

Effect of Elevated Isothermal Cooking on Color Degradation of Cooked Pork Ham Thipayarat A.

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Abstract

This paper aimed to explore the color alteration of cooked ham (rump portion) under high temperature in water immersion cooking using a high pressure cooker prototype. The cooking temperatures were varied from 80 to 140°C at an isobaric condition (0.4 MPa) and the samples of cooked pork were taken intermittently over 120 minutes of cooking. The color of the samples was analyzed using a Hunter scale colorimeter. Color results were reported in terms of L^* , a^* , b^* , ΔE^* , hue and saturation. The moisture content of the cooked pork was also monitored. The moisture content results showed significant distinction of cooked ham quality as a result of different cooking temperatures and could be classified into three groups (i.e., low temperature cooking, 80 °C; medium temperature cooking, 90-100°C; and high temperature cooking 110-140°C). The Tukey's analysis confirmed the statistical significance of the three well-defined cooking regions ($p \leq 0.05$) when using color parameters (L^* , a^* , b^* , ΔE^* , hue and saturation) as criteria with only slight modification of temperature within each temperature range. At low temperature cooking, the color of cooked pork remained fairly stable. High temperature induced rapid color change and exacerbated Maillard reaction intensifying product color. In the medium temperature range, the color started with a lighter color as in the low temperature treatment but later evolved to a darker shade as in the high temperature treatment.

Keywords: Boiling; Pork; Color; Moisture content; Physical properties

Introduction

The making of many Asian dishes and condiments occasionally involves cooking of pork meat, particularly ham cut. As the popularity of these products and their markets are expanding, the need of mass production at an industrial scale becomes increasingly vital. The knowledge of how cooking temperature and means affect the cooked meat quality is of great benefit in improving product quality and energy utilization during the cooking process. Despite the promising potential of many advanced cooking methods (e.g, radio frequency and ohmic heatings), the traditional hot water immersion cooking is still by far the most extensively-used and practical thermal process to cook meat at both domestic and industrial scales (Bouton et. al., 1971; Hearne et. al. 1978 ; Shirsat et. al, 2004; Zhang et al.,2006) and was the focus of this study.

Hot water cooking directly impacts the physiochemical properties of meat in many ways including altering meat color, providing protein hydrolysis and denaturation, improving texture, and causing loss of water-binding capacity (Palka & Daun, 1999). The thermal processing of meat induced protein-protein aggregation and was considered to be the key element to change three-dimensional configuration of the viscous protein extract (Samejima et. al., 1982).

Extensive studies by several authors have been performed to relate different types of thermal processing to meat quality. In frying experiments, a few research groups demonstrated the propagation of meat physiochemical properties including water loss, browning of the product and alteration of lipid profile (Bastida & Sánchez-Muniz, 2001). The effect of heat treatment on browning of food material is a well-recognized development of cooked products as suggested by many authors (Swatland, 2002). Hunter parameters were often used to determine the changing of color attributes of cooked pork meat. To our knowledge, very little research has been performed to unveil the mechanistic

color alteration of cooked pork meat in a water immersion cooking system especially at high cooking temperatures.

Despite the exhaustive lists of publication on meat processing, many aspects of the industrial meat cooking have yet to be explored, for example, how exactly elevated cooking temperature in a water cooking system affects the quality and physicochemical properties, in particular color or external appearance of the cooked product. Therefore, this research was aimed to study color evolution of cooked pork sample as a result of cooking time and temperature. To facilitate this study, an experimental equipment prototype was fabricated enabling cooking of meat samples in an instant, isothermal condition capable of cooking at high temperatures beyond a normal boiling point. The advancement of color during reasonably long cooking time under a wide array of cooking temperatures was monitored. The result of this finding may help shed light on the well-balanced cooking condition to achieve desirable cooked meat color and minimize cooking time. This useful knowledge of high temperature cooking can help the industry to improve the design of industrial cooking process in order to reduce energy consumption as well as satisfy the more demanding quality criteria of cooked pork products of consumers.

Materials and methods

Pork samples

Lean pork meat was selected from the behind muscle of ham cut. The pork meat sample was purchased in bulk from a local supermarket in Bangkok, Thailand. Frozen meat sample was diced into cube shape ($2 \times 2 \times 2 \text{ cm}^3$), covered with plastic film to prevent dehydration and kept in $4 \text{ }^\circ\text{C}$ refrigerator to retain freshness before each experiment.

