Effectiveness of Two Cooking Systems in Destroying Escherichia coli O157:H7 and Listeria monocytogenes in Ground Beef Patties

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ABSTRACT

A rapid, high-temperature double-sided grilling–broiling (DGB) system was compared to a single-sided broiling (SSB) system for cooking of foodservice ground beef patties to reduce microbial numbers and maintain textural quality. Patties (110 g) containing either Escherichia coli O157:H7 or Listeria monocytogenes (10^6-7 CFU/g) were cooked to target internal temperatures of 60 or 68°C on each cooking system and immediately removed from the grills without the additional holding time at 60 or 68°C that is recommended for foodservice cooking of ground beef patties. Actual final internal temperature attained, position on the grill, degree of doneness, cooking time, after-cook weight, texture characteristics, and bacterial counts of the patties were monitored. The DGB reduced E. coli O157:H7 and L. monocytogenes populations in ground beef patties by 5.7 log_{10} and 5.4 log_{10} CFU/g, respectively, when cooked to a target temperature of 60°C (actual final internal temperature of 71.2°C) and by 6.1 log_{10} and 5.6 log_{10} CFU/g, respectively, when cooked to a target temperature of 68°C (actual final internal temperature of 75.8°C). The SSB reduced E. coli O157:H7 and L. monocytogenes populations by 1.3 log_{10} and 1.8 log_{10} CFU/g, respectively, when cooked to a target temperature of 60°C (actual final internal temperature of 62.7°C) and by 2.9 log_{10} and 3.6 log_{10} CFU/g, respectively, when cooked to a target temperature of 68°C (actual final internal temperature of 69.3°C). The DGB system effected a higher, more rapid temperature increase in patties cooked to either target temperature compared to the SSB system. This higher temperature was more effective in destroying pathogens in beef patties. Texture analyses determined that patties cooked on the DGB system had significantly higher values for springiness, adhesiveness, and product height as compared to the SSB system, and patties cooked on either system had significantly higher hardness, gumminess, chewiness, and product height values at the target temperature of 68°C as compared to 60°C.

The first documented case of infection by enterohemorrhagic Escherichia coli O157:H7 in the United States occurred in 1975 (20). Since then, the incidence of foodborne disease outbreaks associated with this pathogen has increased considerably. The most significant have been two outbreaks of hemorrhagic colitis linked to consumption of beef patties in Oregon and Michigan in 1982 (20), and a large multistate outbreak in the western United States in 1993 (4). E. coli O157:H7 was identified in 3.2% of dairy calves and 1.6% of feedlot cattle in the United States (8), and one study demonstrated the presence of E. coli O157: H7 in 3.7% of raw ground beef samples in the United States and Canada (12). The organism was detected in 0.09% of 23,900 ground beef samples analyzed in the United States in an ongoing study since 1994, with an increase to 0.18% of 7,400 samples screened in 1998 (17). Outbreaks have also been linked to consumption of raw and pasteurized milk, apple cider, apple juice, unrefrigerated sandwiches, dry cured salami, mayonnaise, cantaloupe, lettuce, alfalfa sprouts, radish sprouts, and municipal water (3, 8). The more serious forms of the disease are hemorrhagic colitis, hemolytic uremic syndrome, and thrombotic thrombocytopenic purpura that may be life-threatening, requiring high-cost hospitalization procedures (25).

Listeria monocytogenes was first implicated as a foodborne pathogen in the 1980s following its association with outbreaks involving coleslaw and cheese. Undercooked meat and poultry have also been investigated as sources of listeriosis, and incidents reported worldwide have linked the disease to consumption of contaminated chicken, turkey, and pork products (11, 21, 22). Foodborne L. monocytogenes infection is considered to be a significant problem, with a mortality rate of about 33% (14). Ryser et al. have reported L. monocytogenes contamination rates as high as 52% for ground beef (21, 22). Its thermotolerance is estimated to be one of the highest among nonsporeformers (19), and studies on products like meatballs and ground beef have determined that inadequate cooking of meat may also be a source of Listeria infection (7). The U.S. Centers for Disease Control and Prevention estimates the number of listeriosis cases in the United States to be 1,850, with 425 deaths annually (9). Recently, major recalls of hotdogs and delicatessen meats were reported in a listeriosis out-
break resulting in 100 cases in 22 states, including 21 deaths (10).

