End Point Cooking Temperature and Meat Color

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Introduction

Normally, the cooked color of ground beef patties and other beef cuts changes from red to pink to brown as end-point temperature increases. Normally, lamb should follow similar changes and pork would start from a reddish-pink or grayish pink, but normally would be expected to undergo a lessening of the red-pink and increasing appearance of gray, tan and brown.

Doneness, especially the attainment of a "safe" temperature has become important, especially in ground beef because undercooked ground beef has been implicated as a vehicle for *Escherichia coli* O157:H7 (Neill, 1989). In 1993, this organism in undercooked hamburgers from a fast food chain caused several deaths and over 400 confirmed cases of foodborne illness in four states. *E. coli* O157:H7 has been linked to foodborne illnesses including hemolytic uremic syndrome and hemorrhagic colitis. This very alarming incident, plus several others since, has focused a great deal of attention on meat/food safety. The meat industry can ill afford additional such occurrences. In response to such concerns, USDA-FSIS (1989) recommended that precooked patties for food service institutions be cooked to 71°C, and FDA (1993) stated that patties should be cooked to 68°C for at least 15 seconds. However, because of the difficulty in measuring internal temperature of patties, USDA-FSIS (1989) suggested: "Heat all meat patties until they are hot, steaming, and juices run clear. The center of the patty should be grayish-brown with no evidence of pink color."

Since then, this advice has been found inadequate, and in fact, misleading, dangerous, and potentially expensive to the meat industry and to its customers, in light of considerable research. Furthermore, these internal color recommendations do not coincide with expected color and temperature endpoints. Fortunately, USDA (1997) recognized that internal cooked color of meat, especially ground meat, was not a reliable indicator of the safety of ground beef and changed their recommendations to cook ground beef until the internal temperature is 71°C. No mention was made of cooked color. The FDA recommends in the Food Code for food service establishments that ground beef be cooked to 68°C internally with a holding time of 15 seconds (FDA, 1997).

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Premature Browning (PMB)

Premature browning is the phenomenon in which the interior of ground beef patties appears thoroughly cooked, yet the internal endpoint temperature is below that necessary to ensure destruction of any potentially pathogenic microorganisms. With premature browning, patties appear cooked at temperatures as low as 55°C (131°F). This phenomenon is of critical importance given the recent *E. coli* O157:H7 outbreaks. Although premature browning may not be as critical an issue in the fast food industry and in USDA-inspected establishments where specific time-temperature heating is used, it is extremely important in home and institutional preparation.

Marksberry (1990) was the first to report the incidence of what Hague et al. (1994) called premature browning. When cooked to 65°C (149°F), patties from D- and E-maturity carcasses had visual and instrumental values that were less red than those for patties from A-maturity carcasses. This difference was due neither to patty compaction nor fat level and thus could have been related to carcass maturity.

Hague et al. (1994) tested the hypothesis that premature browning was related to carcass maturity. Patties were made from three sources: the quadriceps muscles of A-maturity carcasses, imported beef trimmings from Australia and New Zealand, and the quadriceps muscles of E-maturity carcasses. Fat from a common source at the Kansas State University Meat lab was added to bring fat to 20%, then final grinding was through a 0.32 cm plate. Patties made from all three sources exhibited premature browning; therefore, carcass maturity was not the cause. However, they concluded that visual appraisal alone was not an appropriate indicator of patty doneness. In order to ensure destruction of *E. coli* O157:H7, the best indicators were either a loss of redness-pinkness in the expressible juice color (these juices never ran clear) or specific time-temperature cooking.

Some studies had suggested that length of frozen storage might correlate with the incidence of premature browning (Hague, 1992; Warren, 1994). To test this, Warren (1994) stored patties from 0 to 45 weeks at -15°C (5°F). Length of frozen storage was not critical to premature browning, but it could contribute to the condition if oxidation occurred during frozen storage.

Warren et al. (1996b) further studied the chemical properties of patties that exhibited premature browning. Heme iron, nonheme iron, and total pigment concentrations did not affect premature browning. However, patties that browned prematurely did have higher TBA values and oxidation-reduction potentials and lower total reducing activity than did normal patties. This led to the conclusion that internal cooked color might be related to the oxidative state of the patty prior to cooking.

