Effect of Long Low Temperature-Short High Temperature Cooking Cycle on Physicochemical Properties of Beef

Sanghoon Ko1*, Sang-Ho Yoo1, Suyong Lee1, Seongho Cho2, Kwang-Hwa Kim2 and Rina Hwang2

1 Department of Food Science and Technology, Sejong University, 98 Gunja-dong, Gwangjin-gu, Seoul 143-747, Korea
2 LG Electronics, C&C Group, 327-23 Gasan-dong, Geumcheon-gu, Seoul 153-802, Korea

Received March 1, 2010; Accepted November 8, 2010

A two-step heating process, long low temperature-short high temperature cooking cycle, is used to maximize fat reduction in roast beef. First, the beef was cooked at a low temperature for a long time; then, it was cooked at a higher temperature for a short time. The study examines cooking loss, fat content, texture, and inosine 5'-monophosphate (IMP) production of cooked meat under different heating conditions. In an oven, the internal temperature of the meat increased to a transition point of 48 or 54℃ at oven temperatures of 80 or 100℃ and reached 60℃ at 220℃. The fat was reduced by up to 44.2% compared to 27.8% under conventional roasting conditions. In addition, the two-step heating process kept the meat tender and juicy but improved IMP content.

Keywords: roast beef, long low temperature-short high temperature cooking, convection oven, fat reduction, meat texture

Introduction

Consumers recognize the importance of a low fat diet. Low-fat recipes and cooking method have been accepted to consumers to cook meats which are considered as high in fat. Roasting in an oven is one of popular cooking methods to reduce fat in foods. Roasting should produce a high-quality product but minimize nutrient loss and sensory quality.

In general, conventional roasting of meat is done in one of two ways: by maintaining the same one temperature (160℃) or by starting with a high temperature (250℃) and then reducing to a lower temperature (150℃) (Powell et al., 2000; Jeremiah and Gibson, 2003). The former results in more fat retention, while the latter results in less fat reduction. Consumers who want to maximize fat reduction and minimize the decrease in sensory quality often cook foods for a long period of time at a low temperature.

It is well known that cooking conditions affect quality, since different conditions result in different temperature profiles through the meat (Barbanti and Pasquini, 2005; Christensen et al., 2000; Obuz et al., 2003; Palka and Daun, 1999). Compared to normal oven roasting at temperatures of between 150 and 160℃, lower temperatures increase the cooking time but preserve sensory quality. Due to the low temperature, fewer Maillard reactions occur on the surface of the meat. Temperature control influences changes in meat structure, flavor, and appearance (Christensen et al., 2000; Chung and Chung, 1993; Powell et al., 2000). Cooking food at a high temperature (above 200℃) for a short period of time after cooking at a low temperature for a longer period of time can improve a higher fat reduction and improved sensory qualities such as color and flavor. Temperature control also provides a way to balance meat tenderness. The denaturation of actin and myofibrillar proteins reduces tenderness, but the gelatinization of connective tissue makes the meat tender again. Thus, a long heating time at a low temperature followed by a short time heating at a high temperature can maximize fat reduction and mitigate quality loss.

This study investigates the effects of the long low temperature-short high temperature cooking cycle. The internal meat temperature increases up to a transition point (48 or 54℃) at the first-step cooking temperature (80 or 100℃), and then increases to 60℃ (target internal temperature) at the second-step cooking temperature (220℃). The effect of this two-step heating process on cooking loss, fat reduction, and sensory properties such as hardness and Inosine 5’-monophosphate (IMP) production are studied.

*To whom correspondence should be addressed.
E-mail: sanghoonko@sejong.ac.kr
Materials and Methods

Sample preparation  Frozen whole boneless ribeyes (6-7 kg) were purchased and stored at −18°C before testing. The ribeye steaks were thawed in a refrigerator at 4°C for two days before cooking. As shown in Fig. 1, the thawed ribeyes were cut into three pieces for cooking (M₁, M₂, and M₃) and four pieces for testing without cooking (S₁, S₂, S₃, and S₄). The samples weighed in the ranges of 1700 to 1900 g and 300 to 500 g, respectively.

Six pieces of meat were used to collect from the center of each uncooked sample by cutting parallel to the sagittal plane. Three pieces of 1 cm × 1 cm × 1 cm in size were used to test the texture, and three pieces of 5 g each were used to test juiciness. The remaining portions of the uncooked sample were ground using a food processor (HM-1600, Hanil Electric Co., Seoul, Korea) and then homogenized using a mixer (5KSM150 Artisan series, KitchenAid, St. Joseph, Michigan, USA). The homogenized ground meat was stored in the refrigerator at 4°C for fat and IMP analysis.

Roasting  Randomization was used to determine cooking order and to obtain an unbiased estimate of the error variance. The numbers 1 to 16 were randomly allotted to the 16 meats and randomized using Microsoft Excel. Table 1 lists the meat portions, cooking orders, and corresponding cooking conditions.

