Meat and Muscle Biology™

Consumer Practices and Risk Factors that Predispose to Premature Browning in Cooked Ground Beef[1]

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Abstract: Premature browning is a condition in which cooked ground beef patties turn brown before the USDA recommended temperature of 71°C. This presents a potential food safety concern, as consumers may be eating undercooked meat. Although various intrinsic and extrinsic factors contribute to premature browning, the current knowledge indicates that the myoglobin form present within the interior of patties has a significant influence on cooked color. The objective of the study was to determine the consumer practices of cooking, methods to determine doneness, and type of packaging of their purchased ground beef. The data utilized in this study came from Food Demand Survey (FooDS), which tracks consumer preferences, food expenditures, price expectations, and awareness and concern for a variety of food issues. The sample size of FooDS on-line survey for this study was 1,030. The survey questions consisted of doneness of patties, cooking time, and packaging type of patties. Pictures of different packaging types such as a tray, vacuum package, film wrapped, butcher wrapped paper, frozen patties, and chub were also included. Approximately 67% of respondents indicated that they determine the doneness of ground beef patties by visual observation, 18% identify the doneness by a certain length of time for cooking, and 13.5% use a meat thermometer. Interestingly, 69% of respondents noted that they like a brown interior color of cooked patties. If the patties were prone to premature browning, the chances of consuming undercooked patties are higher. Only 5.7% of people bought patties packaged in a vacuum, while 60% of respondents bought patties packaged in film wrapped or in a tray. Even after 20 yr of attempt by the USDA to educate consumers about safe cooking, the current practices increase the likelihood of premature browning and food safety concerns.

Keywords: cooking temperature, *Escherichia coli* O157:H7, food safety, packaging, premature browning
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Introduction

Foodborne illness results in tremendous health and economic burden (CDC, 2019). The Center for Disease Control and Prevention reported that ground beef had been associated with 56% of the *Escherichia coli* O157:H7 outbreaks in 2014 (Andrews, 2014). Since ground beef is linked with outbreaks of *E. coli* O157:H7 and *Salmonella* contamination, effective pasteurization of ground beef by cooking to recommended temperatures is critical to avoid potential food safety concerns. Prior to the Jack-in-the-Box in the early 1990s, government agencies recommended "brown" as the doneness color for ground beef. Although the USDA-Food Safety Inspection Service has very long recommended using a food thermometer, reporting/detection of premature browning in 1995 has led to include ground beef in the safety guidelines and noted that visual color is not a reliable indicator of doneness (USDA-ARS/FSIS, 1998).

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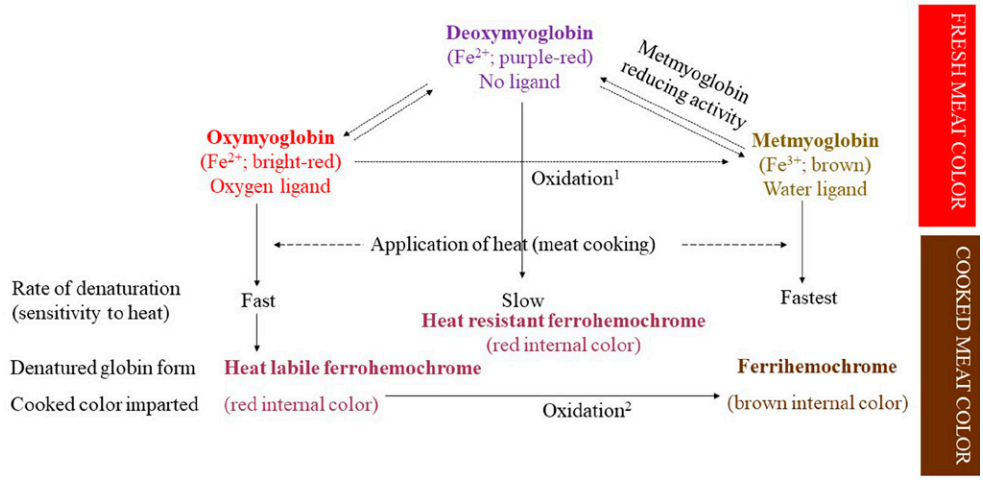

Figure 1. Effects of myoglobin forms on cooked meat color. [1]Conversion from oxymyoglobin to metmyoglobin is not thermodynamically feasible. The arrow indicates visual color change seen during discoloration (AMSA, 2012).[2]In premature browning, conversion of ferrohemochrome to ferrihemochrome is fast, although oxymyoglobin forms ferrohemochrome.