To further investigate this hypothesis, Warren et al. (1996a) chemically modified the pigment in patties prior to cooking for a patty source that was earlier found to be normal in cooked color and for another patty source that exhibited PMB when cooked to 55°C. Patties were either reduced with sodium hydrosulfite, oxidized with potassium ferricyanide, or not altered at all. The internal colors of the patties after chemical modification but prior to cooking were as follows: the reduced patties were purplish-red/red, the oxidized patties were brown, and the untreated patties were red/purplish-red. When the internal cooked color was 55, 65, or 75°C, the reduced patties appeared red and undercooked, whereas the oxidized patties were brown and appeared cooked. This led to the conclusion that the oxidized treatment, which resulted in formation of metmyoglobin, caused premature browning; whereas the reduced treatment, which formed deoxymyoglobin, was important to normal cooked color. The untreated normal patties exhibited the expected red to pink internal color and the untreated PMB patties were brown at all cooked temperatures of 55, 65, and 75°C. However, their work did not distinguish differences that might exist between oxymyoglobin and deoxymyoglobin, both of which are reduced heme iron pigments.

Lavelle et al. (1995) found that patties could be handled in such a manner as to produce either premature brown or normal cooked color. The key to controlling color was to utilize the natural reducing enzymes present in the muscle. All patties were made from aged (17 d) meat. Patties were frozen at -40°C (-40°F) in an oxygenated state, vacuum packaged within 24 h, and stored for ≈245 d at -20°C (-4°F). Prior to cooking, patties were handled in one of two ways. Either they were thawed at 4°C (39°F) in vacuum packages and then cooked, or they were thawed at 4°C (39°F) in vacuum packages and then allowed to reduce at 23°C (73°C) for 4.5 hours before being rechilled and cooked. Patties thawed at 4°C (39°F) had a brown,metmyoglobin internal appearance and purge color and subsequently turned prematurely brown when cooked at 163°C (325°F) to 55°C (131°F). These results appeared to agree with those of Machlik (1965), which showed that the stability of myoglobin pigments to heat was of the order metmyoglobin < oxymyoglobin < deoxymyoglobin. Neither total reducing activity, TBA values, nor α-tocopherol content had an impact on cooked color (Lavelle et al., 1995).

Because Lavelle et al. (1995) did not quantitatively measure the pigments prior to cooking, Hunt et al. (1995a) conducted additional experiments to show how myoglobin form related to cooked color. Interior visual and instrumental color value were measured just prior to cooking to verify that the pigment was essentially either deoxymyoglobin, oxymyoglobin, or metmyoglobin (Table 1). At 55°C (131°F), patties whose interior pigment was either oxymyoglobin or metmyoglobin prior to cooking were prematurely brown, whereas patties that contained deoxymyoglobin had normal cooked color (Table 2). The percent denatured myoglobin was determined by extraction after cooking to 55°C (131°F), and 42.6% of the pigment in deoxymyoglobin patties was denatured, whereas about 75% of the pigment in the oxymyoglobin and metmyoglobin patties was denatured (Hunt et al., 1995b). This indicated that the chemical state of the internal myoglobin prior to cooking determined whether patties turned brown prematurely. When the internal pigment was either oxymyoglobin or metmyoglobin prior to cooking, premature browning resulted.

Another consideration is how frequently does premature browning occur. Killinger et al. (1997) purchased ground beef (20% fat) from two retail stores in Manhattan, Kansas, twice each day for eight days during a two-week period. Product was purchased in the morning (< 2 hours after grinding, based on information provided by the meat managers) and cooked within one hour of purchase. Ground beef purchased in the afternoon was refrigerated (2°C) overnight and cooked the following morning. The time of grinding for the afternoon purchases was unknown, but most had been in display several hours and some may have been from the same grind of the morning samples. Package size was between 430 and 680 g. From each package one patty (113 g pressed with a hand patty maker) was made from surface tissue (outer 1.5 cm). Patties were approximately 9.5 cm in diameter and 1.5 cm thick. Pigment in this portion appeared to be predominantly oxymyoglobin in the morning, and both oxy- and metmyoglobin in the afternoon. A second patty was made with meat from the central-bottom portions of the ground mass. The pigments found in these patties in the morning included oxy- and metmyoglobin while the afternoon samples contained deoxy- and metmyoglobin.