An estimated 5.4 billion hamburgers or cheeseburgers were reported to be served in restaurants in 1997 (18). Destruction of foodborne pathogens in ground beef during cooking is a critical step that ensures the safety of hamburger patties. A process that would achieve the dual objective of ensuring safety and utilizing the minimum effective cooking time would thus be both economical and reliable. In an effort to reduce the risk of *E. coli* O157:H7 and other foodborne infections associated with the consumption of ground beef patties, the Food and Drug Administration and U.S. Department of Agriculture have recommended a minimum target cooking temperature of 68.3°C with 15 or 16 s holding, for foodservice operations (13, 26). At this temperature, because of the lack of homogeneity in patty composition and temperature monitoring difficulties, the recommended internal temperature may not be uniformly attained, constituting a food safety problem. Alternately, overcooking may char and dry out the patties, with a resultant loss in texture (24). A double-sided grilling–broiling (DGB) system with an electric griddle base and quartz hood is often used for foodservice-type cooking of hamburger patties. Infrared heat from the hood broils the product on one side and contact heat from the griddle surface simultaneously seals juices into the center of the product, minimizing burning (15).

The objective of our study was to compare the efficiency of destruction of foodborne pathogens by a rapid, DGB process using a foodservice-type grill as opposed to a conventional single-sided broiling (SSB) method and to compare the textural properties of hamburger patties cooked on each. Preliminary studies using the DGB process had indicated that cooking the patties to 68°C and allowing them to remain on the grill for the additional recommended 15 s after this temperature was reached resulted in drying out and overcooking, with an undesirable patty texture and appearance. Also, in trial runs of the DGB system, it had been determined that cooking the patties to either an arbitrarily selected lower temperature of 60 or to 68°C, followed by immediate removal from the grill, brought about the targeted 5-log reduction in populations of both *E. coli* O157:H7 and *L. monocytogenes* but did not appear to cause undesirable changes in patty texture. Thus, the experimental protocol was modified to include the removal of the patties from the grills when the internal temperature reached 60 or 68°C, with no additional holding time at these temperatures.

**MATERIALS AND METHODS**

**Ground beef preparation and inoculation.** Beef with a 14.69% fat and 64.68% moisture content (2) from a single mature cow (obtained from the University of Georgia Meat Processing Laboratory, Athens, Ga.) was ground (0.32 cm die plate, model 4046 grinder, The Hobart Manufacturing Company, Troy, Ohio), vacuum packaged in B-620 multilayer bags (Cryovac Division, W. R. Grace and Co., Duncan, SC 29334) in 1.8-kg portions, and frozen at −25°C for up to 8 weeks until used. As needed, portions of the beef were thawed overnight at 4°C.

**Bacterial isolates.** *E. coli* O157:H7 strains E009 (beef isolate), E0019 (cattle feces isolate), 204P (pork isolate), 932 (clinical isolate), and 380-94 (salami isolate), and *L. monocytogenes* strains V7 (milk isolate), Scott A (clinical isolate), 301 (Cheddar cheese isolate), Brie (cheese isolate), and LCDC (coleslaw outbreak isolate) were obtained from the Center for Food Safety and Quality Enhancement, University of Georgia, Griffin, Ga. and preserved on Microbank beads (Pro-Lab Diagnostics, Austin, Tex.) at −25°C. Each strain was activated by two consecutive transfers in 9-ml portions of tryptic soy broth (Difco Laboratories, Division of Becton Dickinson and Co., Sparks, Md.) incubated at 32°C for 24 h. To prepare the final inoculum, 500 ml of tryptic soy broth was inoculated with 9 ml of each 24-h culture, incubated at 32°C for 24 h, and centrifuged (8,300 × g, 20 min, 4°C, Sorvall RC-5B refrigerated centrifuge, DuPont Instruments, Newtown, Conn.). Each pellet was washed twice in 100 ml Butterfield’s phosphate buffer (1) (0.1 M, pH 7.0) and finally resuspended in 40 ml Butterfield’s phosphate buffer.