A laboratory-scale pressurized cooker prototype

A laboratory-scale pressurized cooker prototype was modified from the previous work by Leelayuthsoontorn and Thipayarat (2006). The equipment consists of three metal chambers, including a main cooking and a hot water chamber (made of aluminum and equipped with 1500W electric band heater) and a cold water chamber made of stainless steel, as shown in Figure 1. The system was pressurized to allow the cooking water temperature in the hot water chamber to be increased to a predetermined temperature. The hot water was introduced into the main chamber to submerge the pork sample and provide an instant isothermal condition. The cooking temperature in the chamber was controlled using a PID/fuzzy temperature controller equipped with a type-K thermocouple. Prior to drawing samples, cold water from the cold water chamber was added to the main chamber to bring down the temperature below the normal boiling temperature. The liquid in the chamber was released and it was possible to take a sample from the main chamber.

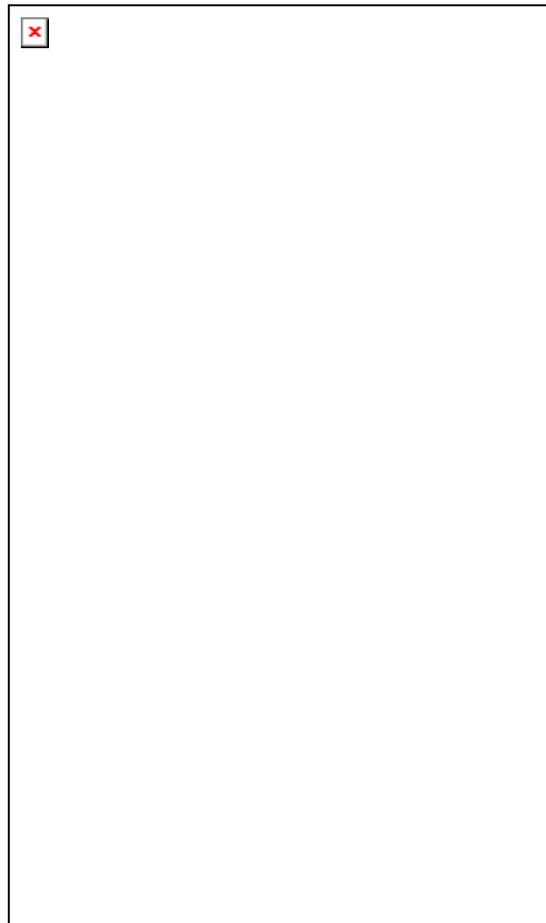


Figure 1 The schematic diagram of the hot water immersion cooker prototype: (C1) cooling water chamber , (C2) cooking water chamber and (C3) pork cooker

Elevated cooking conditions

Pork meat was cooked in excess cooking water. The cooking temperatures were varied as follows; 80,90, 100,110, 120,130 and 140 °C at a constant pressures of 0.4 MPa (gauge pressure). The samples were collected at various cooking times (i.e., 0, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 110 and 120 min). In each sampling point, the meat was sampled in triplicate. The cooked pork meat sample was immediately cooled with cold water (0–2 °C) and the excess water was eliminated by patting with tissue paper before further analyses.

Moisture contents

Approximately 3 grams of cooked meat sample was prepared to measure moisture content using a hot air oven at 105 °C according to AOAC (1995). The dry basis was utilized to determine the change of water binding capacity.

Color measurements

The color of cooked pork meat was measured using a colorimeter, JP7100 (Juki Corporation, Tokyu, Japan). Measurement was performed using the Hunter system of color parameters; L* (lightness), a* (redness/greenness) and b* (yellowness/blueness). The ΔE^* , the hue angle (H) and the saturation (S) were calculated using the following expressions (CIE, 1978);

$$H = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (1)$$

$$S = \sqrt{(a^{*2} + b^{*2})} \quad (2)$$

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (3)$$

The instrument was calibrated by internal light (D65) before carrying out color measurements.

