Injection of Conjugated Lineolic Acid into Beef Strip Loins

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Story in Brief

Beef strip loins (IMPS 180; n=15) were sectioned in thirds, and sections (n = 45) were left untreated (CNT) or injected with either a commercial powder conjugated linoleic acid (CLA) source (Powder) or a commercial oil CLA source (Oil), whose major isomers were 18:2*cis*-9, *trans*-11 and 18:2*trans*-10, *cis*-12 CLA isomers. Fresh Oil steaks had 0.320 and 0.315, Powder steaks had 0.467 and 0.462, and CNT steaks had 0.019 and 0.002% of muscle tissue (wet basis) of the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA isomers, respectively. Lipid oxidation (TBARS) was similar for Oil-treated steaks and lower for Powder-treated steaks, compared to CNT steaks. Powder steaks had similar beef and off flavor characteristics as CNT. Artificial marbling was created with Oil steaks having USDA Small[79] and Powder steaks having USDA Modest[86] marbling scores, while CNT steaks had USDA Slight[94] marbling scores. Injection of CLA can be effective in significantly increasing CLA and potentially creating artificial marbling.

Introduction

Conjugated linoleic acids (CLA) have recently received considerable attention due to possible human health benefits in regard to anticarcinogenicity, cardiovascular health, immune modulation, and lean body mass/fat reduction benefits. Two CLA isomers that are the focus of attention are 18:2*cis*-9, *trans*-11 and 18:2*trans*-10, *cis*-12. These isomers are used in medical research and are typically the 2 major CLA isomers in meat animal lipid fractions, with the *cis*-9, *trans*-11 isomer predominating.

Because of human health interest and animal lipids naturally having higher concentrations of these 2 isomers of CLA, animal and meat scientists have focused on animal diet modulation to enhance CLA in the meat/milk lipids. Studies invoking diet modulation have experienced success in heightening CLA levels in lean tissue lipids of swine and ruminants. However, the increased CLA in the lean tissue lipid fraction of meat animals due to diet modulation, would require complete human dietary lifestyle changes to attain the levels of CLA necessary for possible health benefits. Greater concentrations of CLA in meat tissues are required than is currently available to provide levels necessary for possible health benefits in smaller portion sizes. Therefore, the objective of this study was to determine the effects of injection of 2 commercial sources of CLA into beef strip loins on fatty acid composition, meat quality, retail display, and sensory characteristics.

Experimental Procedures

Fresh beef strip loins (IMPS 180; n = 15) from USDA Select carcasses were obtained from a commercial packing plant, transported to the University of Arkansas red meat abattoir and stored at 34°F until 14 d postmortem. Muscles were subsequently removed from vacuum-sealed bags and all external fat and adjacent muscles were removed from the *longissimus* muscle. Each muscle was transversely sectioned in thirds, allowing for muscle section as the experimental unit (n = 45).

Three treatments were allocated to the sections within each muscle, such that each muscle comprised all 3 treatments (n = 15 per treatment; equally represented at anterior, medial, and posterior positions across muscles). The 3 treatments were an untreated control (CNT), and 2 commercial sources of CLA. One commercial source of CLA was a water-soluble milk powder base (Powder; Tonalin® 60 WDP, Cognis Corp., Cincinnati, Ohio) and the other commercial source was a triglyceride safflower oil base (Oil; Tonalin® TG80, Cognis Corp., Cincinnati, Ohio). Each of the CLA sources predominated in approximately equal concentrations of the *cis*-9,*trans*-11 and *trans*-10,*cis*-12 CLA isomers. Complete fatty acid profiles of the 2 CLA sources are presented in Table 1. Both CLA sources were mixed in 37°F tap water. The powder source was directly added to the water and mixed with a Rotosolver® high-shear mixer (Admix, Inc., Manchester, N.H.). For the oil source, lecithin (Thermolec WFC®, ADM, Decatur, Ill.) was utilized as an emulsifier and was added to the solution at 15% of the oil concentration. The solutions for both CLA treatments were injected into the strip loins at 110% of fresh product weight via a Fomaco 20/40 injector (Reiser Inc., Canton, Mass.) comprising 80 needles with 4 needles/1.97 in^2. Following injection, muscle sections from all 3 treatments were then reweighed, vacuum-packaged and stored at 34°F for approximately 48 h.

At 2 d post-enhancement, muscles were removed from their packages, pH was measured with a probe-type pH meter (Meat Probes, Inc., Topeka, Kan.). Muscle sections were then cut into 1 in steaks for the respective analyses. At this time 3 steaks from each muscle section were vacuum-packaged and stored at 34°F for subsequent fatty acid analysis, Warner-Bratzler shear force, and sensory evaluation. The remaining fabricated steaks were placed on foam trays with absorbent pads and overwrapped with polyvinyl chloride film with an oxygen transmission rate of 14,020 cc $O_2/m^2/24h/atm$-60 gauge (PrimeSource®, Koch Supplies, Inc., Kansas City, Mo.). Those steaks, designated for thiobarbituric acid reactive substances (TBARS), were stored under simulated retail conditions (37°F; deluxe warm white fluorescent lighting, 1600 lx, Philips, Inc., Somerset, N.J.) for 7 days. All analyses were performed on fresh muscle samples.