Premature browning is a condition in which interior of cooked patties appear to have a dull brown or well-done appearance before the USDA recommended temperature of 71.1°C to kill enterohemorrhagic *E. coli* and *Salmonella* spp. (Hague et al., 1994; Warren et al., 1996a, 1996b; Amalaradjou et al., 2010; Mancini et al., 2011). If consumers use brown visual color as an indicator of doneness, then premature browning may contribute to undercooking of ground beef. Previous research has noted that 70% of consumers did not use a meat thermometer to determine temperature has reached the recommended level (Phang and Bruhn, 2011). Hence, it is critical to understand consumer cooking and temperature monitoring practices to formulate strategies to limit its undesirable consequences.

Cooked meat color is primarily due to myoglobin denaturation and the Maillard reaction (King and Whyte, 2006). The interior cooked color of ground meat products is determined primarily by 3 intrinsic factors such as myoglobin form (the major driver), pH, and end-point temperature (Fig. 1; Hunt et al., 1999; Killinger et al., 2000). Myoglobin is the primary protein responsible for meat color and depending on the redox state, it can impart pinkish-purple (deoxymyoglobin), bright-red color (oxymyoglobin), or brown (metmyoglobin). The thermal stability of these 3 myoglobin forms differs with deoxymyoglobin being most heat stable and metmyoglobin the least stable, oxymyoglobin is intermediate in thermal stability. Myoglobin form present within the interior of patties is determined by the type of packaging, storage temperature, and time.

Premature browning was first reported in the 1990s when the meat industry started using modified atmospheric packaging to improve color stability (USDA-ARS/FSIS, 1998). A greater concentration of oxygen within a package can limit the migration of brown metmyoglobin form from the interior to surface and retain bright-red color for a longer time (English et al., 2016; Ramanathan and Mancini, 2018). Hence, beef purveyors started using high-oxygen (80% oxygen; 4 times greater oxygen content than atmospheric oxygen) in modified atmospheric packaging to maximize oxymyoglobin formation than traditional aerobic PVC packaging with 20% oxygen. Although modified atmospheric packaging minimized discoloration; this has led to food safety concerns (Lien et al., 2002; Suman et al., 2016).

Previous study noted that 47% of meat sold in retail is prone to premature browning (Killinger et al., 2006). Even though the food safety messages and recommendations to consumers regarding the use of meat thermometer to assure safe cooking temperature are available, limited knowledge is currently available on consumer practices with respect to the type of packaging and cooking procedure. Therefore, the objective of current study was to determine consumer practices and risk factors that predispose to premature browning in cooked ground beef.

Materials and Methods

The methodology utilized in research has been used in several published studies to determine consumer preferences, food expenditures, price expectations, and awareness and concern for a variety of food issues (Lusk and Norwood, 2016; McFadden and Lusk, 2016; Lusk, 2017). The data utilized in this

Table 1. Questions included in the Food Demand Survey to determine consumer practices related to the doneness of patties, cooking time, and packaging type of patties

Question	Choice options
1: Do you eat ground beef patties (i.e. hamburgers)?	Yes or no
2: How do you determine the doneness of ground beef patties when cooking a hamburger?	A) By using a meat thermometer, B) By visual observation (i.e., looking at the color of meat in the center of the patty), C) By cooking a certain length of time, or D) Other ways
3: What is your preference for the cooked internal color of ground beef patties?	Red, pink, brown, or another color[1] such as gray
4: To what internal temperature (degrees Fahrenheit) does the USDA recommend cooking ground beef patties?	Respondents answered on a slider scale that ranged from 100 to 200 in 1°F increments.
5: How is the ground beef you normally buy packaged?	Vacuum sealed, in a box as frozen patties, in butcher wrapped paper, as a chub, and film wrapped in a tray

[1]Another color represents any personal preference such as gray.

study came from a Food Demand Survey (FooDS) project that conducted in May of 2017. The FoodS is an online survey with a sample size of at least 1,000 individuals each month. The survey is delivered on the 10th of the month unless that date falls on a weekend, in which case it is moved to the next closest Monday. The requisite sample size is typically acquired within 3 d. The data collected do not constitute a panel because a new sample is drawn each month; however, precisely the same questions are posted each month. The survey is administered to an opt-in panel maintained by Survey Sampling International, and participants receive points worth about $1.50 for participating. The survey questions consisted of doneness of patties, cooking time, and packaging type of patties. Details of questions are included in Table 1. Pictures of different packaging types such as a tray, vacuum package, film wrapped, butcher wrapped paper, frozen patties, and chub were also included in the survey.

