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Improving beef color stability: Practical strategies and underlying mechanisms☆

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ABSTRACT

This paper overviewed the current literature on strategies to improve beef color and attempted to logically explain the fundamental mechanisms involved. Surface color and its stability are critical traits governing the marketability of fresh beef when sold, whereas internal cooked color is utilized as an indicator for doneness at the point of consumption. A multitude of exogenous and endogenous factors interact with the redox biochemistry of myoglobin in post-mortem skeletal muscles. The scientific principles of these biomolecular interactions are applied by the meat industry as interventions for pre-harvest (i.e. diet, animal management) and post-harvest (i.e. packaging, aging, antioxidants) strategies to improve color stability in fresh and cooked beef. Current research suggests that the effects of several of these strategies are specific to type of animal, feeding regimen, packaging system, and muscle source. Meat scientists should explore novel ways to manipulate these factors using a biosystems approach to achieve improved beef color stability, satisfy consumer perception, and increase market profitability.

1. Introduction

The beef industry is a critical contributor to the agricultural economy, and the gross value of global beef production is 241 billion US Dollars per year (FAO, 2014). The major producers and exporters of beef include Australia, Argentina, Brazil, Canada, New Zealand, United States, and Uruguay (Millen, Pacheco, Meyer, Rodrigues, & Arrigoni, 2011). Of the quality parameters influencing the marketability of fresh beef, color is the most important one because at the point of sale consumers often associate the bright cherry-red color of fresh beef and the purplish-red color of vacuum-packaged beef as indicators of wholesomeness (Faustman & Cassens, 1990; Hood & Riordan, 1973). Any deviation from these appearances is indicative of poor color functionality and possible spoilage. Discolored beef cuts are often sold at discounted prices or ground to lower-value products such as ground beef, and if discoloration is extensive the product will be discarded. All of these practices lead to economic loss, which is estimated to be more than $1 billion annually in the United States beef industry (Smith, Belk, Sofos, Tatum, & Williams, 2000). On the other hand, the internal color of cooked beef is utilized as an indicator of doneness and safety at the point of consumption (King & Whyte, 2006).

The biochemistry of myoglobin and its interactions with small biomolecules in a complex muscle food matrix govern the color of meat, and numerous other factors affect the color stability of meat from livestock and poultry (AMSA, 2012; Faustman, Sun, Mancini, & Suman, 2010; Giddings, 1977; Livingston & Brown, 1981; Suman & Joseph, 2013). The modern-day agricultural industry must utilize these scientific principles in the form of pre- and/or post-harvest strategies to improve the appearance and color stability of fresh as well as cooked beef to satisfy consumer needs (Troy & Kerry, 2010). Mancini and Hunt (2005) provided a thorough update on such technologies, whereas McMillin (2008) overviewed the applications of modified atmosphere packaging (MAP) in fresh meat retailing. The purpose of this manuscript is to provide a review on current research to improve beef color and to explain the possible fundamental mechanisms involved.

2. Pre-harvest strategies to improve fresh beef color

In forage- and/or grain-based intensive livestock production systems, diet, feeding regimen, and management are important pre-harvest strategies to modulate quality as well as nutritive value of muscle foods (Hocquette et al., 2012; Wood et al., 1999), and these strategies offer themselves as valuable means to improve beef color stability as well.

2.1. Dietary strategies

Concentrations of endogenous antioxidants in skeletal muscles can positively influence meat color biochemistry (Chan & Decker, 1994).

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These effects are dependent on both diet composition and the duration the diet is fed (Schaefer, 2000). Thus, diet is an important pre-harvest factor influencing beef color, and manipulating diet and feed ingredients has been a practical strategy to improve beef color stability.

2.1.1. Feed composition and ingredients

Feed constitutes a major expense in both pasture-raised and grain-finished beef production systems, and there has been a growing trend to exploit alternative feed ingredients (Vasta, Nudda, Cannas, Lanza, & Priolo, 2008). For example, previous research indicated that barley can be utilized as a substitute for corn in finishing diets of beef cattle (Boss & Bowman, 1996). In this point of view, Boles, Bowman, Boss, and Surber (2005) examined the influence of incorporating different barley varieties in finishing diet on color stability and reported that after 12 days of refrigerated display aerobically packaged longissimus thoracis (LT) steaks from steers fed Chinook and H3 barley varieties exhibited greater surface redness than the steaks from animals fed Logan barley variety and corn. Nonetheless, finishing diet had no effect on quality grade, yield grade, or beef tenderness. These findings indicated that the effect of barley on color stability is influenced by variety and that producers should consider the effect on color when selecting barley varieties to replace corn in finishing diet.

Daniel, Dikeman, Arnett, and Hunt (2009) examined the effects of vitamin A restriction during the finishing phase of cattle on color display life of aerobically packaged longissimus lumborum (LL) and triceps brachii steaks. After 6 days of retail display, steaks from vitamin A-restricted steers exhibited greater redness than those from vitamin A-supplemented animals. These results indicated that vitamin A restriction during the finishing phase of cattle can have positive effects on retail color shelf life and that vitamin A restriction might be adopted as a management practice to enhance beef color quality. Nevertheless, the molecular mechanism on how low levels of dietary vitamin A lead to improved color stability is yet to be clearly understood.

2.1.2. Feeding systems

The two common feeding systems for raising beef animals across the world are grass/forage/pasture and feedlot/grain finishing; however, there are large variations between countries on how both of these systems are applied. While grain feeding is popular in North America (Lehmkuhler & Ramos, 2008), pasture finishing is the predominant practice in Brazil, Argentina, Uruguay, Australia, and New Zealand (Van Elswyk & McNeill, 2014) and in other countries where grain is limited.

