51st International Congress of Meat Science and Technology
August 7-12, 2005 – Baltimore, Maryland USA

THE MECHANISM OF BEEF MARROW DISCOLORATION: A SUMMARY OF CAUSES, EFFECTS, AND PREVENTION

R. A. Mancini and M. C. Hunt

Department of Animal Sciences, Kansas State University, Manhattan, KS, 66506, USA

Key Words: Bone Marrow, Color, Packaging, Hemoglobin, Myoglobin, Discoloration

Introduction

The appearance of muscle-based food products is the primary determinant of consumer-purchasing decisions. Although there is an abundance of peer-reviewed literature focused on the mechanism of muscle discoloration, published research evaluating the discoloration of bone marrow is lacking. This is somewhat surprising because industry has expressed an interest in techniques that limit marrow discoloration during display in case-ready packaging. To study the mechanism of bone discoloration, we assessed the roles of bone marrow's primary components (hemoglobin, lipid, and iron) in color and discoloration.

Marrow from carcasses is found in two forms, red and yellow, both of which are a direct result of bone functionality and location. Vertebrae and ribs are abundant in "red, erythropoietic marrow" that is composed of hematopoietic cells, whereas long bones are composed of "yellow, fatty marrow" with little or no hematopoietic potential. As the name implies, this marrow is abundant in fat, yet lacks pigment because of a relatively small amount of hemoglobin and iron. Coinciding with the lack of pigment, Grobbel (2004) reported that humeri packaged in high-oxygen and PVC did not discolor during display. Long bones containing fatty marrow also mature earlier than vertebrae and thus, are designed more for lipid storage (85% lipid in beef femurs compared with 26 to 56% in vertebrae; Kunsman et al., 1981). It is estimated that approximately 34% of the weight of beef cervical vertebrae is marrow (Field, 1999).

Beef hematopoietic marrow contains significantly more total pigment than muscle (28.2 compared to 3.7 mg/g fresh tissue; Field et al., 1980). Essentially all of the pigmentation in beef erythropoietic marrow is due to hemoglobin (99.7% of total pigment content) as opposed to myoglobin, which accounts for a negligible amount of total marrow pigment (0.33% of total; Field et al., 1980). Conversely, muscle color is primarily due to myoglobin. Similar results were reported by Demos and Mandigo (1995), who concluded that the total pigment content of marrow was relatively high (42 mg/g), especially when compared to 85% lean ground beef (6 mg/g). Grobbel (2004) reported that ribs and vertebrae contained more hemoglobin than humeri. Field et al. (1980) suggested that the total pigment values (mg/g) reported in their work also were representative of hemoglobin content because hemoglobin was the only pigment found in cervical and lumbar marrow.

Total iron content was significantly higher in cervical marrow than ground beef (13 compared to 1.6 mg/100g; Demos and Mandigo, 1995). These researchers reported a

strong correlation (r = 0.85) between pigment concentration and iron content. However, Field et al. (1980) noted that iron in bone marrow is not exclusive to hemoglobin, as it can also be stored as free iron and non-heme compounds. Nevertheless, marrow that is susceptible to discoloration (marrow from ribs and vertebrae) contains more total iron than marrow that lacks pigmentation (humeri marrow; Grobbel, 2004).

Numerous characteristics of bone marrow such as its pigment, lipid, and iron content make it susceptible to oxidation and discoloration. However, little work in meat science has focused on determining the mechanism of marrow discoloration.

Objectives

Figure 1 summarizes potential factors involved in erythropoietic bone marrow discoloration. From this, we developed four research questions to better understand the etiology of bone marrow discoloration.

