OXIDATION AND QUALITY OF STEAKS FROM DIFFERENT BEEF MUSCLES AGED IN HiOx ATMOSPHERE PACKAGING

Alessandra A. Silva[1*], Rebecca M. Delles[2], Alma D. True[2], Mariza P. Mello[1], Gregg K. Rentfrow[2] and Youling L. Xiong[2]

[1] Departamento de Engenharia de Alimentos, Faculdade de Zootecnia e Engenharia de Alimentos, Universidade de São Paulo, Pirassununga, Brazil

[2] Department of Animal and Food Sciences, College of Agriculture, University of Kentucky, Lexington, United States

Abstract – Protein and lipid oxidation in meat can occur during postmortem storage (aging), with detrimental effects on meat tenderness and color. Physical and chemical properties from different muscles could also influence meat oxidation and quality. This work aimed to evaluate the oxidation and quality of steaks from different beef muscles [*Longissimus lumborum* (LL), *Semimembranosus* (SM) and *Semitendinosus* (ST)] aged under high oxygen atmosphere (HiOx) for 0, 3, 7, 14 and 21 days. Protein oxidation (carbonyl content) across the storage times was significant in LL muscle, while lipid oxidation (TBARS) was detected mainly in SM muscle. A higher lipid oxidation rate was observed in SM than in other muscles within 14 days. The color parameters deteriorated across the storage times, principally in LL and SM muscles, corresponding to protein and lipid oxidation. Overall, the ST muscle showed the highest *L, *a**, and *b** values within the storage times. An aging effect on muscle was consistently observed in LL muscle. In conclusion, slight differences in protein and lipid oxidation across the storage times were observed among the beef muscles packaged in HiOx, which appeared to hinder beef tenderization and color stabilization over the aging periods investigated.**

Key Words – Protein and lipid oxidation, HiOx packaging, Beef tenderness

I. INTRODUCTION

Protein and lipid oxidation has been associated with meat quality losses. Oxidation can affect meat color by altering the chemical valence of heme-bound iron (from Fe^{2+} to Fe^{3+}), as well as influence meat tenderness by decreasing the proteolytic activity of calpain in aged meat [1]. In order to extend the shelf-life through the preservation of oxymyoglobin and inhibition of microbial growth, steaks have been packaged in high oxygen atmosphere (HiOx) that typically includes gaseous CO_2 also. However, increased protein and lipid oxidation during storage are widely reported in ground pork muscle [2,3]. The magnitude of the oxidation could be influenced by the muscle types, since different muscles or fiber types have different physical and chemical properties [4]. Therefore, the objective of this work was to evaluate the oxidation and quality of steaks from different beef muscles stored under HiOx. One-day postmortem (postrigor) muscle samples were used to test how such a packaging system would also affect the aging process intended for meat tenderization.

II. MATERIALS AND METHODS

The *Longissimus lumborum* (LL), *Semimenbranosus* (SM) and *Semitendinosus* (ST) muscles were collected from 24-h postmortem carcasses of three Angus cattle. Whole muscles were vacuum packaged and stored at −30°C until use (< 30 days). Muscles were thawed overnight in a refrigerator prior to cutting. The muscles were sliced into steaks of 2.5-cm thickness, packaged in HiOx ($80\%O_2/20\%CO_2$) and stored at 4°C in light for 0, 3, 7, 14 and 21 days prior to the specific analyses. Myofibrils were isolated from each muscle as described by Liu *et al*. [5] and submitted to carbonyl analysis using the procedures described previously [5,6]. For the determinations of thiobarbituric acid reactive substances (TBARS) [7], color parameters, and Warner-Bratzler shear force (cooked, 71°C) [8], muscle tissue samples were used. Three independent trials were performed. An analysis of variance was conducted using the Statistix 9.0 software with a model to determine the importance of muscle and

storage time. The means were separated by *Tukey* test when an effect was found significant (P<0.05).

III. RESULTS AND DISCUSSION

A. Meat oxidation

No differences for carbonyl content were observed (P>0.05) among the muscles within the storage times (Table 1). Protein oxidation across the storage times was only observed (P<0.05) in LL muscle (Table 1), where the meat samples under HiOx had the lowest (P<0.05) carbonyl content on day 0 and the highest (P<0.05) carbonyl content on day 14. In this case, the protein oxidation across the storage times may have been triggered in only LL muscle due to its fiber type. The LL is considered an intermediate muscle containing both the glycolytic and oxidative fibers, while the SM and ST are considered white muscles containing predominately glycolytic fibers [9]. Nevertheless, there is a report showing that the carbonyl content was unchanged in *Longissimus* muscle from pigs stored for 14 days under 70%O_2/30%CO_2 [2].

