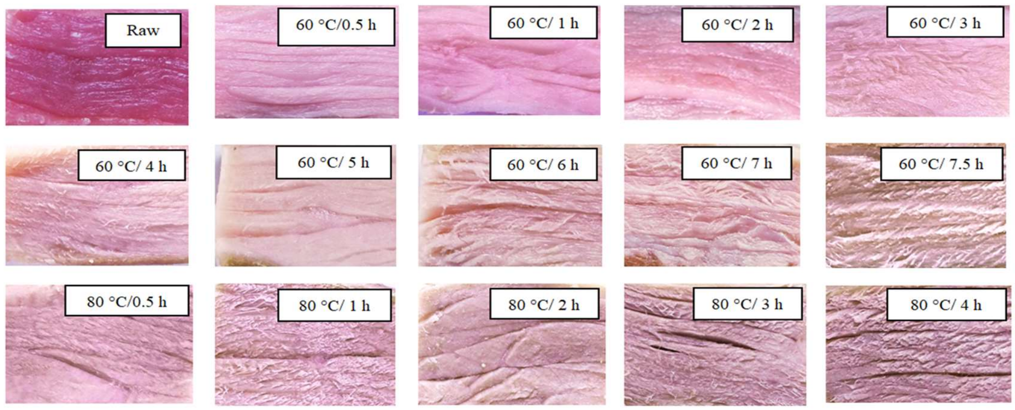

Figure 5 Digital images of the longitudinally cut surface of local Thai beef after sous-vide cooking at 60°C or 80 °C for up to 7.5 h. The raw sample appeared moist with regularly oriented muscle bundles and with a distinct red color. Over time, there was a gradual loss of red pigment, along with disruption of the fibers and appearance of gaps between the fibers.

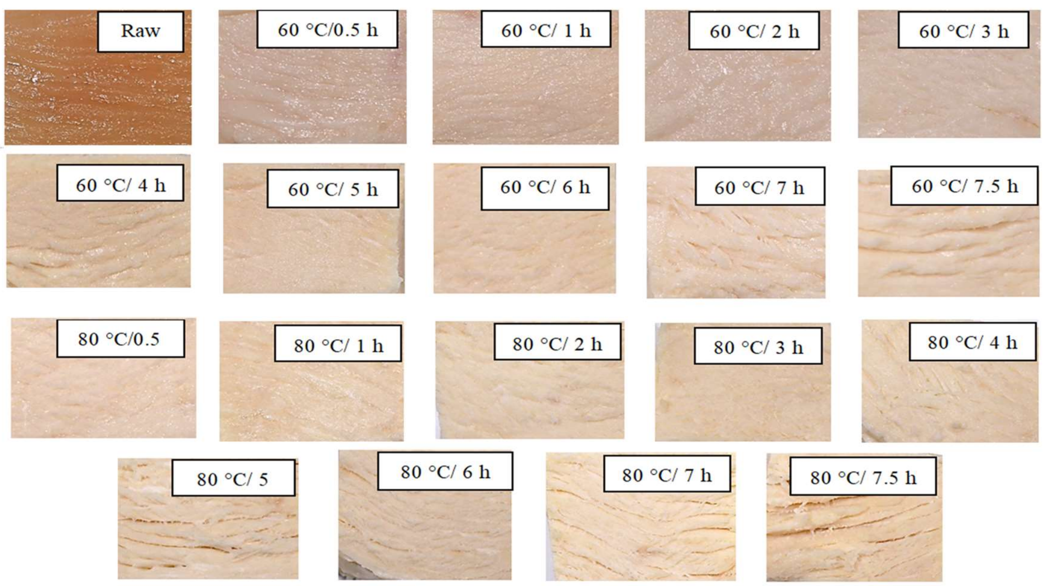

Figure 6 Digital images of the longitudinally cut surface of chicken breast after sous-vide cooking at 60°C or 80 °C for up to 7.5 h. The raw sample appeared moist with regularly oriented muscle bundles. During cooking, the samples became much paler, and there were signs of fiber disruption and appearance of gaps between the fibers.

4. Conclusion

Cooking temperature and cooking time affected the physical characteristics and surface structure of sous-vide cooked chicken breast and local Thai beef. Greater cooking temperature resulted in lighter and more yellow hue in beef, with a decrease in redness. However, sous-vide cooking did not affect lightness or yellowness of chicken breast. Sous-vide cooking at 60°C produced meat with a higher percentage of cooking yield and decreased sous-vide loss compared to samples cooked at 80°C. Increasing the sous-vide cooking time resulted in greater decreases in redness and cooking yield for the beef. Sous-vide cooking at low temperature resulted in lower shear force values, indicative of a more tender piece of meat. Increased tenderness may be related to greater breakdown of connective tissue or myofibrillar proteins, while solubilization of myofibrillar proteins may help increase juiciness. Surface texture imaging showed that cooking at 60°C helped retain a tight surface structure that could help retain juices, while sous-vide cooking at higher temperature and longer cooking time created more open spaces and longitudinal shrinkage that promote juice loss.

5. Acknowledgments

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