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Effects of food ingredients and oxygen exposure on premature browning in cooked beef

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ABSTRACT

Premature browning (PMB) in the centre of cooked hamburgers and beef loin (M. *longissimus dorsi*) steaks was assessed visually and instrumentally. Rosemary extract, ascorbic acid, sodium lactate, polyphosphate or lingonberry juice were added to freshly ground beef with predominant oxymyoglobin, and hamburgers were cooked to 62 °C. In general, the tested ingredients did not reduce the extent of PMB in hamburgers, but polyphosphate tended to reduce PMB due to increased pH. Control burgers made of vacuum packaged meat with deoxymyoglobin were cooked to 62, 69 and 75 °C, and did not express PMB. Beef loins were injected with a solution of sodium lactate, polyphosphate and sodium chloride. Loin steaks were stored under 75% O_2/25% CO_2 for 5 days and also cooked to 62 °C. Injected steaks had less PMB than non-injected controls, but of a low magnitude unlikely to influence the perception of doneness. The study demonstrated that anaerobic packaging is the most efficient measure to avoid PMB in beef.

1. Introduction

Consumers are facing challenges in evaluating cooked beef for its degree of doneness. Premature browning (PMB) is a condition in which meat appears fully cooked despite not having reached a safe internal temperature, leading to the possible survival of pathogenic bacteria (Lavelle, Hunt, & Kropf, 1995). With PMB the muscle pigment myoglobin is brown/grey and denatured at temperatures of approximately 60 °C, while normally this should occur at 70–75 °C. Beef that either is ground or injected is more at microbiological risk than intact meat (Buchanan & Doyle, 1997; Gill, Moza, & Barbut, 2009). US food control authorities have established a zero tolerance for the *Escherichia coli* serogroup O157 in ground beef, and six other pathogenic serogroups of *E. coli* including O26, O45, O103, O111, O121 and O145 have been suggested to be covered under this regulation (USDA, 2011a). Furthermore, USDA (2011b) recommends that ground beef should be cooked to 160 °F or 71 °C for 1 s, or 155 °F or 68 °C for 15 s, to avoid foodborne illness. A recent study on consumer behaviour demonstrated that in a 200 person test group 70% of the group cooked burgers to a lower temperature than recommended (Phang & Bruhn, 2011). Moreover, only 4% of the group used a food thermometer to verify doneness of their burgers, and the knowledge of safe cooking procedures was very limited.

The extent of PMB is dependent on the form of the muscle pigment myoglobin in the interior of raw meat prior to cooking (Killinger, Hunt, Campbell, & Kropf, 2000). The pigment exists in four forms: oxymyoglobin (OMb), deoxymyoglobin (DMb), metmyoglobin (MMb) and carboxymyoglobin (COMb). Myoglobin can be found as bright red OMb after exposure to oxygen (O_2) or air, or as brown/grey MMb after oxidation by exposure to low residual O_2 or long time storage. In hamburgers, OMb turned grey and both OMb and MMb denatured at 55–60 °C, typical characteristics for PMB (Hunt, Sørheim, & Slinde, 1999; John et al., 2004). The same pattern for PMB with OMb was obtained in beef loin steaks and enhanced beef steaks, respectively (John et al., 2005; Seyfert, Hunt, Mancini, Kropf, & Stroda, 2004). Packaging of whole or ground beef in vacuum creates purple DMb, while modified atmosphere packaging with approximately 0.4% carbon monoxide yields cherry red COMb. Both DMb and COMb prevented PMB and resulted in myoglobin denaturation and browning in the temperature range 70–80 °C (Hunt et al., 1999; John et al., 2004, 2005). Increased pH of the raw beef reduced the incidence of PMB by increasing the temperature for myoglobin denaturation, in particular in the range 55–70 °C (Hunt et al., 1999; Trout, 1989).