Each piece of meat was placed on a rack in a roasting pan for even heat circulation. The heat was transmitted to the meat by forced-air convection in a closed oven (LWS3081ST, 133 L, LG Electronics, Changwon, Korea). During cooking, the internal meat temperature was continuously monitored by inserting a thermocouple (T-type, Omega Engineering, Inc., Stamford, CT, USA) into the geometric center of the meat without touching the fat. A data logger (34970A, Agilent Technologies, Santa Clara, CA, USA) collected and stored the temperature data. Cooking began without preheating; initial ambient temperature of the oven was about 25°C. Meat sample taken out of a refrigerator was roasted immediately without any additional treatment such as seasoning. The internal temperature of the meat sample was about 4°C.

Temperature sets were designed for the experiments. The two-step heating process consisted of low-temperature cooking for a long time followed by high-temperature cooking for a short time (Table 2). The first oven temperature was set to 80 or 100°C. The internal meat temperature increased up to 80% (48°C) or 90% (54°C) of target temperature 60°C. When the internal meat temperature reached 48 or 54°C (cooking transition point), the oven temperature was increased to 220°C.

The criteria to design the temperature sets of the long low-short high temperature cooking were total cooking time and degree of fat reduction. In our preliminary study, the total cooking time was about 2 h for conventional cooking and about 3 h for long low-short high temperature cooking. When the cooking transition point was 70% (42°C) of the target internal temperature of meat, total cooking time was similar to that of the conventional cooking but fat reduction was not relatively low. On contrary, when the cooking transition point was 95% (57°C) of the target internal temperature of meat, total cooking time was too long (over 4 h) since it took a long time to reach at the cooking transition point. Thus, the experimental sets of the cooking transition point were 80% and 90% of the target internal temperature of meat.

Cooking ended when the internal meat temperature reached 60°C. Thus, four experimental sets were tested: LT80_48, LT80_54, LT100_48, and LT100_54. The effects of the cooking temperatures were compared to those of conventional convection cooking at 160°C.

Table 1. The meat portions and the cooking orders and their corresponding cooking conditions.

<table>
<thead>
<tr>
<th>Cooking conditions</th>
<th>Cooking order</th>
<th>Meat portions</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT80_48_1</td>
<td>15</td>
<td>Rb6_M1</td>
</tr>
<tr>
<td>LT80_48_2</td>
<td>3</td>
<td>Rb1_M3</td>
</tr>
<tr>
<td>LT80_48_3</td>
<td>7</td>
<td>Rb3_M1</td>
</tr>
<tr>
<td>LT80_54_1</td>
<td>6</td>
<td>Rb2_M3</td>
</tr>
<tr>
<td>LT80_54_2</td>
<td>11</td>
<td>Rb4_M2</td>
</tr>
<tr>
<td>LT80_54_3</td>
<td>2</td>
<td>Rb1_M2</td>
</tr>
<tr>
<td>LT100_48_1</td>
<td>12</td>
<td>Rb5_M1</td>
</tr>
<tr>
<td>LT100_48_2</td>
<td>4</td>
<td>Rb2_M1</td>
</tr>
<tr>
<td>LT100_48_3</td>
<td>14</td>
<td>Rb5_M3</td>
</tr>
<tr>
<td>LT100_54_1</td>
<td>10</td>
<td>Rb4_M1</td>
</tr>
<tr>
<td>LT100_54_2</td>
<td>9</td>
<td>Rb3_M3</td>
</tr>
<tr>
<td>LT100_54_3</td>
<td>1</td>
<td>Rb1_M1</td>
</tr>
<tr>
<td>CC160_1</td>
<td>16</td>
<td>Rb6_M2</td>
</tr>
<tr>
<td>CC160_2</td>
<td>13</td>
<td>Rb5_M2</td>
</tr>
<tr>
<td>CC160_3</td>
<td>8</td>
<td>Rb3_M2</td>
</tr>
</tbody>
</table>
After cooking, the meat was removed from the oven and wrapped with aluminum foil for 15 min. The internal temperature continued to increase due to residual heat, and the juice redistributed evenly in the meat. Subsequently, the aluminum foil was removed, and the meat was left to cool to 25°C for 1 h before sampling. Cooking losses were evaluated by differences in the weight of the cooked and the uncooked samples.

**Fat content measurement** The total fat content was determined using the Soxhlet extraction method (AOAC 2000). In brief, 20 g of the homogenized sample was placed in a thimble filter (Keystone Scientific, 3.47 mL), and petroleum ether was allowed to extract fat for 8 h. After evaporating petroleum ether from the filtrate, the total amount of fat was calculated.