Numerous studies describe the effects of feeding regime on the acceptability of beef by consumers in the United States (Duckett, Neel, Lewis, Fontenot, & Clapham, 2013; Sitz, Calkins, Feuz, Umberger, & Eskridge, 2005) and the European Union (Realini et al., 2009, 2013). These results highlight the criticality of feeding management in international beef trade. Investigations by Insani et al. (2008) examined the impact of different feeding regimes on color attributes of fresh beef in Argentina. After 7 days under refrigerated retail display, aerobically packaged psoas major (PM) steaks from grass-fed animals demonstrated greater redness than the steaks from feedlot-finished animals. The authors attributed this observation to the higher levels of antioxidant vitamins (α-tocopherol and β-carotene) in pasture-raised steaks than their feedlot-finished counterparts.

Niche markets are a growing segment in the agricultural sector of many countries. Raising Jersey steers for beef production has potential in such niche markets since Jersey animals produce beef with high marbling (Albertí et al., 2008). However, the breed's slow growth rate is a limiting factor in beef production systems (Lehmkuhler & Ramos, 2008). Since forage levels have been previously reported (O'Sullivan et al., 2004) to influence fresh beef quality, Arnett et al. (2012) studied the effect of dietary forage levels (12 vs. 24% on dry matter basis) on quality attributes of beef from Jersey animals. While dietary forage level had minimal effects on carcass traits (i.e. hot carcass weight, dressing percentage) and palatability attributes (i.e. shear force, cooking loss, overall acceptability) of Jersey beef, aerobically packaged longissimus steaks from Jersey animals fed 24% forage demonstrated greater redness than their counterparts from animals fed on 12% forage after 5 days of simulated retail display at 3 °C. In addition, the redness of steaks from Jersey beef fed 24% forage was similar to the commodity beef loin steaks from conventionally raised feedlot cattle. These findings indicated the importance of feeding regime on marketability of beef in niche markets.

2.1.3. Vitamin E supplementation

Vitamin E (α-tocopherol) is an antioxidant used in animal feeds to prevent lipid oxidation. Lipid-soluble vitamin E is an effective polyphenolic free radical scavenger that inhibits free radical-induced peroxidation of polyunsaturated fatty acids in plasma membranes (Buttriss & Diplock, 1988). Extensive investigations have been undertaken internationally on the color-stabilizing effect of vitamin E in beef, and these studies clearly documented that supranutritional supplementation of vitamin E minimizes lipid oxidation and improves color stability (Arnold et al., 1992; Chan et al., 1996; Faustman, Cassens, Schaefer, Buege, & Scheller, 1989; Formanek, Kerry, Buckley, Morrissey, & Farkas, 1998; O'Grady et al., 1998; Smith, Morgan, Sofos, & Tatum, 1996). Lipid oxidation is a major contributor to metmyoglobin (MMb) formation and fresh meat discoloration (Faustman et al., 2010), and beef myoglobin is inherently more susceptible to oxidation by nucleophilic attack by reactive lipid peroxidation products than pork myoglobin (Suman, Faustman, Stamer, & Liebler, 2007).

Vitamin E delays the onset of lipid oxidation in membrane lipids by scavenging free radicals (i.e. singlet oxygen and peroxyl radical) that are known promoters of the lipid peroxidation process, and the delay in the formation of reactive secondary peroxidation products was offered as the reason for improved color stability (Lynch, Kerry, Buckley, Faustman, & Morrissey, 1999). Vitamin E supplementation is used as an efficient, sustainable, and consumer-friendly pre-harvest strategy to improve beef color stability (Faustman, Chan, Schaefer, & Havens, 1998; Kerry, Buckley, & Morrissey, 2000; Liu, Lanari, & Schaefer, 1995; Sales & Koukolova, 2011). Clearly there is an interaction between vitamin E concentration in the diet and the time the antioxidant is fed (Arnold, Arp, Scheller, Williams, & Schaefer, 1993; Roeber, Belk, Tatum, Wilson, & Smith, 2001) as it has been shown that some muscles do not accumulate the antioxidant at fast as others (Dunne, Monahan, O'Mara, & Moloney, 2005; Lynch et al., 1999). Numerous recent studies across the globe examined the usefulness of vitamin E as a strategy to improve color stability and redness of beef that is inherently susceptible to oxidation, and the results suggest that there are numerous feed stuffs that would benefit from vitamin E supplementation leading to an enhancement of beef color stability.

The move to increase bio-derived energy sources has led to corn by-products that have potential for animal feed. For instance, distiller's grains plus solids (dry or wet) are biofuel by-products widely used in beef production (Klopfenstein, Erickson, & Bremer, 2008). Several studies reported that distiller's grains can negatively impact color and oxidative stability in beef (Kinman et al., 2011; Leupp et al., 2009; Mello et al., 2012; Roeber, Gill, & DiCostanzo, 2005). In this perspective, Bloomberg et al. (2011) examined the usefulness of vitamin E to improve color of beef from animals fed on wet distiller's grains and observed that supplementation of 250 or 500 IU vitamin E per animal per day can minimize discoloration in steaks. These findings indicated the potential to utilize distiller's grains in combination with vitamin E in beef industry without compromising color stability.

Larraín, Schaefer, Richards, and Reed (2008) examined the effect of diet and vitamin E on beef color and found that supplementation of vitamin E to animals raised on corn-based diet increased surface redness of aerobically packaged gluteus medius (GM) and LL steaks during a 15-day refrigerated simulated retail display. Investigations by Franco et al. (2012) also examined the effects of vitamin E dietary