Statistical analysis

Means and standard deviations (SD) were calculated with SPSS statistical software (Version 12.0.0 Evaluation, SPSS Inc., Chicago, Illinois, USA). The software was also used to verify significant differences between treatments using two-way-analysis of variance (ANOVA) followed by Tukey's honest significant difference test (HSD) at $p \leq 0.05$ to identify statistical differences among groups.

Results and discussion

Moisture content

The results of moisture content measurement shown in Figure 2 were analyzed with Tukey's test and displayed 3 distinct groups of moisture content pattern ($p < 0.05$). The first group was the mild cooking temperature (80 °C) displaying rather shallower profile with the initial moisture content of 74% decreasing to the final moisture content of 64%. The second group was the extreme cooking temperature (i.e., 110, 120, 130 and 140 °C). The final moisture content of this group sharply dropped to 61-62%. The moisture content pattern of the third group was characterized by the shift of the moisture content patterns from the one similar to the first group at the beginning to the second group as the cooking time increased. The 90 and 100°C treatments were in this group.

It has been widely-accepted that the increase in cooking temperature and time have a profound impact on protein denaturation. The moisture content result displayed water loss, perhaps as a result of initial heat-shrinkage of the endomysium during cooking as suggested by (Swatland, 2002). Pearson and Dutson (1994) reported that cooking temperature, ending temperature, and heating rate directly affected cooking loss. Higher cooking temperature yielded higher cooking loss (Combe et al., 2004). At the cooking temperatures above 60 °C, shrinkage and coagulation of myofibrillar and connective tissue proteins occurred which lead to the release of entrapped cell water (Bendall & Restall, 1983; Hamm, 1986). This phenomenon caused the release of fluid from the myofibre, which later was gelatinized with the perimysium to create the distinct texture of cooked meat (Swatland, 2002). Therefore, it was hypothesized that the rapid decrease in moisture loss in the initial cooking period was predominantly as a result of protein denaturation and the shifting pattern of moisture content in the medium cooking temperature treatment was resulted from the changing of meat physiochemical properties due to long cooking time.

Several authors reported a higher weight loss in pork loin cooking experiments when applying higher cooking temperature and using different cooking means (Gardes et al., 1995). Water loss was reported to proportionally increase with increasing oven temperature (Palka & Daun, 1999) and to depend more significantly (quadratically) on the final core temperature of the sample (Murphy et al., 2001). In contrast to the previous work by Vaudagna et al. (2002) suggesting water loss was only slightly affected by cooking time, this water immersion cooking experiment demonstrated that there exists a temperature range (i.e., 90 and 100°C) within which a reasonably long cooking time enables a significant decrease of the moisture content of cooked meat. This moisture shift,

as a result of long cooking time, may signify some physiochemical changes which were later explored in more details using the CIE color indices.

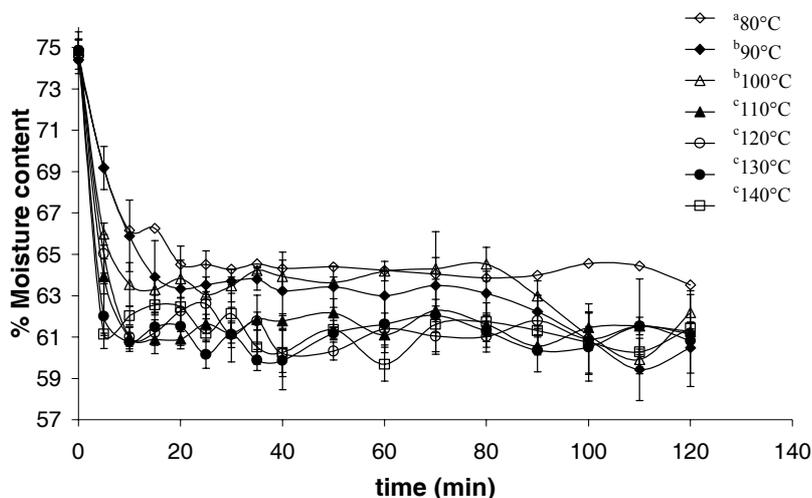


Figure 2 Experimental moisture content percentage profiles of pork meat at different temperatures (Tukey's test, $p < 0.05$)

Evolution of color parameters

Lightness (L^*)