Statistical analysis

The Food Demand Survey is a rapid response system to understand emerging policy or marketing issues (Lusk and Murray, 2014). The FooDs is a national monthly online survey, and the current study had a sample size of 1,030 individuals. The results are weighted to match the US population in terms of age, gender, education, and region of residence (Lusk and Tonsor, 2016). The survey consists of a series of questions that are asked in exactly the same way each month. The results are expressed as a percentage in each category. The margin of error, representing twice the standard error and thus a 95% confidence interval for the population proportion, was calculated for each sample proportion with the following equation:

$$MoE = \pm 2 * \sqrt{\left(\frac{\hat{\rho}(1-\hat{\rho})}{n}\right)}$$

where MoE is the margin of error, $\hat{\rho}$ is the sample proportion, and n is the sample size (n = 1,030). Two proportions were considered different if their margins of error did not overlap.

Results and Discussion

Consumer perception plays a significant role in the judgment of final product quality. This is particularly important in determining the safe cooking temperature of ground patties. In the current survey, out of 1,030 respondents, 88% responded yes to the first questions (do you eat ground beef or cook hamburger). Hence, 906 respondents' observations were considered for the study.

Ground beef is a popular beef product sold in retail (Shahbandeh, 2018). Most consumers are aware that ground beef is a potential source of pathogenic bacteria; hence adequate cooking is necessary to prevent foodborne outbreaks. A panel of food safety experts' ranked use of meat thermometer offers the most critical opportunity to minimize the risk due to foodborne pathogens (McCurdy et al., 2006). In previous research, although 64% of consumers had access to a thermometer, the majority of people looked for visual cues to determine doneness of patties. Popular magazines and cooking shows contradict the USDA recommendation for using a meat thermometer, instead recommending a fixed cooking time (Phang and Bruhn, 2011; Food Network, 2019). Likewise, in the current research 66.7% of respondents used visual observation, while 19.2% cooked patties to a certain length of time to determine doneness (Fig. 2). Only 13.5% of respondents used a meat

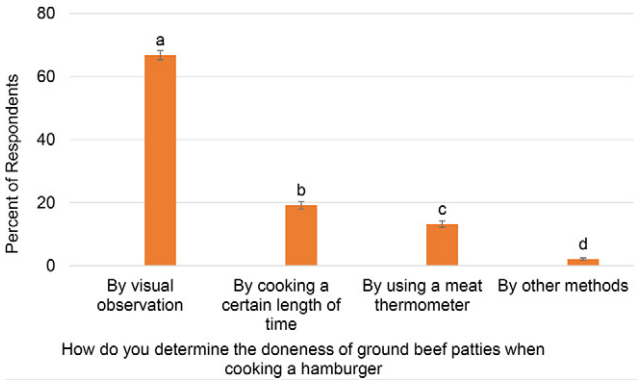

Figure 2. Different ways to determine doneness of ground beef patties. Standard error bars are indicated. Responses with a different letter (a–d) are different at 95% confidence interval.

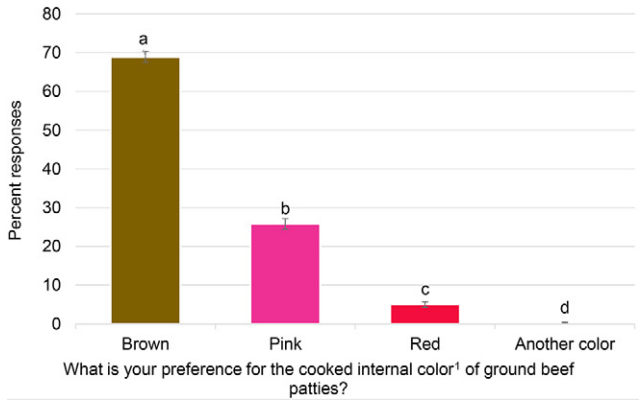

Figure 3. Responses for internal color preferences of cooked patties. Standard error bars are indicated. Responses with a different letter (a–d) are different at 95% confidence interval. [1]Another color represents any personal preference such as gray.

thermometer to ascertain meat has reached pasteurization temperature. Previous study noted only 8.8% of consumers used a meat thermometer to determine the endpoint temperature (Reynold, 2018). Interestingly, 69% of respondents indicated that they prefer a brown interior color for cooked patties (Fig. 3). If the patties were prone to premature browning, the chances of eating undercooked patties would be greater.