**Preparation of inoculated patties.** A 25-g random sample was obtained from each thawed, hand-mixed ground beef bulk portion for analysis as an uninoculated control. Ground beef weighing approximately 1,810 g was then inoculated with an equal concentration mixture of either *E. coli* O157:H7 or *L. monocytogenes* strains (approximately 3.5 ml of each strain) to a final concentration of 10^6/g and homogenized in a mixer for 1 min at setting 2 (model K5-A, Hobart Manufacturing Co.). Two 25-g samples were obtained for determination of precook microbial numbers. Portions (110 g) were weighed out and formed into uniform patties that were cooked within 1 h of inoculation. The patty molds were made from Pyrex glass petri dish lids (9.3 cm diameter, 15 mm high) etched at opposite ends along the diameter to form U-shaped grooves through which thermocouples could be inserted. Teflon-coated copper constantan thermocouples (0.022 × 0.038 diameter, Omega Engineering, Stamford, Conn.) attached to a Molytek 3702 multichannel recorder and data logger (Partlow Corporation, New Hartford, N.Y.) were threaded through 11-gauge spinal needles and inserted through each patty within the mold. The needles were removed and used to guide the end of the probe to the geometric center of the patty. Initial stabilized thermocouple temperatures were noted for each patty. The prepared patties were placed on foil sheets until a batch of eight were ready to be cooked on the DGB (Lang XL-24 B clamshell griddle, Lang Manufacturing Company, Everett, Wash.) or a batch of four could be placed on the SSB (smokeless indoor grill, model R4550, Farberware Inc., Bronx, N.Y.).

**Cooking methods.** The cooking systems were preheated to stable operating temperature levels prior to use. The SSB was operated at a surface temperature of 129.9°C (maximum setting), while the DGB was adjusted to a grill temperature of 176.6°C and a quartz hood temperature of 815°C. The DGB setting was selected in accordance with manufacturer’s instructions and previously performed experiments that detected the appropriate temperature at which the patties were cooked with minimum charring. Patties were placed on the grill, and their positions (numbers 1–4) were noted for each. When cooking to a target internal temperature of 60°C, the patties were turned over when the internal temperature reached 30°C and immediately removed from the grill when the internal temperature reached the targeted 60°C. Likewise, when cooking to the target internal temperature of 68°C, the patties were turned over at 34°C internal temperature and immediately removed from the grill when the internal temperature reached 68°C. Cooking time (min) was recorded for each patty, and the actual final internal temperature of each patty after being...
removed from the grill was noted. This determined the continued temperature rise due to latent heat that may contribute to the cooking and lethal effects of each grill. Each cooked patty was transferred to an individual sterile petri dish for analysis.

**Microbiological analysis of patties.** The after-cook weight and visual scores indicating degree of doneness of each patty were recorded. Visual scores for cooked patties were determined by trained personnel, based on the *Ground Beef Patty Cooked Color Guide* (16) using a five-point scale ranging from 1 (medium rare) to 5 (well done). Personnel were trained during preliminary runs of the experiment. Twenty-five-gram samples from the center of each patty were weighed, placed into a sterile stomacher bag with 225 ml of Butterfield's phosphate buffer, and homogenized in a stomacher (Tekmar model 400, Tekmar, Cincinnati, Ohio) for 60 s at normal speed. The sample was serially diluted with Butterfield's phosphate buffer and portions plated onto plate count agar (PCA) (Difco Laboratories) and sorbitol MacConkey agar (Oxoid Ltd., Basingstoke, Hampshire, England) for enumeration of *E. coli* O157:H7, and on PCA and modified Oxford formulation *Listeria* selective agar (Oxoid Ltd.) for enumeration of *L. monocytogenes*. The initial uninoculated control samples and inoculated precook samples of ground beef were homogenized, diluted, and plated in a similar manner. Plates were incubated at 42°C (PCA, sorbitol MacConkey agar) or 32°C (PCA, modified Oxford formulation *Listeria* selective agar) for enumeration of *E. coli* O157:H7 (24 h) or *L. monocytogenes* (48 h), respectively. Colonies were counted on PCA plates, sorbitol nonfermenting pale colonies were counted on sorbitol MacConkey agar plates, and brownish-black colonies were counted on modified Oxford formulation *Listeria* selective agar plates. Identity of suspected *E. coli* O157:H7 and *L. monocytogenes* colonies (two for each treated patty, one from each type of agar medium) were confirmed using the MICRO ID Microbiological identification system (Remel, Lenexa, Kans.). In addition, all *E. coli* O157:H7 colonies confirmed positive by the MICRO ID method were serotyped using *E. coli* H antisera H7 (Difco Laboratories).