Treated with ANOVA, the results for lightness in Figure 3 were analyzed with Tukey's test displaying 6 distinct profiles of lightness progression ($p < 0.05$). The abrupt increase of L^* value from 45 to 63 was attributed to protein denaturation. By applying the previous classification of cooking temperature range using the moisture content result, the L^* patterns were also able to be characterized into 3 cooking regions with only slight modification. At low temperature cooking (i.e., 80 and 90 °C), the value of lightness of cooked pork sample remained high and constant. Again, there was a medium cooking temperature range (i.e., 100 and 110°C) where L^* patterns shifted from a lighter color shade to a darker color shade as the cooking time extended. This shifting of lightness value emphasized the significance of cooking time that was able to alter the product color as seen earlier in the shifting of moisture content. When the pork samples were subject to high temperature cooking (e.g., 120, 130 and 140°C), the lightness value started to depreciate rapidly which was highly correlated with browning development. The higher the cooking temperature, the darker and browner the color appeared.

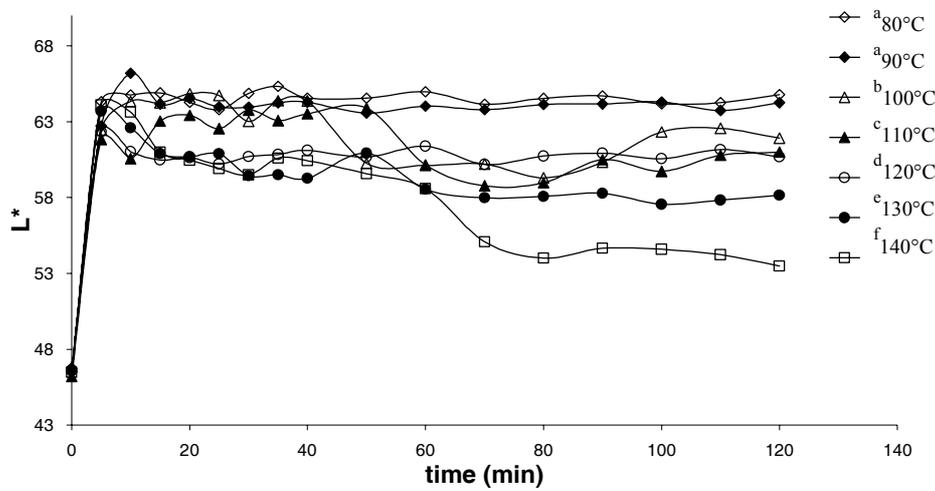


Figure 3 Experimental L* color profiles of pork meat at different temperatures (Tukey's test, $p < 0.05$)

Redness (a^*)

In Figure 4, the profiles of redness (a^* value) of cooked ham were almost a mirror image of the L^* profiles. With an initial display of the drastic drop of a^* value due to denaturation, the remaining cooking process showed rather steady or slight increase of a^* value. For a^* value, the ANOVA treatment indicated 5 significantly different profiles as a result of different cooking temperatures (Tukey's test, $p < 0.05$); however, the 3 cooking regions based on cooking characteristics were still applied.

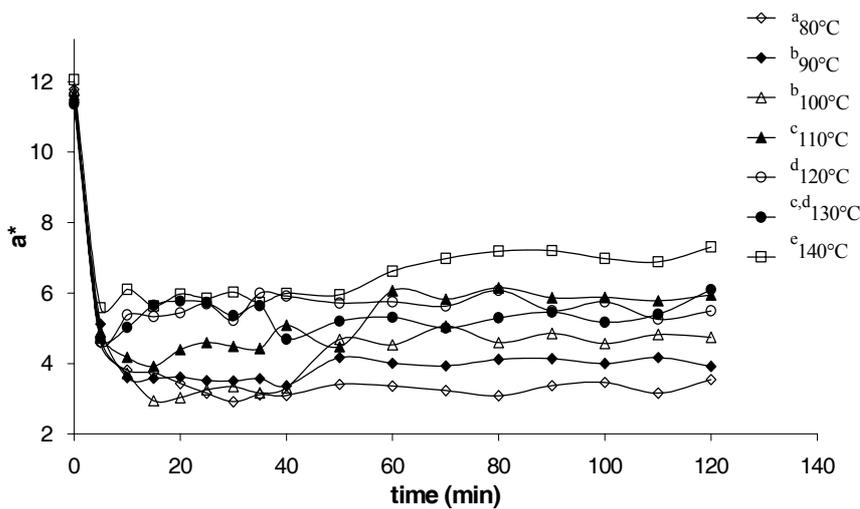


Figure 4 Experimental a^* color profiles of pork meat at different temperatures (Tukey's test, $p < 0.05$)