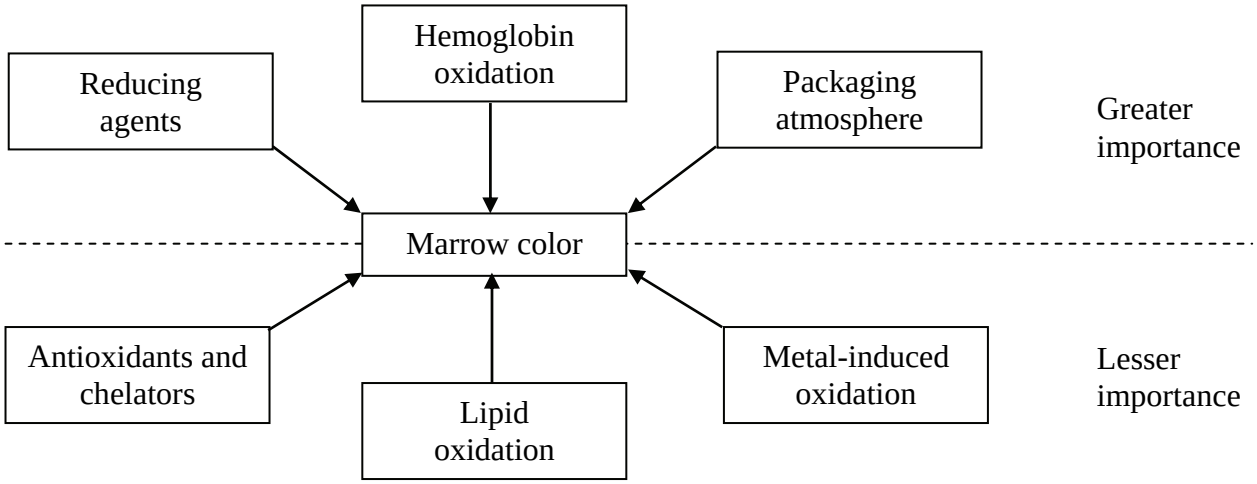

Figure 1: Potential factors involved in the discoloration of erythropoietic bone marrow.

Results & Discussion

Research question 1: What is the role of packaging atmosphere in beef erythropoietic marrow discoloration?

Mancini et al. (2005) and Grobbel et al. (2005a) suggested that excluding oxygen from modified atmosphere packages will improve the color stability of erythropoietic marrow from beef bones. Mancini et al. (2005) also reported that 0.4% carbon monoxide (30%CO_2 and 69.6%N_2) significantly improved vertebrae (red marrow) color stability during storage at 4°C. On the other hand, high-oxygen packaging (80% O_2) had a detrimental effect on vertebrae color during display (Mancini et al., 2004; Lanari et al., 1999). Other work has suggested that ribs and vertebrae will discolor in traditional aerobic packaging (polyvinyl chloride overwrap; Grobbel, 2005a). This implicates

hemoglobin's redox state in the color development and stability of red marrow. Hemoglobin's affinity for carbon monoxide suggests that the use of low levels of carbon monoxide in packages will maintain a bright-red marrow color during storage and display because of the formation of carboxyhemoglobin.

Research question 2: Can erythropoietic marrow discoloration be slowed by reducing agents such as ascorbic acid and sodium erythorbate?

Ascorbic acid or sodium erythorbate applied to the surface of ribs and vertebrae inhibited discoloration during display (Mancini et al., 2004). Although these reducing agents were most effective at concentrations between 0.5 and 10%, applications greater than 3% resulted in no significant color stabilizing advantage during 7-days of display. The effectiveness of ascorbic acid was improved by glutathione (Mancini, 2004), which plays a role in the recycling of water-soluble antioxidants. Grobbel et al. (2005b) also reported that ascorbic acid (2.5%) was useful for stabilizing marrow color. Grobbel (2004) noted that vertebrae marrow stability during display decreases with increased postmortem age.

Research question 3: Will minimizing lipid oxidation have a beneficial effect on bone marrow color?

The contribution of pigment and lipid oxidation to the surface color of cut bones is unknown. We hypothesized that hemoglobin oxidation, rather than lipid oxidation, was primarily responsible for the discoloration of erythropoietic marrow. Thus, a series of experiments (Mancini, 2004) were designed to determine whether the mechanism and sources of erythropoietic bone marrow discoloration are more water-soluble or lipid-soluble. Increasing ascorbic acid's lipophilicity diminished its ability to stabilize marrow color. Compared with ascorbate-6-palmitate (amphipathic), ascorbic acid better stabilized the surface color of ribs and vertebrae displayed in high-oxygen MAP (80% oxygen). Other lipid soluble antioxidants such as vitamin E, propyl-gallate, and dodecyl-gallate had no positive affects on vertebrae marrow color. Water-soluble glutathione tended to minimize discoloration more than lipoic acid. During display, TBARS values for untreated vertebrae in high-oxygen slightly increased from 0.6 to 0.8 (Grobbel, 2004).

Research question 4: Can marrow discoloration be minimized by chelation of metal catalyzing oxidation?