**Texture analysis of cooked patties.** Texture profile analysis of cooked patties was done on a Texture Analyzer TA XT2 (Texture Technologies Corporation, Scarsdale, N.Y.) with a crosshead speed of 1.7 mm/s, for various characteristics including hardness, cohesiveness, springiness, adhesiveness, chewiness, resilience, and gumminess. Duplicate 2.84-cm² core samples from each cooked patty cooled to room temperature were compressed twice to 70% of their original height with autotriggering set at 0.010 kg.

**Statistical analysis.** Twenty-four and 12 replications were performed for the thermal inactivation and texture analysis studies, respectively. Experimental data were analyzed as per the least-squares fixed effects model using the General Linear Model program in SAS (23). The model included the main effects of cooking process, endpoint temperature, position of patties on the grills, and all appropriate interaction effects. Means were separated using the LSD procedure of SAS and results analyzed at the 0.05 level of significance.

**RESULTS AND DISCUSSION**

Ground beef patties were cooked with either a food-service-type DGB system or a conventional SSB system to target internal temperatures of 60 and 68°C. After the patties were removed from the grills, the actual mean final internal temperature reached by DGB-cooked patties was 71.2°C (60°C target) and 75.8°C (68°C target), while for the SSB-cooked patties, corresponding temperatures were 62.7°C (60°C target) and 69.3°C (68°C target). Thus, though the patties were removed from the grills at 60 or 68°C target temperatures without the recommended holding time, it was observed that patties cooked to either target temperature on the DGB system attained final internal temperatures in excess of 70°C, this being the minimum temperature at which no additional holding time is recommended (13). Cooking to the same target internal temperature with an SSB system in comparison with a DGB system was significantly different for destruction of both *E. coli* O157:H7 and *L. monocytogenes*. On selective media, the DGB reduced *E. coli* O157:H7 populations by 4.4 log₁₀ and 3.2 log₁₀ CFU/g more compared with the SSB at the lower and higher target temperatures, respectively (Fig. 1). Similarly, the DGB produced a 3.6-log₁₀ and a 2.0-log₁₀ CFU/g greater reduction in numbers of *L. monocytogenes* compared to the SSB at the lower and higher target temperatures, respectively (Fig. 2). Counts obtained on nonselective media closely paralleled those on selective media, with an observed difference of less than 0.5 log₁₀ CFU/g. Also, counts of background microbial flora were obtained from uninoculated samples of ground beef and approximated 2 to 3 log₁₀ CFU/g. In the following discussion, cooking temperatures mentioned will refer to target internal temperatures. The reader should bear in mind that the corresponding actual final temperatures attained were higher, as indicated above. There was significant interaction between cooking process type and target temperature for destruction of both *E. coli* O157:H7 and *L. monocytogenes*, indicating that, although pathogen destruction by the DGB was greater than the SSB at both cooking temperatures, this difference between systems was greater at the lower cooking temperature than at the higher. While the DGB was almost equally efficient at bringing about the targeted 5-log pathogen reduction at both target internal
temperatures, the SSB at the target temperature of 60°C resulted in a 1.8-log_{10} CFU/g reduction in numbers of _L. monocytogenes_ and a 1.3-log_{10} CFU/g reduction for _E. coli_ O157:H7. Though the lethal effect increased with temperature (i.e., the SSB at the target temperature of 68°C reduced _E. coli_ O157:H7 populations by 2.8 log_{10} CFU/g and _L. monocytogenes_ by 3.6 log_{10} CFU/g), a much higher SSB temperature or a longer cooking time would be needed to observe equivalent lethal effects on both systems, as determined from the interaction effects. Because the SSB was operated at the maximum possible temperature setting, a determination of the equivalent higher temperature needed was not feasible. Thus, additional studies would need to be performed to evaluate the effect of longer cooking times on bacterial destruction with the SSB system; the increase in cooking times should then bring about a corresponding increase in the extent of bacterial destruction. Position of patties on the grill and interaction between target temperature and grill position did not significantly affect pathogen destruction.