The formation of raw meat DMb, which is favourable for avoiding or reducing PMB, can be facilitated by the addition of reducing agents and other food ingredients. Various ingredients have been evaluated for their ability to stabilise raw beef colour, although less is known about the function of these ingredients on cooked colour. The reducing agents sodium erythorbate, sodium ascorbate, ascorbic acid and ascorbyl palmitate were added to ground beef (Sepe et al., 2005). All agents, but in

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particular the two first mentioned, were effective in reducing PMB. Lactate is an antimicrobiological agent that is frequently used in marinades for injection of beef. Enhancement of beef steaks with 2.5% lactate resulted in a darker cooked colour, and contributed to less PMB in meat stored under high O_2 (Suman, Mancini, Ramanthan, & Konda, 2009). Rosemary is an effective and commonly used antioxidant for fresh beef packaged and stored in air or high O_2 atmospheres, by increasing the colour stability of raw meat (Balentine, Crandall, O'Bryan, Duong, & Pohlman, 2006; Sánchez-Escalante, Djenane, Torrescano, Beltrán, & Roncalés, 2001). Salt (NaCl) may be used at low levels in enhancement solutions, but acts as a pro-oxidant. NaCl in concentrations of 1, 2 and 3% increased myoglobin denaturation and consequently PMB in beef muscles (Trout, 1989). In the same study, tripolyphosphate, another commonly used ingredient for enhanced beef, also resulted in higher myoglobin denaturation per se. However, the increased pH by addition of tripolyphosphates can counteract early pigment denaturation (Trout, 1989).

The juice of the Scandinavian lingonberries (*Vaccinium vitis-idaea*) has a scarlet colour and a sweet bitter taste. Lingonberries are rich in antocyanidins, flavonols, citric acid and benzoic acid (Määttä-Riihinen, Kamal-Eldin, Mattila, González-Paramás, & Törrönen, 2004), as well as glucose and sucrose (Viljakainen, Visto, & Laakso, 2002). These sugars may act as reducing agents. The lingonberry juice has been tested in many types of foods, but has not been evaluated for meat products.

The aim of the present study was to examine reducing agents and other food ingredients for their ability to reduce PMB in beef. First, different ingredients were studied separately in a test system of freshly ground beef containing predominantly OMb. In the second test, injected beef loin steaks stored under a high O_2 atmosphere were used to investigate the effectiveness of a combination of ingredients.

2. Materials and methods

2.1. Production of hamburgers

Vacuum packaged beef trimmings with 14% fat were obtained from a slaughterhouse (Furuseth, Dal, Norway) 5 days post mortem. The meat was ground twice through a 4 mm plate. As shown in Table 1, the following ingredients to ground beef were tested in series H1–H5: rosemary extract (Guardian Rosemary 09, Danisco, Copenhagen, Denmark), L(+)-ascorbic acid (BASF AG, Copenhagen, Denmark), L-sodium lactate (Purasal S, Purac, Gorinchem, The Netherlands), polyphosphate with a mixture of di- and triphosphates (Canal 2110, Budenheim KG, Budenheim, Germany) and lingonberry juice (Askim Frukt-og Bærpresseri, Askim, Norway), respectively. Series H6 was a control with no additives. The compounds in series H1–H5 were added to distilled water and blended as 5% solutions into the meat. The meat for series H1–H6 was freshly ground from the same batch with the pigment predominantly OMb, as viewed shortly after grinding. In addition, three extra controls of series H7, H8 and H9 with purple DMb were made from the same batch by storing ground beef without ingredients and water under vacuum for 2 days until nearly complete reduction of the pigment. One hundred grams of meat or meat blends were used for making hamburgers 80 mm wide and 16 mm high in a manual pressure mould. The ground beef test was repeated with three separate batches. For each series 4 hamburgers were made per batch to a total of 12 hamburgers per series, or 108 hamburgers for the experiment.

Table 1
Overview of ingredients used in the hamburger experiment.

