Postmortem NIR tissue oximetry: Factors affecting measurements of myoglobin-oxygen status in beef *longissimus* muscle

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Introduction

Meat color perceived by consumers serves as a valuable guide to assess the overall quality and wholesomeness of meat (Kropf, 1993; Mancini and Hunt, 2005). The bright cherry-red color of meat is influenced by tissue oxygen consumption, obstacles to oxygen diffusion, and the thickness of the oxymyoglobin layer (Mancini and Hunt, 2005; McKenna et al., 2005). The dynamics of meat color depends on several physical properties of muscle including myoglobin redox status and concentration (Kropf, 1993). Physical, chemical, and anatomical differences in muscles cause large variations in color from cut to cut, within a cut, and cuts made parallel or perpendicular to the muscle fibers (Xia et al., 2007; Swatland and Irie, 1992) and these structural differences are associated with variations in meat color and color stability (Mancini and Hunt 2005). Clearly, muscle fiber orientation impacts measurements of tenderness and cook yield (Bouton et al., 1975); however, variations in myoglobin (Mb) redox dynamics, oxygen penetration, and color stability due to muscle fiber orientation (parallel or perpendicular) are not well documented. Visual appraisal of meat discoloration by human perception is subjective, time consuming, and imprecise (Arnold, et al., 1992) and the instrumental procedures used for the meat pigment quantification such as reflectance spectrophotometry are inherently affected by surface properties of the sample and are limited by the depth of visible light penetration (AMSA 1991; Arnold et al., 1992). Among the various meat color measurement techniques available, near-infrared (NIR) methods have the advantage of being nondestructive, rapid, inexpensive, and are considered suitable for online measurements of oxygenation in tissues and tissue pigment forms. NIR tissue oximetry provides continuous real-time measurements of changes in the myoglobin oxygen status, thus providing information on tissue oxygenation and hemodynamics (Ferreira, Hueber, and Barstow, 2007). This study was designed to evaluate how muscle fiber orientation of meat cuts affects NIR tissue oximeter assessments of muscle oxygen status and myoglobin redox forms. Our specific objectives were to determine: 1) the amount of deoxymyoglobin (DMb), oxymyoglobin (OMb), and total myoglobin (TMb) in beef muscle (*longissimus*) stored in several packaging formats; and 2) the relationships between tissue oximeter responses to the post-rigor muscle fiber orientation and surface measures of color.

Materials and methods

The *longissimus lumborum* (LL) from 3 beef loins (USDA Select, A-maturity) were fabricated at 10-d postmortem into steaks about 5cm × 8cm × 10cm with the fiber orientation being either perpendicular (PR) or parallel (PL) to a designated muscle surface. Steaks were assigned to 4 packaging treatments; 1) vacuum packaging (VP); 2) high-oxygen modified atmosphere packaging (HiOx-MAP; 80% O_2, 20% CO_2); 3) polyvinyl-chloride film over-wrap (PVC; 21,700 cc O_2/m^2/24 h); and 4) HiOx-MAP that was converted to PVC after 2-d for subsequent storage in PVC (HiOx-PVC). Steaks were stored at 2ºC for d 0, 2, 4, 10, and d 15 in dark and scanned in triplicate at each storage time using a HunterLab MiniScan™ XE Plus Spectrophotometer. Values for CIE L*, a*, and b* (Illuminant A and 2.5 cm aperture) were used to calculate hue angle ($\tan^{-1}$ b*/a*) and chroma ($a^{*2} + b^{*2}$). Tissue Oximetry of the steaks was evaluated for Mb redox status by using a NIR system (OxiplexTS model 96208, ISS, Champaign, IL). The data were analyzed using type-3 tests of fixed effects of the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). F-Test denominator degrees of freedom were estimated using the Satterthwaite adjustment. Least square means for significant F-Tests were separated using least significant differences.

