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Factors influencing internal color of cooked meats

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ABSTRACT

This manuscript overviews the pertinent research on internal color of uncured cooked meats, biochemical processes involved in meat cookery, and fundamental mechanisms governing myoglobin thermal stability. Heat-induced denaturation of myoglobin, responsible for the characteristic dull-brown color of cooked meats, is influenced by a multitude of endogenous (i.e., pH, muscle source, species, redox state) and exogenous (i.e., packaging, ingredients, storage) factors. The interactions between these factors critically influence the internal cooked color and can confuse the consumers, who often perceive cooked color to be a reliable indicator for doneness and safety. While certain phenomena in cooked meat color are cosmetic in nature, others can mislead consumers and result in foodborne illnesses. Research in meat color suggests that processing technologies and cooking practices in industry as well as households influence the internal cooked color. Additionally, the guidelines of many international public health and regulatory authorities recommend using meat thermometers to determine safe cooking endpoint temperature and to ensure product safety.

1. Introduction

Cooking of meat is an ancient practice that has evolved into refined daily cooking techniques (Nam, Jo, & Lee, 2010) as well as sophisticated modern thermal processing units with multiple process controls (Barbosa-Canovas, Medina-Meza, Candogan, & Bermudez-Aguirre, 2014). Thermal processing of raw meats is necessary to destroy microorganisms and pathogens, which can be a major source for several foodborne illnesses. For this reason, USDA-FSIS has set specific internal temperature guidelines (USDA, 2013) for cooking muscle foods and recommends using a food thermometer to ensure that the product reaches the required internal temperature to destroy pathogens. Numerous food safety agencies in other countries have provided additional time–temperature combinations that render cooked meats safe for consumption (FDA, 2011).

The cooking process for fresh, uncured meat denatures myoglobin (Mb) resulting in a dull-brown appearance in the interior of the product. Nonetheless, the interior color can vary based on the degree of doneness achieved. Because consumers associate the change in color of meat from red (raw) to brown (cooked) as a function of thermal treatment, they frequently use internal cooked color of meat products as an indicator of doneness and safety at the point-of-consumption (King & Whyte, 2006; Holownia, Chinnan, & Reynolds, 2003; Mancini & Hunt, 2005; Suman, Hunt, Nair, & Rentfrow, 2014). In cooked meat products, dull-brown interiors are considered the hallmark of a well-done product, whereas a pinkish interior color indicates meat cooked to a lower degree of doneness, which can be undercooked and unsafe (King & Whyte, 2006). Any deviation from the brown appearance in cooked meats can influence consumer perceptions of meat safety. Unfortunately, these visual descriptions of internal color are not very accurate or precise. Furthermore, color judgements vary with the observer, the object, and the type and intensity of the lighting, which can lead to inappropriate food safety decisions (AMSA, 2012). From this perspective, internal cooked color in meats is not only a cosmetic concern but also a food safety issue.

The purpose of this manuscript is to review the relevant research on internal color of cooked meats, biochemical processes involved in cooking meat, and fundamental mechanisms governing cooked color phenomena. In addition, the science of cookery methods is covered only by stating the cooking method employed in the reviewed literature.

2. Biochemistry of cooked meat pigments

The dull-brown color in cooked meats is due to the heat-induced denaturation of Mb, the water-soluble sarcoplasmic heme protein responsible for the red color of fresh meat. Therefore, the biochemistry of cooked color differs from the color phenomena in fresh meats, where the heme protein is in its native state. Nonetheless, the relationship is strong between the chemistry of Mb in raw meat and cooked product, and many factors (endogenous and exogenous) affect both (Mancini & Hunt, 2005; Suman & Joseph, 2013; Suman & Joseph, 2014).

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Myoglobin, the heme pigment primarily responsible for the red color of fresh meats, denatures upon exposure to heat. Thermal denaturation of Mb is a process not necessarily happening at a particular point, but rather occurring over a short range of temperature (Bernofsky, Fox, & Schweigert, 1959; Bowers, Craig, Kropf, & Tucker, 1987). Lytras, King, and Ledward (2000) studied the kinetics of Mb denaturation in beef and lamb burgers cooked to wide range of internal temperatures and observed that Mb denaturation follows a first order kinetics. Several studies documented increased Mb denaturation in meats as internal cooking temperatures increased (Bernofsky et al., 1959; Machlik, 1965; Nusimovich, Celmi, & Pagliaro, 1979; Howe, Gullett, & Usborne, 1982; Bowers et al., 1987; Trout, 1989; Hague et al., 1994; Lavelle, Hunt, & Kropf, 1995; Hunt, Sorheim, & Slinde, 1999; Mancini, Kropf, Hunt, & Johnson, 2005).

The chemistry of pigments in cooked meat depends on the predominant redox form of Mb in raw meat before the cooking begins. Therefore, factors governing the chemistry of pigments and color in fresh meat profoundly affect the color of cooked meat as well. Exposure to heat (during cooking/thermal processing) leads to the unfolding (denaturation) of the globin portion of Mb and results in a concomitant exposure of heme group to the external environment. The exposed heme moiety is more susceptible to oxidation than the heme in its native state. One result of the heat-induced denaturation of globin is that pigments in cooked meats coagulate and become insoluble in water/buffers (Tappel, 1957; Cornforth, 2001). Therefore, reflectance measurements must be used to study cooked meat pigments, while absorbance spectrophotometry is widely used to study fresh meat pigments (Cornforth, 2001; AMSA, 2012).