Series	Additive	Concentration %	Myoglobin form[a]	Core temp. °C
H1	Rosemary extract	0.1	OMb	62
H2	Ascorbic acid	0.05	OMb	62
H3	Na-lactate	1.8	OMb	62
H4	Polyphosphate	0.5	OMb	62
H5	Lingonberry juice	5.0	OMb	62
H6	Control — no ingredients	–	OMb	62
H7	No ingredients	–	DMb	62
H8	No ingredients	–	DMb	69
H9	No ingredients	–	DMb	75

[a] OMb — oxymyoglobin, DMb — deoxymyoglobin.

2.2. Production of injected steaks

The steak test consisted of five vacuum packaged beef loins (M. *longissimus dorsi*) (Furuseth) of Norwegian Red Cattle obtained 4 days post mortem. The average weight of the loins was 2.9 kg (min. 2.7, max. 3.1 kg). The loins were divided into two parts: one for injecting marinade (series S1) and one untreated control (series S2). The marinade consisted of L-sodium lactate (Purasal S), polyphosphate (Canal 2110) and sodium chloride to concentrations of 1.8, 0.5 and 0.3% in the injected meat, respectively, based on a targeted injection volume of 8%. The meat was injected in a Suhner WS 20 machine (Suhner AG, Bremgarten, Switzerland) with 2 mm thick needles at a distance of 25 mm between the needles. The injected meat rested for 3 h. Then injected and non-treated pieces of meat were sliced into 25 mm steaks and packaged on a Polimoon 511VG tray sealing machine (Promens, Kopavogur, Iceland) by flushing with a food grade gas mixture of 75% O_2 and 25% CO_2 (AGA, Oslo, Norway). Trays of polyethylene terephthalate (Wipak Mulipet, Wipak Oy, Natsola, Finland) were supplied with pieces of polyvinylchloride netting in the bottom of the trays to facilitate gas absorption from both sides of the steaks. The trays were sealed with an ethylene vinyl alcohol top film (Wipak Biaxer, Wipak). Oxygen transmission rates of the trays and top film were 7 and 5 $cm^3/m^2/24$ h at 23 °C and 50% relative humidity, respectively. The gas to meat ratio was approximately 4:1. The steaks, 6 per treatment, were stored in darkness at 4 °C for 5 days.

2.3. Cooking of hamburgers and steaks

The cooking times to selected end point temperatures in hamburgers and steaks were determined by pre-trials. Hamburgers of series H1–H6 were cooked to approximately 62 °C in the centre, while hamburgers of series H7, H8 and H9 which were stored in vacuum were cooked to approximately 62, 69 and 75 °C, respectively. The steaks of series S1 and S2 were cooked to approximately 62 °C. All burgers and steaks were treated on a double plate grill (Silex S-161, Elektrogeräte GmbH, Arnsberg, Germany). For all cooking treatments, the grill temperatures were set at 165 °C for the lower plate and at 180 °C for the upper plate, which was placed approximately 1 cm above the surface of the meat. The positions of the four burgers and steaks on the plate for each internal temperature were rotated. The total cooking time for burgers with different end temperatures was approximately 6, 7 and 8 min, respectively, and for steaks approximately 7 and 7 1/2 min for the injected and non-treated samples, respectively. The burgers and steaks were flipped after half of the cooking time. The lowest core temperature of each burger and steak was recorded approximately 30 s after completed cooking by inserting a 1 mm thick needle thermistor in multiple internal spots (Teck-Skotselv, Skotselv, Norway).

2.4. Analyses

Instrumental colour analyses of hamburgers and steaks were performed with a Minolta Chromameter CR-400 (Konica Minolta Sensing Inc., Osaka, Japan) with an 8 mm viewing port and illuminant D_{65}. The instrument was calibrated against a white tile ($L^* = 97.16$, $a^* = 0.25$ and $b^* = 2.09$). The cooked burgers and steaks were divided