**Juiciness measurement** Juiciness was measured by a press method according to a previous report (Gujral et al., 2013) for 1 min in an ice bath. The extraction mixture was centrifuged at 3000 × g for 10 min. Then, 10 mL of supernatant was neutralized to pH 6.5-6.8 using 1 M KOH. The neutralized supernatant was allowed to stand in an ice bath for 30 min to precipitate the potassium perchlorate, which was then removed by filtration. The filtrate solution was made up to 20 mL and then stored at −30 °C for HPLC analysis. Quantification was based on standard curves using external standards and calculations carried out in the HP software.

**Results and Discussion**

**Validation** We assumed that the average fat content at the ends of the meat represent the content for the entire sample. As shown in Fig. 1, a whole ribeye was cut into three pieces of about 1800 g each for the cooked sample (M1, M2, and M3) and four pieces of about 400 g each for the uncooked sample (S1, S2, S3, and S4). Thus, the mean fat content of two successive S samples, Si and Si+1, represents the fat content of Mi. For example, the fat content for M1 before cooking can be obtained by averaging the fat content of S1 and S2 on both sides of M1.

To validate this assumption, we prepared 13 M samples for testing after cooking and 13 S samples for testing before cooking. Fig. 2 shows the validation data obtained for the fat measurement. The fat content of the M samples ranged from 25.0 to 32.5%; this shows that fat was distributed randomly. The difference in fat content for the S and M samples ranged from −14.1 to 5.9%. The average difference and standard deviation were −2.2 and 5.95%, respectively. Fat content from the M sample was not statistically different from that of the S sample, since the p-value was larger than 0.05. This result validates the effectiveness of the raw meat sample.

**Cooking temperature sets** The rate of cooking depends on the surface temperature of the meat, which is affected by ambient oven temperature. High temperatures increase heat conduction and surface evaporation, whereas low temperatures slow heat conduction but reduce evaporation. In the preliminary study, we tested 60 and 70°C as the target internal temperatures. But at 70°C, the meat was dry, so 60°C was chosen as the targeted internal meat temperature for this study.

A long low temperature-short high temperature cooking
which affected the retention of water and fat. We can assume that ambient oven temperature is the most important factor for cooking loss and fat reduction. A low ambient temperature yields a more homogeneous appearance and less-distinct layers of doneness. Cooking loss and fat reduction were vigorous at high ambient temperature such as 220°C. High ambient temperature makes meat juice run out, since melted fat released from the surface. Longer cooking time at the high ambient temperature drained more meat juice. Thus, the length of the cooking time at 220°C was the critical factor. Cooking loss is significantly related to water loss and fat drip. As the meat temperature increases, the water capacity decreases due to the thermal denaturation of meat proteins (Straadt et al., 2007; Shaarani et al., 2006; Bertram et al., 2006). The gelatinization of collagen significantly influences water capacity. The melted fat moves through the gaps in denatured meat structures; this increases the uniformity of the fat distribution in the meat and may act as a barrier to moisture loss during cooking. The amount
cycle was strategized to improve fat reduction and sensory quality in roast beef. First, the meat was cooked at a low temperature for a long time; then, it was cooked at a higher temperature for a short time. The internal meat temperature increased to a transition point of 48 or 54°C at lower oven temperatures of 80 or 100°C and reached 60°C at 220°C.

Fig. 3 shows typical temperature profiles of meats at different two-step-cooking sequences. Table 2 lists the cooking times and heating conditions. The total cooking time was 124 min for conventional roasting at 160°C. The total cooking times were relatively long when the first-step cooking temperature was low (LT80_48 and LT80_54), since it took a long time to reach the transition point. The first-step cooking period was about 77 to 87% of the total cooking time. As expected, the cooking time increased when the transition temperature increased. The second-step cooking period was about 12 to 23% of the total cooking time and played a large role in the cooked meat quality.

Effect on cooking loss and fat reduction Table 3 presents the cooking loss and fat reduction for different heating conditions. For conventional cooking, the average cooking loss was 593.4 g for about 1800 g of raw meat. The cooking loss was 688.1 and 634.8 g, respectively, for LT80_48 and LT100_48 and 645.0 and 565.3 g, respectively, for LT80_54 and LT100_54. In general, the amount of cooking loss increased with the cooking time. The cooking loss was greater for the two-step heating process.

Cooking loss and fat reduction were found to be proportional to the length of the cooking time at 220°C. As shown in Table 2, the second-step cooking times of LT80_48, LT80_54, LT100_48, and LT100_54 were 52, 50, 38, and 27 min, respectively. At LT80_48, the meat sample was exposed at 220°C for the longest time. The cooking loss and fat reduction of LT80_48 were the largest. The surface temperature as high as 220°C changed the meat surface structure which affected the retention of water and fat.