Of the 13.5% of consumers that used a meat thermometer in the present study, the average and median cooking temperatures were 72.2 and 71.6°C, respectively (Table 2). Interestingly, 28% of respondents cooked ground beef to <68.3°C (Fig. 4). In the current survey, approximately 25.8% of respondents preferred pink in the interior of patties. This suggests that personal preference or not knowing the USDA recommended temperature in ground beef patties can predispose to food safety challenges, especially when packaged in aerobic conditions that favor the formation of oxymyoglobin and metmyoglobin.

Premature browning depends on packaging, age of meat, postmortem muscle pH, and frozen/fresh conditions (King and Whyte, 2006). Vacuum packaged patties will have predominant deoxymyoglobin form in the interior (myoglobin form resistant to premature browning), while film wrapped will have oxymyoglobin and possibly metmyoglobin in the center (form prone to premature browning). In the United States and United Kingdom, aerobic packaging is the most common type of packaging for ground beef (McMillin, 2008). Consumers associate a bright-red color to freshness and wholesomeness. Both polyvinyl overwrap and high-oxygen packaging can form predominant oxymyoglobin on the surface. In addition, depending on the oxygen concentration within packages (as in high oxygen), oxygen can diffuse from the surface to interior, and results in the formation of oxymyoglobin in the center. Oxymyoglobin form has lower thermal stability than deoxymyoglobin. In this study, the majority of respondents purchased meat in a tray and overwrap (61%; Fig. 5). Myoglobin form within the interior of these patties can be oxy- or metmyoglobin. Furthermore, in patties that have been stored longer and in the central portion of thicker packages of ground beef, deoxymyoglobin can also be formed when the meat had deoxygenated and returned to a reduced state, thus these portions will form a normal pink color while the outer portions will premature brown. In the current research, only 5.7% of people bought patties packaged in vacuum, while 60% of respondents bought patties packaged in film wrapped or in the tray. Patties packaged in vacuum will have a pinkish-purple color of deoxymyoglobin (vs bright red or brown) and will be resistant to premature browning due to its greater stability to heat. In the current research, 6.4% respondents purchased patties in frozen state. Freeze-thawing can increase the incidence of premature browning (Van Laack et al., 1996). The heat transfer to frozen patties can be differ-

Table 2. Summary of cooking temperature and percentage responses

Percentage of response	Cooking temperature, °C
Average cooking temperature	72.2
Median cooking temperature	71.6
28%	68 to 71.1
54%	> 71.1
32.5%	< 68.3
34%	> 73.8

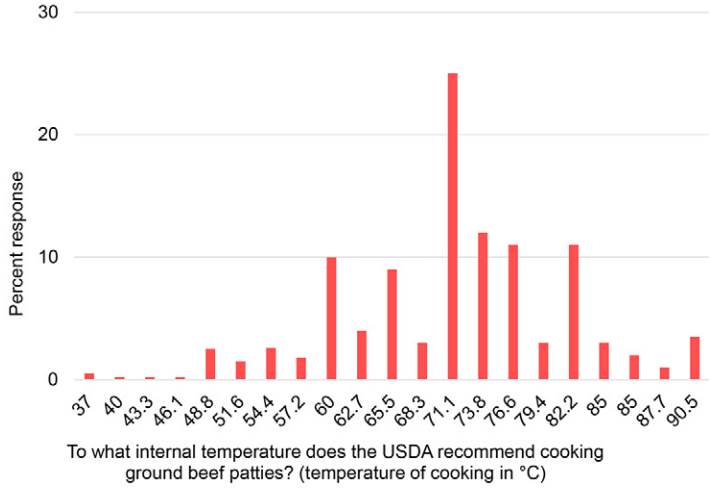

Figure 4. Histogram showing the distribution of cooking temperature.

ent from unfrozen patties and the label recommendation on cooking time can lead to insufficient cooking.