Results and discussion

Figure 1 shows a fiber orientation × packaging interaction ($P<0.05$) of NIR tissue oximeter response for percentages of OMb, DMb, and TMb. The LL steaks cut perpendicular to the fiber orientation and packaged in

HiOx-MAP contained 65% of OMb while those packaged in HiOx-PVC had 60% of OMb (Figure 1a) compared with steaks cut parallel to the fiber orientation (*P<0.05*). A similar but opposite trend for fiber orientation effects was observed for DMb (Figure 1b). TMb (3.71mg/g) did not differ (*P>0.05*) for fiber orientation except in steaks packaged in HiOx-PVC, which may be due to location concentration differences (Figure 1c). There was a packaging × d interaction (*P<0.05*) for percentages of OMb and DMb in the 4 packaging formats. As expected at d 0, OMb percentages of steaks cut PR and PL (Figure 2B) and packaged in VP were less than 5%, 7% in PVC, and 28% in HiOx-MAP and HiOx-PVC. By d 2, OMb dramatically increased to 78% in HiOx-MAP and HiOx-PVC packaged steaks cut either PR or PL, whereas the PVC packages had 48% and VP was < 5% regardless of their fiber orientation. On d 10, the OMb level increased to 90% in PR steaks packaged in HiOx-MAP and remained same in PR steaks packaged in HiOx-PVC (PR). However, the OMb level in PL steaks declined to 71% in HiOx-MAP, 66% in HiOx-PVC, with no change in either PR and PL steaks packaged in PVC and VP. By d 15, percent OMb declined further in the all aerobic packages and increased slightly in the VP. DMb (Figure 2A) followed an opposite pattern; however PR steaks in general had lower percentages of DMb compared to PL steaks packaged in HiOx-MAP and HiOx-PVC. These data clearly demonstrate that fiber orientation influenced the myoglobin oxygen status in aerobic packaging formats. This study shows the changes induced in myoglobin redox forms due to fiber orientation, packaging, and postmortem storage can be quantitated by NIR tissue oximetry. There was a storage day x MAP-treatment interaction (*P<0.05*) of instrumental color (Figure 3). Steaks packaged in HiOx-MAP, HiOx-PVC, and PVC decreased in a* and chroma (*P<0.05*) as postmortem storage day advanced from d 0 to 4, 10, and 15 (Figure 3B & F). On d 2 and d 4, steaks packaged in HiOx and HiOx-PVC had greater redness intensity (more a* and chroma; *P<0.05*) than steaks packaged in PVC and VP. However, instrumental b* decreased for steaks packaged in HiOx, HiOx-PVC, and PVC from d 0, 2, 4, 10 to d 15 with no change in VP steaks (Figure 3C). There were no significant change in L*-values from d 0, 4, 10 till d 15 (Figure 3A). Hue angles increased for steaks packaged in VP from d 0, 2 and 4 and then decreased from d 10 to 15 (*P<0.05*) (Figure 3E). Differences between HiOx-MAP, HiOx-PVC, PVC, and VP were evident on d 15. These color measurements would be expected considering the redox forms of myoglobin present in the packages.

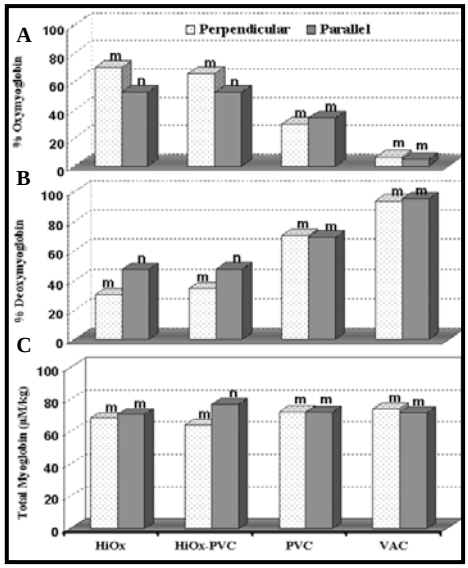

Figure 1. Fiber orientation × packaging interaction of NIR tissue oximeter response for percent A) OMb, B) DMb, and C) TMb.