Cooking on the DGB to a given target internal temperature was significantly more rapid compared with the SSB (Table 1). The difference between mean DGB cooking times at target temperatures of 60 and 68°C was minimal (0.08 min), as opposed to a 5.82-min difference in the mean SSB cook times at the same temperatures. In addition, the position of the patty on the SSB was found to be significant for cooking time, with the positions closest to the incoming current having the longest cooking time. This effect could indirectly affect pathogen destruction, due to position-dependent variations produced in cook times. Patties were positioned on the SSB relative to the incoming current, with positions 3 and 4 being closest to incoming current and positions 1 and 2 being farthest. Similarly, positions 1 and 2 on the DGB were in a vertical line toward the front of the grill and positions 3 and 4 toward the back. The DGB also produced patties with a lower after-cook weight as compared to the SSB at the same temperatures (Table 1), because a slower-cooking broiler like the SSB causes less loss of moisture and fat, especially at the lower target internal temperature of 60°C. Predictably, percentage cook loss was also significantly affected by the interaction of cooking system and temperature, with the DGB at the 68°C target temperature producing patties with the highest cook loss (Table 1). Mean degree of doneness values for the SSB-cooked patties were 3.5 and 3.9 at target internal temperatures of 60 and 68°C, respectively, while those for patties cooked on the DGB system were correspondingly higher, with means of 3.8 and 4.1, respectively. However, studies have shown that degree of doneness evaluations based on visual scores may not always be reliable, because premature browning reactions occur, where the product looks well done at temperatures lower than 71°C or due to a combination of conditions, a pink color may still be present even in patties cooked to 71°C (27). Nevertheless, our study determined that, under identical precooking conditions, patties cooked on the DGB consistently rated higher doneness scores as compared to SSB-cooked patties.

Textural properties of the patties were compared to determine if the cooking processes, target cooking temperatures, position of patties, and their interactions significantly affected patty texture (Table 2). No interaction effects (i.e., cooking system × cooking temperature or patty position × cooking temperature) were found to affect texture of cooked patties significantly. Cooking by different systems had a significant effect on springiness. The DGB process produced patties with higher springiness as compared to the SSB. This could be because the double-sided system cooks more quickly than the SSB, rapidly increasing internal patty temperature, resulting in a higher actual final internal temperature. Fast cooking produces rapid changes in patties, such as protein denaturation, melting and expulsion of fat, evaporation, and drainage of water (24). A combination of heating and drying effects causes an increased amount of

![FIGURE 2. Reduction of _L. monocytogenes_ numbers in inoculated ground beef patties cooked to target internal temperatures of 60 and 68°C using the single-sided broiler (S) and the double-sided griller-broiler (D), obtained on modified Oxford formula Listeria selective agar. Error bars denote the standard error of the mean. Actual final internal temperatures attained at the 60°C target were 62.7°C (S) and 71.2°C (D) and at the 68°C target were 69.3°C (S) and 75.8°C (D).](image-url)
TABLE 2. Least-squares mean observations of textural properties of hamburger patties cooked on the single-sided broiler (SSB)\(^a\) or double-sided griller–broiler (DGB)\(^b\)