The patty from the inner portion of the package was cooked first (< 2 minutes after formation) to minimize changes in myoglobin forms. The patty from the outer layer was cooked six to eight minutes after formation. All patties were cooked to 55°C on a griddle at a surface temperature of 177°C measured with an Omega flexible tip surface probe. Internal temperature of the patties was measured intermittently by inserting an 18 gauge hypodermic thermocouple attached to a temperature recorder into the center of the patty. Cooking time ranged from 5.25 to 8 minutes.

Prior to cooking the outer surfaces of the patty was scored visually using a scale of: 1 = purple-red, 2 = dark reddish purple, 3 = bright red, 4 = brownish-red, 5 = very brown. Visual scoring occurred under 1076 lux of deluxe warm white fluorescent lighting. The interior color of the patties was assumed to be the same as the exterior since cookery was immediately after patty formation and determination of exterior color. In addition, exterior color was measured using a portable Minolta colorimeter to determine CIE L*a*b* values. Readings were taken from four quadrants of the raw patties. Cooked patties were first cut vertically and the two interior surfaces were scored visually. Then the half-circles of the patties were cut perpendicular to the first cut and three instrumental readings were taken from the center of the patty using the Minolta. The visual score for cooked patties was: 1 = very dark red to purple, 2 = bright red, 3 = very pink, 4 = slightly pink, 5 = tan (no evidence of pink).

The visual scores for uncooked patties taken from the outside of the package and those purchased in the morning were brighter red ($P < 0.05$) than those taken from the interior of the package and those purchased in the afternoon, respectively. Uncooked patties purchased in the morning were more ($P < 0.05$) red (a*) and yellow (b*) than those purchased in the afternoon. Furthermore, patties taken from the outside tissue in the package were more yellow ($P < 0.05$) than those from the interior.

Visual scores (vertical cut) for cooked patties made from the outer tissue of the package and for patties from packages purchased in the morning were more ($P < 0.05$) premature brown than those made from the interior tissue or from packages purchased in the afternoon and stored overnight. Visual scores for the patty halves cut horizontally followed the trends shown by the visual scores for the vertical cuts, but the horizontal surfaces tended to be more obviously brown.

Cooked patties that were purchased in the morning were lighter ($P < 0.05$) than those purchased in the afternoon. The a* values of patties made from the inside of the package were higher (more red; $P < 0.05$) than those for patties made from outside tissue. Additionally, patties purchased in the afternoon were much redder (higher a* values) than those purchased in the morning.

To determine premature browning, the frequency of visual scores was determined. Patties with a score of 4.0 or higher were considered premature brown. Considering all cooked patties, 47% of the patties (30 of 64) were premature brown. Patties from the outer portion of the package had a higher incidence (59%) of premature browning than those from the inside portion of the package (34%). Patties purchased in the morning had a higher incidence (53%) of premature browning than those purchased in the afternoon (41%).

Purchasing ground beef and refrigerating it overnight allows more oxymyoglobin and more metmyoglobin to transform into deoxymyoglobin which would result in a lower incidence of premature browning in ground beef patties. From a consumer's point of view, buying hamburger and allowing it to sit overnight is not always practical. In order to minimize risk, ground beef patty doneness should not be judged by color, but should be verified by measuring the internal temperature of the patty.

Persistent Red or Pink Color in Cooked Meat

This condition is defined as the appearance of red or pink in meat cooked adequately for safety, but having an appearance of insufficient heat treatment. Persistent pink cooked color in meat has become a serious problem because of the persistent, but misleading message that cooking to gray or brown is necessary to assure "safety" from foodborne diseases caused by pathogens. This "pinking" occurs in a variety of meats including very lightly pigmented turkey and chicken breast. Historically, consumers have been most concerned with pink color in cooked pork or poultry, since they expect it to appear fully cooked, thus providing assurance of a safe food to consume. Pink cooked intact muscle beef and ground beef has been accepted, but recent food poisoning incidents involving *E. coli* O157:H7 in undercooked hamburgers (ground beef) has heightened consumers' awareness of the potential risks associated with undercooked beef, most notable in ground beef. Thus, meat that is thoroughly cooked is being rejected by consumers.