Table 1 Protein and lipid oxidation across the storage times in steaks from different beef muscles under high oxygen atmosphere

Storage time (day)	Muscle		
	LL	SM	ST
Carbonyl content (nmol/mg of protein)			
0	0.72 (0.055)^{B}	0.90 (0.035)	0.81 (0.290)
3	0.76 (0.050)^{AB}	0.90 (0.205)	1.06 (0.035)
7	1.28 (0.135)^{AB}	1.48 (0.120)	1.48 (0.185)
14	1.57 (0.220)^{A}	1.75 (0.070)	1.56 (0.130)
21	1.37 (0.510)^{AB}	2.03 (0.940)	2.11 (1.130)
TBARS (mg of MDA/kg of muscle)			
0	0.13 (0.035)^{b}	0.21 (0.043)^{aB}	0.14 (0.050)^{b}
3	0.13 (0.019)	0.19 (0.046)^{B}	0.16 (0.030)
7	0.80 (0.641)	0.29 (0.076)^{B}	0.85 (0.648)
14	0.73 (0.304)^{b}	1.10 (0.412)^{aA}	0.71 (0.349)^{b}
21	1.04 (0.749)	0.60 (0.245)^{AB}	1.03 (0.451)

Legend: Means (standard error); LL = *Longissimus lumborum*; SM = *Semimembranosus*; ST = *Semitendinosus*; TBARS = thiobarbituric acid reactive substances; MDA = malondialdehyde. ^{a,b}Means followed by different lowercase letters among the muscles within the storage time differ significantly (P<0.05). ^{A,B}Means followed by different uppercase letters across the storage times within the muscle differ significantly (P<0.05).

Differences in TBARS were observed (P<0.05) among the muscles within the days 0 and 14 of storage (Table 1), indicating that the SM muscle had higher (P<0.05) values than the LL and ST muscles, which did not differ (P>0.05). Higher TBARS values for the SM muscle may be a result of higher concentrations of polyunsaturated fatty acids [10]. Because of this, likely, lipid oxidation across the storage times was only detected in SM muscle (Table 1). In this muscle, the TBARS values were higher (P<0.05) at 14 days than at 0, 3, and 7 days. The TBARS values at 21 days of storage were not different (P>0.05) from others storage times. A higher TBARS value was also verified in ground pork muscle packaged in HiOx at 14 days of storage [3].

B. Meat color

Within all the storage times, the ST muscle had the highest (P<0.05) L^* values and the SM muscle had the lowest (P<0.05) L^* values (Figure 1A). The higher lightness in the surface of the ST muscle in comparison to the other muscles seems to be related to higher moisture and drip loss [4]. In turn, the LL muscle had intermediate (P<0.05) L^* values within the days 3 and 14.

The L^* values were the highest (P<0.05) for steaks from LL muscle stored under HiOx for 3, 7, 14 and 21 days with no differences (P>0.05) between them (Figure 1A). When steaks from SM muscle under HiOx were evaluated, the L^* values were the highest (P<0.05) at 21 days of storage. In steaks from ST muscle, the L^* values were the highest (P<0.05) at 7 and 21 days of storage. Overall, these changes in L^* values could be attributed to the individual properties of each muscle such as fat content, moisture and water-holding capacity.

As to a^* values, there were differences (P<0.05) among the muscles within the days 0, 3 and 7 (Figure 1B). Within the days 0 and 3 of storage, the ST muscle had higher (P<0.05) a^* values than the LL and SM muscles, which were similar (P>0.05). Yet, within the day 7, the LL and ST muscles yielded the highest (P<0.05) a^* values and the SM muscle yielded the lowest (P<0.05) a^* values. Also, a decrease (P<0.05) of the a^* values across the storage times was observed in all the muscles (Figure 1B). However, the discoloration in ST muscle was slower than in other muscles, beginning at day 14. The discoloration of the steaks would likely be due to the bacterial growth during storage.