We can assume that ambient oven temperature is the most important factor for cooking loss and fat reduction. A low ambient temperature yields a more homogeneous appearance and less-distinct layers of doneness. Cooking loss and fat reduction were vigorous at high ambient temperature such as 220°C. High ambient temperature makes meat juice run out, since melted fat released from the surface. Longer cooking time at the high ambient temperature drained more meat juice. Thus, the length of the cooking time at 220°C was the critical factor. Cooking loss is significantly related to water loss and fat drip. As the meat temperature increases, the water capacity decreases due to the thermal denaturation of meat proteins (Straadt et al., 2007; Shaarani et al., 2006; Bertram et al., 2006). The gelatinization of collagen significantly influences water capacity. The melted fat moves through the gaps in denatured meat structures; this increases the uniformity of the fat distribution in the meat and may act as a barrier to moisture loss during cooking. The amount

---

**Fig. 2.** Method validation data of fat contents at different meat portions. White and black histograms represent the fat content of M (samples for cooking but not cooked) and the average fat content at the left and right ends (fresh samples) of M, respectively.

---

**Fig. 3.** Typical temperature profiles of meats at different two-step-cooking sequences.
of the cooking loss depends on the cooking method. A short cooking time results in a less loss. The correlation is not linear, however, as cooking loss is determined by cooking time and heating rate. Many studies have shown that a longer cooking time results in greater cooking loss and fat reduction (Barbanti and Pasquini, 2005; James and Calkins, 2008; Obuz et al., 2003). However, no study has examined the effect of low-temperature cooking followed by high-temperature cooking.

**Effect on texture** Changes in hardness relate to protein denaturation, shrinkage of collagen fibers, and gelatinization of collagen (Christensen et al., 2000; Bouton and Harris, 1981; Palka and Daun, 1999; Davey and Kevin, 1974). In this study, uniaxial compression was used for the deformation test. When a meat sample is deformed under uniaxial compression, the structural elements are densificated. Structural densification releases the juices stored in the meat. At larger strains, structural elements may collapse or fracture; thus, the compacted structure offers increased resistance. Table 3 presents the textures obtained under different heating conditions. In general, heating at low temperatures decreased the hardness of the meat. The average hardness under conventional conditions was 1.23 kgf. The hardness was 2.03 and 1.70 kgf, for LT80_48 and LT100_48, respectively, and 0.90 and 0.73 kgf, for LT80_54 and LT100_54, respectively. Heating the meat to first 48°C at low temperature and subsequently to 60°C at 220°C produced a harder texture; heating it to 54°C produced a softer texture regardless of length of the cooking time at the lower temperature. However, the p-value (0.097) obtained from the t-test was larger than 0.05, indicating no difference in hardness under different conditions. All samples were tender, since about 1 to 2 kgf was a small force compared to that of a mouth bite. In conclusion, the two-step process maintained tenderness.

**Effect on IMP content** Table 3 shows the IMP content in the cooked meats under different heating conditions. Heating the meat to 48°C resulted in the largest content of IMP regardless of length of the cooking time at the lower temperature. The increase in IMP content found was similar to that found in previous studies (Cambero et al., 2000). IMP content increased significantly when the internal meat temperature was raised to between 55 and 75°C. In our study, the heating conditions affected the magnitude of the IMP increase. The two-step process produced higher amounts of IMP than conventional cooking conditions, as evidenced by the p-value of 0.009.

Our results could be explained by the fact that the heating intensity for conventional cooking (about 2 h) was much higher than that for the two-step cooking process.
less than for the two-step cooking condition (about 3 to 5 h). Cambero et al. (2000) also found that the IMP content decreased slightly above 85°C due to IMP degradation. The lower IMP productions at LT80_54 and LT100_54 conditions could be explained by IMP degradation. The IMP produced during the initial stage of cooking might have degraded at higher temperatures.

Compared to fresh meat, the content of IMP increased after cooking (data not shown) under all heating conditions. Metabolites of adenosine monophosphate (AMP) in fresh meat underwent substantial changes during the cooking process. Several studies have reported that ATP metabolites are converted into IMP during cooking (Arya and Parihar 1979). Control of the cooking temperature can significantly change in the concentrations of IMP, showing direct correlation with sensory quality (Cambero et al., 2000).

Conclusions

The proposed a two-step heating process, long low temperature-short high temperature cooking cycle, can maximize fat reduction while keeping meat tender and juicy like conventional roasting. However, further studies are necessary to adopt the two-step heating method widespread. Relationships between two-step heating process and physicochemical changes in nutrients, taste, and flavor should be understood in detail. Changes in sensory quality are supposed to be understood more systemically at different two-step heating conditions. An assisting heating element would be helpful to shorten cooking time of the two-step heating in the oven. Finally, an optimized two-step heating conditions can be applied to automated oven settings.

Acknowledgements This study was carried out with the support of C&C Group, LG Electronics, Republic of Korea.

References