Persistent red color in ground beef patties has become a costly economic problem for beef processors and for the food service industry, mainly due to consumer rejection. Consumers complain when cooked ground beef patties, which are normally very slightly pink to grey inside, retain a red or pink "raw" color after cooking. Additional cooking may remove the red, pink color but not without a concurrent loss of quality, particularly in texture and juiciness (Mendenhall, 1989). Persistent red color is simply a situation where a fully cooked beef patty remains red to pink internally after reaching the recommended cooking temperature. Variation in the color of precooked meat products cooked to the same internal temperature has been a problem in the meat industry for over 30 years (Hunt and Kropf, 1987).

Many possible causes of persistent red color have been addressed. Possibly the most simple, but infrequent cause, is undercooking of ground beef. However, several other causes are not as easily recognized. Red to pink color in fresh cooked meat has been attributed to several factors, most importantly pH. Examples are patties immersed in meat juice (Kropf, unpublished), nitric oxide (Brant, 1984), carbon monoxide or oxides of nitrogen contamination from either gas-fired ovens (Pool, 1956) or exhaust fumes (Froning, 1983), addition of dried egg albumen during processing, differing concentration of myoglobin (Froning et al., 1989), pre-slaughter stress leading to elevated muscle cytochrome concentration (Babji et al., 1982), and the formation of a reduced nicotinamide-denatured globin hemochrome during cooking (Cornforth et al., 1986); Mendenhall, 1989). Trout (1989) states that any one or a combination of these factors may be responsible for isolated occurrences, but they cannot fully explain the widespread nature of the problem. Very enlightening reports by Cornforth (1988, 1991) have been useful in elucidating causes and outlining preventive steps.

A large proportion of persistent red or pinking problems in cooked beef and other meats is due to the formation of reduced hemochrome pigment. Beef can be cooked high enough (to 160°F) to cause a color change to gray-brown, but this color can revert to red/pink under reducing conditions. Thus, the myoglobin must not have been fully denaturated. Both heat and reducing conditions appear necessary for formation of red/pink reduced hemochrome. Slight acidification or oxidation has been effective in some meat products to change the cooked pigment from the reduced stage and convert it to an oxidized form that will give the cooked meat a more done appearance. Other approaches, still in early research stages, might utilize some added ingredients that become reduced more readily than myoglobin, thus using up the reducing potential in the cooked meat rather than have it convert the cooked meat pigment from the *ferrihemochrome* form (with a "done" appearance) to the reduced *ferrohemochrome* form (with an undercooked or even a "raw" appearance).

A very important cause of persistent red color is the use of beef with a pH of 6.0 or higher. The high pH protects myoglobin form heat denaturation so that the bright red pigment (oxymyoglobin) or purple-red (deoxymyoglobin) may be present a higher cooked temperatures, especially in the middle of hamburger patties, even when the outside surface is charred. High pH beef frequently is derived from sources such as cow, bull or dark cutting carcasses. This problem is more extensive if patties are not cooked immediately after forming, but are held under refrigeration before cooking. This holding period allows patties to set up, or "gel," which facilitates handling of the patties when cooking. Remixing and reforming can break up the gel, but represents a further processing cost.

Schoenbeck et al. (1998) cooked ground beef patties (113 g, 20% fat) made from muscle of pH 5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 6.3, and 6.4 to end-point temperatures of 66, 71, 77, and 82°C and evaluated internal color for both patties that had primarily oxymyoglobin internally before cooking and also deoxymoglobin internally. Myoglobin denaturation also was measured. Oxymyoglobin patties became sharply more resistant to thermal denaturation at pH 6.2 or higher while deoxymyoglobin patties had a more linear decrease in thermal denaturation with increased pH. Ingredients that would elevate pH, e.g., phosphates, could enhance the persistent red color.