Conclusions

Ground beef has been linked to the occurrence of foodborne illness and cooking is an important step in risk mediation. The survey results indicated that the majority of consumers prefer their cooked ground beef has a brown internal color and 86.5% of consumers did not use a meat thermometer to ensure safe recommended cooking temperature. The survey respondents were using packaging conditions that promote oxymyoglobin and can result in premature browning. The current study suggests that consumer practices increase the likelihood of premature browning and risk associated with eating undercooked patties. Increasing oxygen content in packaging has the potential to minimize wastage due to discoloration, but can lead to cooked color and safety concerns. Characterizing the factors that contribute to premature browning, developing strategies for predictable cooked internal color, and adopting novel consumer educational practices can limit foodborne outbreaks due to consumption of undercooked meat.

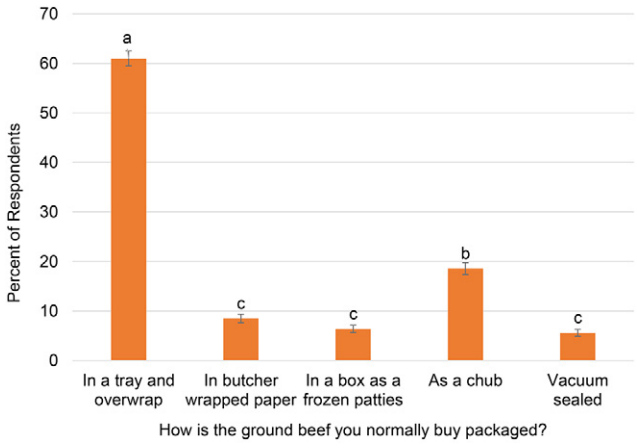

Figure 5. Different packaging types of purchased ground beef. Standard error bars are indicated. Responses with a different letter (a–c) are different at 95% confidence interval.

Literature Cited

Amalaradjou, M. A. R., S. A. Baskaran, R. Ramanathan, A. K. Johny, A. S. Charles, S. R. Valipe, T. Mattson, D. Schreiber, V. K. Juneja, R. Mancini, and K. Venkitanarayanan. 2010. Enhancing the thermal destruction of *Escherichia coli* O157:H7 in ground beef patties by trans-cinnamaldehyde. Food Microbiol. 27. doi:10.1016/j.fm.2010.05.006

AMSA. 2012. Guidelines for meat color measurement. http://www.meatscience.org/publications-resources/printed-publications/amsa-meat-color-measurement-guidelines.

Andrews, J. 2014. CDC shares data on *E. coli* and *Salmonella* in beef. Food Saf. News. https://www.foodsafetynews.com/2014/10/cdc-shares-mass-of-data-on-e-coli-and-salmonella-in-beef/ (accessed 28 Sept. 2019).

CDC. 2019. List of selected multistate foodborne outbreak investigations. Centers Dis. Control Prev. https://www.cdc.gov/foodsafety/outbreaks/multistate-outbreaks/outbreaks-list.html (accessed 28 Sept. 2019).

English, A. R., G. G. Mafi, D. L. VanOverbeke, and R. Ramanathan. 2016. Effects of extended aging and modified atmospheric packaging on beef top loin steak color. J. Anim. Sci. 94:1727–1737. doi:10.2527/jas.2015-0149

Food Network. 2019. Perfect burger. https://www.foodnetwork.com/recipes/bobby-flay/perfect-burger-recipe-1957542 (accessed 28 Sept. 2019).

Hague, M. A., K. E. Warren, M. C. Hunt, D. H. Kropf, C. L. Kastner, S. L. Stroda, and D. E. Johnson. 1994. Endpoint temperature, internal cooked color, and expressible juice color relationships in ground beef patties. J. Food Sci. 59:465–470. doi:10.1111/j.1365-2621.1994.tb05539.x

Hunt, M. C., O. Sørhelm, and E. Slinde. 1999. Color and heat denaturation of myoglobin forms in ground beef. J. Food Sci. 64:847–851. doi:10.1111/j.1365-2621.1999.tb15925.x

Killinger, K. M., M. C. Hunt, R. E. Campbell, and D. H. Kropf. 2000. Factors affecting premature browning during cooking of store-purchased ground beef. J. Food Sci. 65:585–588. doi:10.1111/j.1365-2621.2000.tb16053.x

Killinger, K. M., M. C. Hunt, R. E. Campbell, and D. H. Kropf. 2006. Factors affecting premature browning during cooking of store-purchased ground beef. J. Food Sci. 65:585–588. doi:10.1111/j.1365-2621.2000.tb16053.x