A variety of pink or brown pigments are formed in cooked meats (Table 1). Globin denaturation in metmyoglobin (MetMb) leads to the formation of denatured globin hemichrome (also known as ferrihemochrome), which is responsible for the dull-brown color in cooked meats. Unfolding/denaturation of globin in ferrous Mb results in formation of pink–red ferrohemochrome (denatured globin hemochrome). Ferrohemochrome is subsequently and readily oxidized to ferrihemochrome. Cooking of CO-treated meat leads to heat-induced denaturation of carboxymyoglobin (COMb) and the formation of pink–red pigment, denatured globin CO hemochrome (Cornforth, Calkins, & Faustman, 1991). If the heme iron is maintained in the reduced ferrous state, a variety of additional pink hemochromes is possible in cooked meats. After heat-induced denaturation of globin, nicotinamide or other nitrogen-containing ligands can bind with the heme at the coordinate previously occupied by globin. However, the denatured globin may remain associated with heme while nicotinamide or nitrogen-containing ligands associate with the sixth coordinate of heme. Although Maillard reaction products (unrelated to Mb-derived brown pigments) form on the external surfaces of meats during cooking, their contribution is mainly to aroma, not to the internal cooked color (Mottram, 1998). From this standpoint, biochemistry of cooked meat color is primarily dictated by heat-denatured Mb pigments.

3. Factors influencing Mb thermal stability

Both endogenous and exogenous factors affect the redox chemistry of Mb in fresh meat, and most of them also affect the heme protein's thermal stability and thus, the cooked color. The most important of the influences found in meat processing, which govern Mb thermal stability are pH, the redox state of Mb, the primary structure (amino acid sequence) of Mb, and the presence of antioxidants and prooxidants. Practically speaking, these four things determine color phenomena in cooked meats.

3.1. Meat pH

The typical ultimate pH of post-mortem skeletal muscle in beef, pork, and lamb is 5.5–5.8, whereas post-mortem pH of avian muscles ranges from 5.7 to 6.0. In contrast, the pH of live muscle is ≈7.2. As muscle is converted to meat, glycogen breaks down and lactic acid accumulates, and this is reflected as a declined pH. The rate and extent of the pH decline significantly influence Mb functionality and stability (Scopes, 1964; Lawrie, 1965). Mb is more stable at pH 7.4 than at pH 5.6 (Livingston & Brown, 1981; Gotoh & Shikama, 1974). Several previous studies (Table 2) examined the relationship between meat pH, Mb thermal stability, and cooked color in beef, lamb, pork and turkey. Most studies report that Mb in meat at a pH < 5.4 is less stable to heat, whereas high meat pH (>6.0) protects Mb against heat-induced denaturation and increases the internal redness of cooked meats.

3.2. Redox state of Mb

The thermal stability of Mb is influenced by the protein's redox state. Machlik (1965) demonstrated that the extent of Mb denaturation depends on the protein's redox state, namely deoxymyoglobin (DeoxyMb), oxymyoglobin (OxyMb), and MetMb. The relative resistance of Mb forms to heat-induced denaturation was DeoxyMb > OxyMb > MetMb. Further studies (Lavelle et al., 1995; Warren, Hunt, & Kropf, 1996; Warren, Hunt, Kropf, Hague, et al., 1996; Hunt et al., 1999) indicated that both oxidized (MetMb) and oxygenated (OxyMb) pigments in raw ground beef patties are more prone to heat-induced denaturation than their reduced counterpart (DeoxyMb). Investigations using purified Mb in model systems have also documented that beef MetMb had less resistance to heat-induced denaturation than DeoxyMb and OxyMb (Sepe et al., 2005). Furthermore, Hunt et al. (1999) clearly demonstrated the Mb thermal denaturation to be critically influenced by the interactions between redox state, pH, and endpoint temperature. In addition, COMb was slightly more thermally stable than DeoxyMb, and both were considerably more stable than MetMb and OxyMb (Ballard, 2004). The implication is that at a given endpoint cooking temperature, meat containing mostly DeoxyMb or COMb will more likely have red/pink interiors than meat with high proportions of MetMb and OxyMb.

3.3. Primary structure of Mb

The primary structure of Mb dictates its tertiary (three-dimensional) structure, which in turn influences protein's interactions with ligands and macromolecules, ultimately affecting both fresh and cooked meat color. Redox stability of Mb is influenced by its primary structure via mechanisms such as autoxidation, heme retention, oxygen affinity, and interactions with biomolecules (Fig. 1; Suman & Joseph, 2013). Thus, Mb primary structure governs the resistance to heat-induced denaturation and influences the color of cooked meats. Comparative studies on thermal stabilities of turkey and beef Mb (Joseph, Suman, Li,

Table 1
Biochemistry of pigments in cooked meats.
Reproduced from Suman and Joseph (2014) with permission

Pigment	Meat species	Color	Oxidation state of heme iron	Status of globin	Reference
Denatured globin hemochrome	Cooked pork or beef	Pink or red	Fe^{2+}	Denatured	Tappel (1957); Ghorpade and Cornforth (1993)
Denatured globin hemichrome	Cooked pork	Brown, tan or gray	Fe^{3+}	Denatured	Tarladgis (1962)
Nicotinamide hemochrome	Turkey	Pink or red	Fe^{2+}	Denatured	Tappel (1957); Cornforth et al. (1986)
Denatured globin CO hemochrome	Cooked beef	Pink or red	Fe^{2+}	Denatured	Tappel (1957); John et al. (2004)