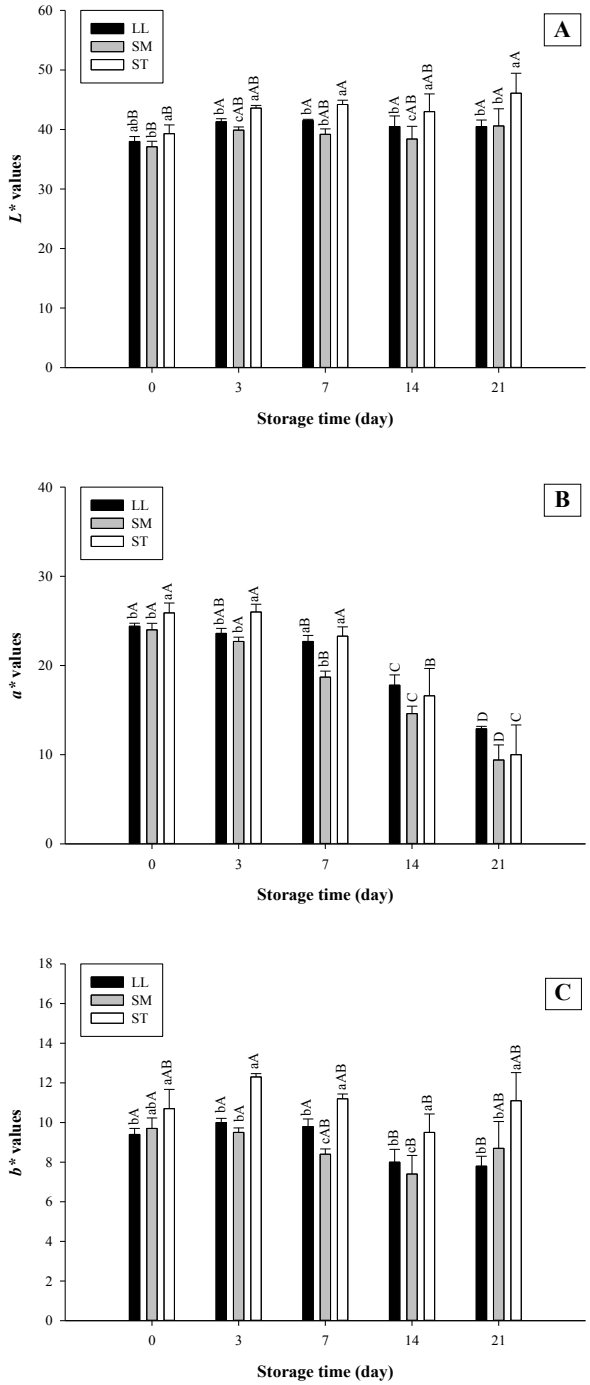

Figure 1. The *L** (A), *a** (B), and *b** (C) values across the storage times in steaks from different beef muscles under high oxygen atmosphere

Legend: LL = *Longissimus lumborum*; SM = *Semimembranosus*; ST = *Semitendinosus*. [a,b,c]Means followed by different lowercase letters among the muscles within the storage time differ significantly (P<0.05). [A,B,C,D]Means followed by different uppercase letters across the storage times within the muscle differ significantly (P<0.05).

The ST muscle also had the highest (P<0.05) *b** values within all the storage times (Figure 1C). Within the days 0, 3 and 21, the *b** values were the lowest (P<0.05) for the LL and SM muscles with no differences (P>0.05) between them. At 7 and 14 days of storage, only the SM muscle had the lowest (P<0.05) *b** values. Probably, the discoloration in SM muscle is a consequence of higher lipid oxidation (Table 1). In all the muscles, the *b** values were the lowest (P<0.05) on 14 days of storage (Figure 1C).

Steaks packaged in HiOx usually have increased color stability, but the lightness and chroma were negatively affected across the storage times in all muscles in this study.

C. Meat tenderness

The shear force values in LL muscle were influenced by the storage times (Figure 2). There was a decrease (P<0.05) in shear force values on day 3, but the values remained similar (P>0.05) from day 3 to day 21. The only exception was observed for day 14, which showed higher (P<0.05) shear force values than day 3.

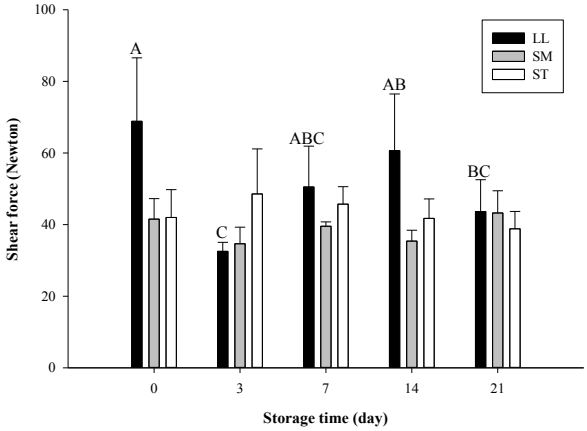

Figure 2. Shear force values (cooked meat, 71°C) across the storage times in steaks from different beef muscles under high oxygen atmosphere

Legend: LL = *Longissimus lumborum*; SM = *Semimembranosus*; ST = *Semitendinosus*. [A,B,C]Means followed by different uppercase letters across the storage times within the muscle differ significantly (P<0.05).