King, N. J., and R. Whyte. 2006. Does it look cooked? A review of factors that influence cooked meat color. J. Food Sci. 71. doi:10.1111/j.1750-3841.2006.00029.x

Lien, R., M. C. Hunt, S. Anderson, D. H. Kropf, T. M. Loughin, M. E. Dikeman, and J. Velazco. 2002. Effects of endpoint temperature on the internal color of pork patties of different myoglobin form, initial cooking state, and quality. J. Food Sci. 67:1011–1015. doi:10.1111/j.1365-2621.2002.tb09445.x

Lusk, J., and S. Murray. 2014. New tool (FooDS) identifies consumers' views on food safety. Choices. 29:1–7.

Lusk, J. L., and F. B. Norwood. 2016. Some vegetarians spend less money on food, others don't. Ecol. Econ. 130:232–242. doi:10.1016/j.ecolecon.2016.07.005

Lusk, J. L., and G. T. Tonsor. 2016. How meat demand elasticities vary with price, income, and product category. Appl. Econ. Perspect. Policy 38:673–711. doi:10.1093/aepp/ppv050

Lusk, J. L. 2017. Consumer research with big data: Applications from the Food Demand Survey (FooDS). Am. J. Agric. Econ. 99:303–320. doi:10.1093/ajae/aaw110

Mancini, R. A., R. Ramanathan, S. P. Suman, G. Dady, and P. Joseph. 2011. Effects of succinate on ground beef color and premature browning. Meat Sci. 89:189–194. doi:10.1016/j.meatsci.2011.04.016

McCurdy, S. M., M. T. Takeuchi, Z. M. Edwards, M. Edlefsen, D. H. Kang, V. E. Mayes, and V. N. Hillers. 2006. Food safety education initiative to increase consumer use of food thermometers in the United States. Br. Food J. 108:775–794. doi:10.1108/00070700610688403

McFadden, B. R., and J. L. Lusk. 2016. What consumers don't know about genetically modified food, and how that affects beliefs. FASEB J. doi:10.1096/fj.201600598

McMillin, K. W. 2008. Where is MAP going? A review and future potential of modified atmosphere packaging for meat. Meat Sci. 80:43–65. doi:10.1016/j.meatsci.2008.05.028

Phang, H. S., and C. M. Bruhn. 2011. Burger preparation: What consumers say and do in the home. J. Food Prot. 74:1708–1716. doi:10.4315/0362-028X.JFP-10-417

Ramanathan, R., and R. A. Mancini. 2018. Role of mitochondria in beef color: A review. Meat Muscle Biol. 2:309–320. doi:10.22175/mmb2018.05.0013

Reynold, J. 2018. Evaluation of consumer food safety behaviors at home. MSc. thesis, Virginia Tech, Blacksburg. https://vtechworks.lib.vt.edu/handle/10919/84545

Shahbandeh, M. 2018. U.S. beef market. Statistics & facts. Statista. https://www.statista.com/topics/1447/beef-market/ (accessed 24 Sept. 2019).

Suman, S. P., M. N. Nair, P. Joseph, and M. C. Hunt. 2016. Factors influencing internal color of cooked meats. Meat Sci. 120:133–144. doi:10.1016/j.meatsci.2016.04.006

USDA-ARS/FSIS. 1998. Premature browning of cooked ground beef. Food safety and inspection service public meeting on premature browning of ground beef. https://www.fsis.usda.gov/wps/portal/fsis/topics/f (accessed 24 Aug. 2019).

Van Laack, R. L. J. M., B. W. Berry, and M. B. Solomon. 1996. Effect of precooking conditions on color of cooked beef patties. J. Food Prot. 59:976–983. doi:10.4315/0362-028X-59.9.976

Warren, K. E., M. C. Hunt, and D. H. Kropf. 1996a. Myoglobin oxidative state affects internal cooked color development of ground beef patties. J. Food Sci. 61:513–516. doi:10.1111/j.1365-2621.1996.tb13145.x

Warren, K. E., M. C. Hunt, D. H. Kropf, M. A. Hague, C. L. Waldner, S. L. Stroda, and C. L. Kastner. 1996b. Chemical properties of ground beef patties exhibiting normal and premature brown internal cooked color. J. Muscle Foods 7:303–314. doi:10.1111/j.1745-4573.1996.tb00606.x