The lower temperature treatments showed less red pigment and rather stable profiles of a^* once reaching a plateau. In contrast, when cooking temperatures increased, the final a^* value increased. The medium cooking temperature range (i.e., 100 and 110°C) again displayed a shift of the profile from that of lower to higher cooking temperatures

which was correlated well with the previous results. The higher a^* values in the higher cooking temperature treatments (e.g., 120, 130 and 140°C) coincided with the browning development of cooked meat.

Yellowness (b^*)

Like the L^* and a^* values, the b^* value in Figure 5 showed the variation of yellowness as a result of different cooking temperatures. Unlike the previous two reported values, the initial change of b^* value due to protein denaturation was less pronounced, especially at low temperature cooking. The ANOVA test indicated 5 significantly different groups of profiles and the 3 well-defined cooking regions were less explicit (Tukey's test, $p < 0.05$).

At low temperature cooking (i.e., 80 and 90°C), the b^* value profile was rather flat. However, the increase of b^* value was more apparent at higher cooking temperatures. At a mild temperature range (i.e., 100 and 110°C), the b^* value profile more or less showed a shifting phenomenon from less yellowness to more intense yellowness as a result of long cooking time. The higher cooking temperature treatments (i.e., 120, 130 and 140°C) resulted in the sharp increase of b^* value (related to more browning) at the initial transient phase and the b^* value remained relatively unchanged. The increase of b^* value in the higher cooking temperature treatments corresponded well with the development of browning.

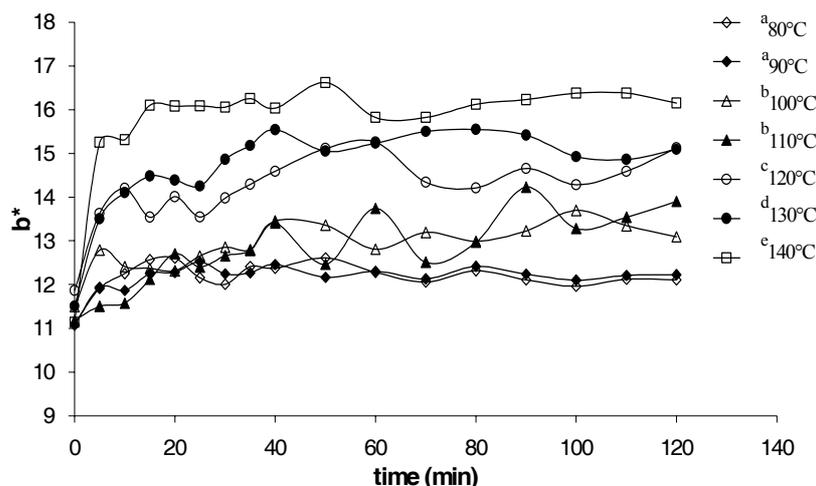


Figure 5 Experimental b^* color profiles of pork meat at different temperatures (Tukey's test, $p < 0.05$)

Color evolution model during cooking

As the ham samples were processed using high temperature water immersion cooking, several chemical reactions, including protein denaturation, Millard reaction, and thermal hydrolysis, progressed and produced a significant impact on the color attributes. The color of pork meat is mainly influenced by myoglobin and cooking methods by applying thermal treatment to denature the globin protein (Ledward, 1971). Upon heating, red meat turned to a darker color as red oxymyoglobin was denatured and oxidized to produce the brown metmyoglobin and other small molecule contents (Yongliang & Yud-Ren, 2001). These changes took place when the meat temperature was around 55–75 °C (Hunt et al., 1999) and the meat was completely denatured at around 80 to 85°C (Bernofsky et al., 1959).