The contribution of iron to the oxidative instability of muscle foods is well documented. However, the role of iron in the oxidation of bone marrow pigments is unknown although marrow from erythropoietic bones contains more hemoglobin and iron than muscle. Vertebrae treated with 2.5% EDTA (topical application) will significantly discolor within 1 day after packaging in high-oxygen (Mancini, 2004). The "moderately gray" to "all gray" color of EDTA-treated vertebrae remained relatively stable throughout display. The inability of EDTA to minimize vertebrae surface discoloration suggests that free iron has a minor role in both marrow pigment oxidation and surface discoloration. Citric acid oxidized hemoglobin on the surface of vertebrae, resulting in discoloration that was reversed by ascorbic acid. Combining EDTA or citric acid with ascorbic acid provided no additional benefits compared to treatment with only ascorbic acid; thus,

inactivation of ascorbic acid via metals in erythropoietic marrow likely has little affect on the reducing agent's ability to stabilize vertebrae color.

The aqueous phase of erythropoietic beef marrow is the primary candidate for discoloration whereas the lipid portion had no significant role in marrow color (Mancini, 2004). Within the water-soluble phase, hemoglobin's redox state was the principal determinant of marrow color; thus, manipulating pigment redox status will have a dramatic affect on the color life of erythropoietic marrow. This could be accomplished by promoting ferrous hemoglobin with the use of either water-soluble reducing agents or packaging atmosphere, both of which were effective at maximizing color stability during storage and display. Reducing lipid oxidation and chelating metals appeared to have no impact on the oxidative stability of hemoglobin within erythropoietic marrow.

Conclusions

To improve the color stability of erythropoietic marrow, the beef industry can utilize technologies that minimize hemoglobin oxidation such as ascorbic acid, sodium erythorbate, or ultra-low oxygen packaging combined with low levels of carbon monoxide. Focusing on the water-soluble fraction of marrow, rather than lipid oxidation and other more non-polar fractions, should be the most effective way to improve marrow color stability.

References

Demos, B. P. & Mandigo, R. W. (1995). Composition and chemistry of mechanically recovered beef neck-bone lean. Journal of Food Science, 60, 576–579.

Field, R. A. (1999). Bone marrow measurements for mechanically recovered products from machines that press bones. Meat Science, 51, 205–214.

Field, R. A., Sanchez, L. R., Kunsman, J. E., & Kruggel, W. G. (1980). Heme pigment content of bovine hemopoietic marrow and muscle. Journal of Food Science, 45, 1109–1112.

Grobbel, J. P. (2004). Evaluation of factors relating to the 'Black bone' condition in packaged beef bones and ways to decrease the incidence. Kansas State University Masters Thesis, Manhattan, Kansas.

Grobbel, J. P., Dikeman, M. E., Smith, J. S., Kropf, D. H., and Milliken, G. A. (2005a). Effects of polyvinyl chloride overwrap film, high-oxygen modified atmosphere packaging, or ultra-low oxygen modified atmosphere packaging on bone marrow discoloration in beef humerus, rib, thoracic vertebrae, and scapula bones. Journal of Animal Science, In Press.

Grobbel, J. P., Dikeman, M. E., Yancey, E. J., Smith, J. S., Kropf, D. H., and Milliken, G. A. (2005b). Effects of ascorbic acid, rosemary, and Origanox in preventing bone marrow discoloration in beef lumbar vertebrae packaged in different packaging systems. Meat Science, In Press.

Kunsman, J. E., Collins, M. A., Field, R. A., Miller, G. J. (1981). Cholesterol content of beef bone marrow and mechanically deboned meat. Journal of Food Science, 46, 1875–1787.

Lanari, M. C., Schaefer, D. M., & Scheller, K. K. (1995). Dietary vitamin E supplementation and discoloration of pork bone and muscle following modified atmosphere packaging. Meat Science, 41, 237–250.

Mancini, R. A. (2004). Factors affecting beef bone marrow color. Kansas State University Dissertation, Manhattan, Kansas.

Mancini, R. A., Hunt, M. C., Hachmeister, K. A., Kropf, D. H., & Johnson, D. E. (2004). Ascorbic acid minimizes lumbar vertebrae discoloration. Meat Science, 68(3), 339–345.

Mancini, R. A., Hunt, M. C., Hachmeister, K. A., Kropf, D. H., & Johnson, D. E. (2005). Exclusion of oxygen from modified atmosphere packages limits beef rib and lumbar vertebrae marrow discoloration during display and storage. Meat Science, 69(3), 493–500.