Nitroso pigments, similar to those formed in meat curing, may cause a pink pigment in cooked meat. Possible causes include nitrate or nitrite contamination from atmospheric aerosols, table tops, meat containers, equipment or tools that have previously been used for cured meat. Also, the addition of nitrate-containing ingredients, such as celery, onions, green peppers, carrots, beets or leafy green vegetables to beef in meat loaves, meat balls or similar combination foods may cause the pink color. Nitrate or nitrite contamination from water or spices added to meat products are also possible sources. In addition, ammonia leaks from refrigeration units (Shaw et al., 1992) ammonia on equipment after sanitizing, nitrogen containing gases in exhaust gases inhaled during transport or in the atmosphere of poorly ventilated confinement environments for animals are possible sources. Protein additives dried in an open flame drier may be *nitrosylated* by combustion gases containing oxides of nitrogen and cause reddening or pinking. The location of the *Nitroso pigment* may be used as a diagnostic tool for this cause of persistent pinkness. Often the cured color is just on the surface or surrounding the nitrite-containing ingredient, but the color may at times be dispersed throughout the product.

Dirty gas jets or a poorly adjusted gas-fired oven can result in incomplete gas combustion with carbon monoxide and oxides of nitrogen created in the "within-oven" atmosphere. These can react with meat pigments and will produce a heat stable red color on the surface of the meat to a depth of 1/8 to 1/4 inch, but not in the product interior. Recent work by Cornforth (1998) surface pinking in both cooked turkey and beef was not observed with up to 149 ppm carbon monoxide or 5 ppm nitric oxide (NO), but as little as 0.4 ppm nitrogen dioxide (NO_2) caused pinking.

In visiting with school lunch suppliers or users, when precooked ground beef patties are sealed in a plastic bag, those immersed in meat juice in the bottom of the bag frequently will show a persistent red color on their surface. The reason for this is not clear, but preventing immersion in juice is helpful in minimizing the problem. In our preliminary work, we have not been able to duplicate this, but the mechanism likely involves reductive reactions of the heme pigment.

Some of the above reasons for the persistent red color in cooked beef have been documented and confirmed while other causes are somewhat speculative and disagreement exists about their contribution to this problem. Solutions to the problem may be rather simple or very complex. For instance, the influence of nitrate/nitrite containing ingredients can be easily tested by removal of individual ingredients to determine if this will eliminate the problem. On the other hand, problems associated with high pH meat are less easily resolved. Frequently, occurrence of the persistent colors are sporadic, making accurate diagnoses difficult.

Determination of reflectance spectra of the red areas or of absorbance spectra of extracts from these areas can provide useful clues about the chemical state of myoglobin, which may be helpful in identifying the cause of a persistent red color problem. *Nitrosohemochrome*, (the heated cured meat pigment) and *nicotinamide hemochrome* pigment, either of which could contribute to the problem, have unique reflectance or absorbance characteristics at specific wavelengths. Such information can help establish cause.

Concluding Statements

1. We owe it to our customers (consumers) to base our working recommendations and assessment of doneness on science, not tradition.

2. Cooking to reach a temperature endpoint of 71.1°C (160°F) or 68.4°C (155°F) for 15 seconds is the best assurance of "safe" ground beef. A large educational program in necessary for consumers. While some home used thermometers will work, development of rapid response thermometers with a very small temperature sensitive point at a reasonable cost is a critical need.

3. Ground beef patties cooked to a brown internal endpoint have two very serious disadvantages. First, this does not guarantee "safety," in fact in some cases the risk assessment indicates 10,000 to 11,000 times the risk of being unsafe and undercooked. Second, a concentrated effort to cook to brown will result in overcooking in may cases, with a serious loss of desired sensory properties.

4. Ground beef patties cooked to a slightly pink internal appearance is a built-in quality control indicator providing the pigment at time of cooking is deoxymoglobin.

5. Additional work is needed to clearly identify the major factors related to persistent cooked colors. Unfortunately, the recommendation to cook to the "brown" internal color has been counter productive to the industry and ignores the science of myoglobin thermal denaturation under various conditions.

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