Meat with an appreciable myoglobin concentration changed from red to grayish-brown when cooked (Pearson & Tauber, 1984). The browning development formed during cooking resulted from the interaction of several chemical reactions producing denatured globin nicotinamide hemichromes (Tappel, 1957), myoglobin (Bernofsky et. al., 1959), Maillard reaction products (Pearson et. al., 1962), metmyochromogen (Tarladgis, 1962) and haematin diimidazole complexes (Ledward, 1974). Cooking conditions including temperature and time greatly contributed to the color attributes of cooked pork meat. The visual appearance of cooked meat depends not only on the specific thermal effects on the color pigment but on other macro- and microstructure changes due to the light scattering properties of the cooked meat (MacDougall, 1983)

ΔE^* evolution

The result of overall color change of cooked pork sample showed that the color change pattern was able to be significantly differentiated into 7 different patterns (Tukey's test, $p < 0.05$). In all treatments, the initial color change was rapid as a result of denaturation and oxidation of oxymyoglobin (Yongliang & Yud-Ren, 2001). Once the raw meat was denatured, the cooking time had little or no effect on the overall color change in the mild cooking temperature treatments (i.e., 80 and 90°C). The higher temperature treatments resulted in less overall color difference because the cooked pork color was developed into a darker shade resulting in color indices similar to raw meat color.

As the cooking temperature increased, the effect of cooking time was intensified. In the medium range of cooking temperature (i.e., 100 and 110°C), the profile pattern of overall color change initially progressed similarly to the mild temperature treatment (Figure 6).

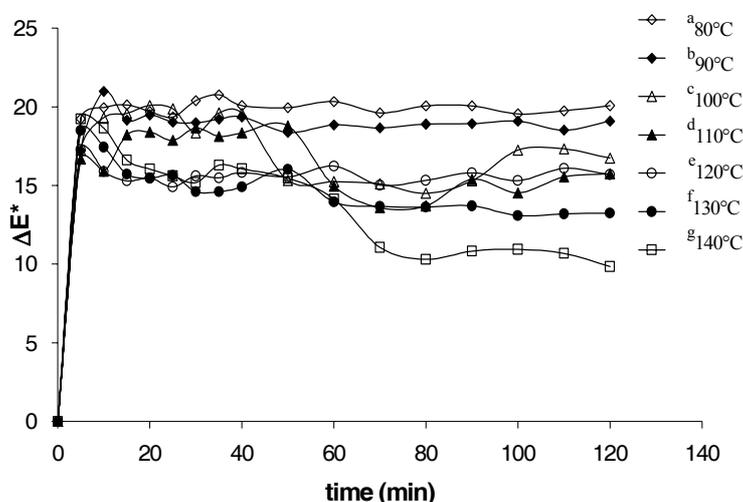


Figure 6 Experimental ΔE^* color profiles of pork meat at different temperatures (Tukey's test, $p < 0.05$)

However, as the cooking time increased, the profiles diverged to smaller values of color change before reaching a new plateau. This phenomenon punctuated the effect of cooking time in water immersion cooking. As the temperature increased, the initial pattern was shortened. In the high cooking temperature treatments (i.e., 120, 130 and 140°C), there was an initial overshoot and the value of ΔE^* dropped quickly as the color of cooked product turned brown. Similar to the result of Swatland (2002), the pork meat sample developed more brown color characterized by lowered L^* , but higher a^* and b^* as cooking time increased. The ΔE^* reduction was indicative of browning effect since the

brown color was in the same color shade as the uncooked meat resulting in the decrease of ΔE^* value.

Hue angle (H) and Saturation (S) evolution

In Figure 7, the hue angle result separated color tone of the raw pork meat (ca 0.8 radian) from the cooked pork meat (ca 1.25 radian). The hue angle differentiated the effects of cooking temperature and times on cooked pork color tone. Different cooking temperature resulted in 4 different color tones (Tukey's test, $p < 0.05$). Higher cooking temperature produced smaller value of hue angle. As the hue angle shifted from the average value of 1.35 to 1.15 radians, the color tone developed toward brown color shade in the color circle as a result of Maillard reaction. At milder temperature (i.e., 90, 100 and 110°C), longer cooking time activated browning reaction approaching the same degree of browning similar to cooking at higher temperatures. The cooking temperature and time did not only produce different hue angle but also different color purity or chroma.