The protein oxidation was also verified at 14 days of storage in LL muscle (Table 1). This suggests that the protein oxidation could have led to decreased meat tenderness. A higher cross-linking

between proteins from pork packaged in HiOx resulted in increased shear force [2].

No significant differences ($P>0.05$) for meat tenderness were observed among the muscles in this study (Figure 2). The shear force values for the three muscles were similar to those found in previous work [11]. On the other hand, there is a report showing that the LL muscle had lower shear force values when compared to the SM and ST muscles [12]. Also, some reports showed that the SM muscle has higher shear force values than the ST muscle [13,14].

IV. CONCLUSION

Protein and lipid oxidation in LL, SM and ST muscle under HiOx occur in different ways and at different postmortem times. An apparent relationship was detected between protein oxidation and tenderness during the aging of LL muscle. This was noted by the increase in protein oxidation and reduction of tenderness over the aging time. Furthermore, greater lightness and intensity of red and yellow color were observed in steaks aged from ST muscle under HiOx. Concurrently in this muscle, no increase in lipid or protein oxidation was noted, even though the steaks were packaged in HiOx and aged for 21 days. Our results indicate that there are differences in the response pattern of oxidation in the muscles studied, and that this negatively affects the beef tenderness and color across the aging times.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Kentucky for use of its animals and facilities, and the "Fundação de Amparo a Pesquisa do Estado de São Paulo" (FAPESP) for providing the scholarship to the first author (#2010/08565-9 and #2012/06099-6).

REFERENCES

1. Rowe, L.J., Maddock, K.R., Lonergan, S.M. & Huff Lonergan, E. (2004). Oxidative environments decrease tenderization of beef steaks through inactivation of μ-calpain. Journal of Animal Science. 82: 3254-3266.
2. Lund, M.N., Lametsch, R., Hviid, M.S., Jensen, O.N. & Skibsted, L.H. 2007. High-oxygen packaging atmosphere influences protein oxidation and tenderness of porcine longissimus dorsi during chill storage. Meat Science. 77:295–303.
3. Delles, R.M., Xiong, Y.L. & True, A.D. (2011). Mild protein oxidation enhanced hydration and myofibril swelling capacity of fresh ground pork muscle packaged in high oxygen atmosphere. Journal of Food Science 76: 760-767.
4. Jeremiah, L.E., Dugan, M.E.R., Aalhus, J.L. & Gibson, L.L. (2003). Assessment of the chemical and cooking properties of the major beef muscle and muscle groups. Meat Science 65:985-992.
5. Liu, Z., Xiong, Y.L. & Chen, J. 2009. Identification of restricting factors that inhibit swelling of oxidized myofibrils during brine irrigation. Journal of Agricultural and Food Chemistry. 57:10999–1007.
6. Levine, R.L, Garland, D., Oliver, C.N., Amici, A., Climent, L., Lenz, A.C., Ahn, B.W., Shaltiel, S. & Stadtman, E.R. 1990. Determination of carbonyl content in oxidatively modified proteins. Methods Enzymol. 186:464–78.
7. Sinnhuber, R.O. & Yu, T.C. (1977). The 2-thiobarbituric acid reaction, an objective measure of the oxidative deterioration occurring in fats and oils. Journal japan Oil Chemistry Society. 26:259-267.
8. AMSA. Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness of Fresh Meat. National Livestock and Meat Board, Chicago, IL. 1995.
9. Kirchofer, K.S., Calkins, C.R. & Gwartney, B.L. (2002). Fiber-type composition of muscles of the beef chuck and round. Journal of Animal Science. 80:2872-2878.
10. Raes, K., Balcaen, A., Dirinck, P., De Winne, A., Claeys, E., Demeyer, D. & De Smet, S. (2003). Meat quality, fatty acid composition and flavor analysis in Belgian retail beef. Meat Science, 65: 1237-1246.
11. Shackelford, S.D., Wheeler, T.L. & Koohmaraie, M. (1995). Relationship between shear force and trained sensory tenderness ratings of 10 major muscle from *Bos indicus* and *Bos taurus* cattle. Journal of Animal Science. 73:3333-3340.
12. Belew, J.B., Brooks, J.C., McKenna, D.R. & Savell, J.W. (2003). Warner–Bratzler shear evaluations of 40 bovine muscles. Meat Science 64: 507-512.
13. Rhee, M.S., Wheeler, T.L., Schackelford, S.D. & Koohmaraie, M. (2004). Variation in palatability and biochemical traits within and among eleven beef muscles. Journal of Animal Science, 82: 534-550.
14. Reuter, B.J., Wulf, D.M. & Maddock, R.J. (2002). Mapping intramuscular tenderness variation in four major muscles of the beef round. Journal of Animal Science. 80:2594-2599.