<table>
<thead>
<tr>
<th>Cooking process type</th>
<th>Springiness(^c)</th>
<th>Hardness (kg)(^d)</th>
<th>Cohesiveness (kg)(^d)</th>
<th>Gumminess (kg)(^d)</th>
<th>Chewiness (kg)(^d)</th>
<th>Product height (mm)(^d)</th>
<th>Adhesiveness (kg mm)(^d)</th>
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<tr>
<td>SSB</td>
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<td>DGB</td>
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<td>Target internal temperature</td>
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</tr>
<tr>
<td>60°C</td>
<td>0.59 B</td>
<td>13.47</td>
<td>0.41</td>
<td>5.57</td>
<td>3.32</td>
<td>20.10 B</td>
<td>−0.14 B</td>
</tr>
<tr>
<td>68°C</td>
<td>0.64 A</td>
<td>13.96</td>
<td>0.42</td>
<td>5.86</td>
<td>3.83</td>
<td>21.66 A</td>
<td>−0.33 A</td>
</tr>
</tbody>
</table>

\(^a\) Grill temperature = 129.9°C.
\(^b\) Grill temperature = 176.6°C, quartz hood temperature = 815°C.
\(^c\) Means in the same column within each of cooking process or target internal temperature with different letters are significantly different (\(P < 0.05\)).

Muscle protein denaturation and decreases water-holding capacity, resulting in accompanying cook loss and shrinkage (24) that may increase springiness. In comparison, patties cooked on the SSB would be subject to less protein denaturation and retain more moisture, with resulting decreased springiness. Berry (5) similarly found that high-temperature broiling–grilling of patties to well done may create more springiness in the product. Target internal temperature and position of patties did not significantly affect springiness. Target internal temperatures were found to have a significant effect on patty hardness, with considerably harder patties produced at the higher target temperature. Cooking longer, to a higher target temperature (68°C), results in greater moisture loss, increased tissue hardening, and greater crust thickness that may contribute to an increase in patty hardness (24, 28). Grill type and position of patties did not significantly affect patty hardness. Cohesiveness of the patties was not significantly affected by main or interaction effects. Target internal temperature significantly affected patty gumminess, with patties cooked to the 68°C target temperature having significantly larger gumminess values compared to patties cooked to the 60°C target temperature. Because gumminess is measured by the combined effect of hardness and cohesiveness (6), the trend for these values naturally follows those obtained for hardness, as the cohesiveness of the different categories of patties was found to be largely similar. Patties cooked to a target temperature of 68°C were found to be significantly chewier than those cooked to 60°C. This characteristic is determined by the combination of hardness, cohesiveness, and springiness (6). Berry (5) similarly determined that, regardless of method, high temperature cooking to well done creates more chewiness in the product. Cooking method and position of patties did not significantly affect chewiness. Both cooking method and target internal temperature were found to affect patty height significantly. The mean precook patty height was 14 mm; cooking on the DGB and to the higher target temperature increased patty height more than cooking on the SSB or to the lower target temperature, respectively. Studies have shown that various types of contact cooking result in dimensional changes in the patties, including decreases in thickness of 25% or thickness increases during single-sided cooking. Increases were attributed to an upward bulging of patties as well as actual thickness changes during cooking (24). It is possible that double-sided cooking produces an even greater increase in product height, resulting in patties with a fuller appearance, with a more definite crust formed simultaneously on both patty surfaces. This effect would also be positively influenced by the higher target temperature of 68°C. Grill type was the only variable found to produce significant differences in patty adhesiveness, with higher values observed with the DGB-cooked patties, indicating a possible redistribution of internalized moisture between the inner layers and the outer dry crust during texture analysis.

The results of our study indicate that a DGB process was more effective than an SSB process in destroying *Escherichia coli* O157:H7 and *L. monocytogenes* in cooked ground beef patties, as, when cooked to the same target internal temperature on both cooking systems, the DGB rapidly achieved a higher actual final internal temperature. Analyses of texture characteristics determined that patties cooked on the DGB had higher values for springiness, adhesiveness, and product height as compared to the SSB. While these are probably positive characteristics in determining patty texture, additional sensory panel tests would be needed to draw definite conclusions from the data obtained in this study. Furthermore, additional studies are needed to determine bacterial destruction with the SSB system when patties are cooked for longer periods of time on this system.

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