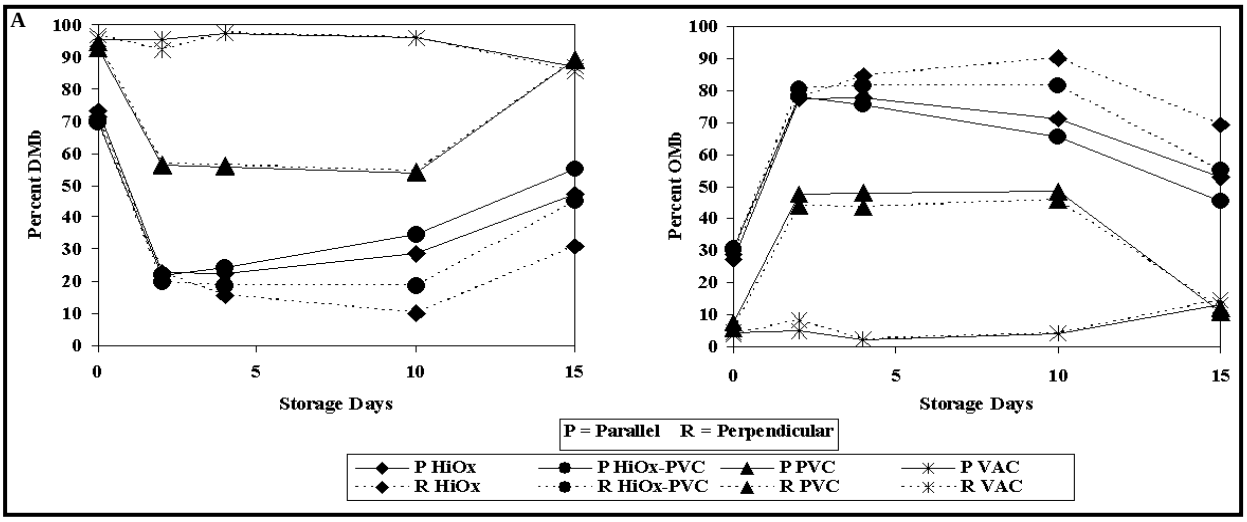

Figure 2. Packaging x d interaction of tissue oximeter response on A) DMb, and B) OMb.

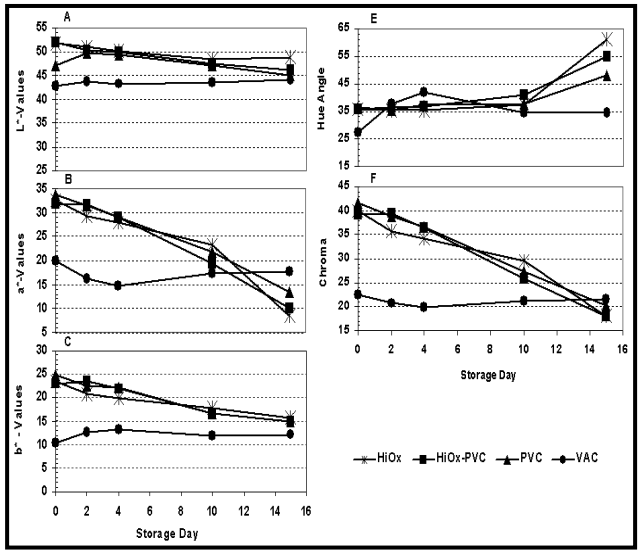

Figure 3. Storage day x MAP-treatment interaction of MiniScan response.

Summary

Fiber orientation and storage day impacted (P<0.05) TMb, OMb, DMb, and instrumental color measurements in all packaging formats. Steaks with perpendicular fiber orientation tended to have more OMb and greater color stability than steaks cut parallel to the fiber orientation. Packaging format did not to affect TMb; however, OMb increased and DMb decreased as exposure to oxygen increased. As postmortem storage advanced OMb levels decreased.

Conclusions

Tissue oximeter measurements have potential for real-time monitoring of the myoglobin redox forms and oxygen status of meat packaged in a variety of packaging formats. To obtain repeatable NIR tissue oximetry measurements on post-rigor muscle; fiber orientation, tissue oxygen exposure, and storage time must be controlled.

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