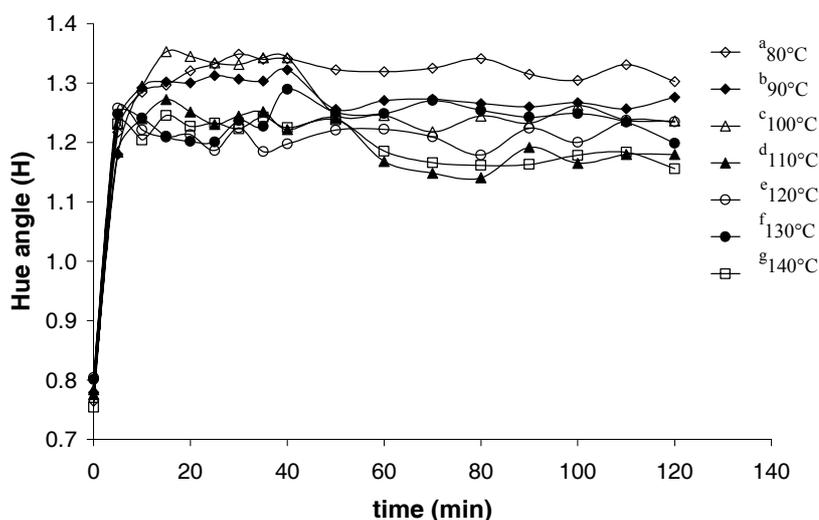


Figure 7 Experimental Hue angle (H) color profiles of pork meat at different temperatures (Tukey's test, $p < 0.05$)

The saturation result magnified the differentiable patterns of different cooking temperatures and showed 7 patterns of cooking conditions (Tukey's test, $p < 0.05$). The effect of cooking time was less pronounced in the saturation plot (Figure 8) but improved the clarity of the cooking temperature profiles. Higher cooking temperatures increased the saturation value closer to the raw meat property. Cooking at low temperature reduced the saturation index.

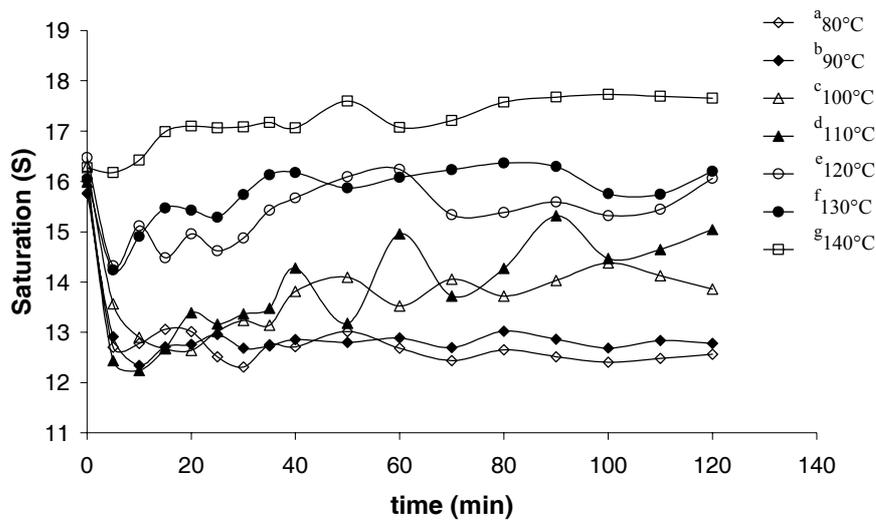


Figure 8 Experimental Saturation (S) color profiles of pork meat at different temperatures (Tukey's test, $p < 0.05$)

Conclusion

Different isothermal cooking in a water immersion system strongly affected the CIE color indices of cooked pork. Not only the effect of high cooking temperatures above a normal boiling point was explored but also the effect of long cooking was demonstrated. High cooking temperature activated a few chemical reactions including Maillard reaction contributing to the development of brown color and caused dehydration of the cooked pork sample. The increase of browning as indicated by the CIE color indices was corresponding well with the decrease of moisture content. The shifting of cooked pork color was evident when the pork samples were cooked at a medium temperature range (ca 100 and 110°C) with a reasonably long cooking time. Low cooking temperatures resulted in less browning and more stable color retention than higher temperature cooking.

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