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For Warner-Bratzler shear force (day 6 post-enhancement) steaks (1-in thick) were removed from their vacuum-sealed packages and cooked in a Blodgett forced-air convection oven (Blodgett Oven Co., Burlington, VT) until the internal temperature of each steak was 158°F. Internal temperature was monitored using Teflon-coated copper-constantan thermocouples (Omega Engineering, Inc., Stamford, Conn.) attached to a Doric multichannel data logger (VAS Engineering, Inc., San Diego, Calif.). After cooking, steaks were allowed to cool to room temperature for approximately 2 h. Upon cooling to room temperature, six 0.50-in diameter cores were taken parallel to the muscle fibers from each steak for Warner-Bratzler shear force (WBS; AMSA, 1995). Each core was sheared with a Warner-Bratzler shear attachment using an Instron Universal Testing Machine (Instron Corp., Canton, Mass.) equipped with a 110-lb load cell and 9.84-in/min crosshead speed.

Cooking loss of the steaks was determined during the cooking process for WBS. After steaks were removed from the vacuum-sealed packages, each steak was weighed on a balance prior to cooking. Upon completion of cooking, a final weight was obtained and cooking loss was determined as the difference between the fresh and cooked weight divided by the fresh weight x 100.

On days 2, 3, and 4 post-enhancement, sensory evaluation was conducted across 5 sessions with 3 replicates of each treatment represented each session. Prior to each sensory session, the designated steaks were removed from their vacuum-sealed packages and cooked as previously described for Warner-Bratzler shear force. Immediately after cooking, steaks were cut into 0.39 in x 0.39 in x 1 in pieces and held in a food warmer (Alto-Shamm, Inc., Menomonee Falls, Wis.) at 145°F for approximately 10 min prior to sensory evaluation and during the evaluation process. Samples (9) were served in a random order to each panelist, each session. Sensory panelists (9) were selected and trained according to AMSA (1995) guidelines. Each panelist was allowed to evaluate each sample at his/her own pace. Panelists evaluated myofibrillar and overall tenderness, connective tissue amount, juiciness and beef flavor on an 8-point scale (1 = extremely tough, abundant, extremely dry, extremely non-beef like; 8 = extremely tender, none, extremely juicy, extremely beef like). Panelists also evaluated samples for off flavor intensity on a 5-point scale (1 = extreme off flavor, 5 = no off flavor). Tests were conducted under color neutralizing lights with partitioned booths to isolate panelists.

Marbling scores of all steaks were assessed by 3 experienced individuals on day 0 of display due to an artificial marbling effect from the CLA treatments. Marbling scores were assigned to each steaks using USDA marbling photographs (National Cattlemen's Beef Association, Centennial, Colo.).

On day 0, 3, and 6 of simulated retail display 15 steaks (n = 5 per treatment/day) were sampled for TBARS (ppm malonaldehyde) as previously described by Jimenez-Villarreal et al. (2003) to assess the degree of lipid oxidation.

On day 4 post-enhancement, steaks utilized for fatty acid analysis were removed from vacuum-sealed packages and sectioned transversely in half, such that one half was utilized for fresh, uncooked fatty acid analysis and the other was utilized for cooked fatty acid analysis. Cooked sections were cooked as previously described for Warner-Bratzler shear force. Fresh and cooked samples were cubed, and 0.53 oz from each sample were freeze-dried in duplicate for 96 h utilizing a vacuum pressure of < 10 microns Hg at < - 58°F on a freeze dryer (Labconco Corp., Kansas City, Mo.). After drying, moisture percentage was calculated as the difference between the wet and dry sample weights divided by the wet weight multiplied by 100. Duplicates from each sample were then commingled and ground using a home-style electric coffee grinder. Ambient air exposure was minimized to avoid moisture uptake by samples.

Direct transesterification of duplicate 0.01 oz of dried muscle tissue from each sample was performed based on the methodology of Murrieta et al. (2003) using 0.2 M KOH in anhydrous methanol as the catalyst and tridecanoic acid as the internal standard. Fatty acid methyl esters were separated using a Hewlett-Packard 5890 GLC (Hewlett-Packard, Avondale, Pa.) equipped with a flame ionization detector and a 109.36 yds x 0.01 (i.d.) fused silica capillary column (SP-2560, 7.874×10^{-6} in film thickness, Supelco, Bellefonte, Pa.). Oven temperature was maintained at 324°F for 32 min, then increased at 35°F/min to 383°F and held for 15 min, followed by an increase to 455°F at 36°F/min and held for 5 min. Injector and detector temperatures were 482°F. Helium was the carrier gas with a split ratio of 50:1 and a 7.87-in/sec column flow. Fatty acids were identified by comparing retention times with fatty acid methyl ester standards (Matreya, Inc., Pleasant Gap, Pa., Nu-Chek Prep, Inc., Elysian, Minn., Supelco, Bellefonte, Pa.) and are reported as % wet tissue.

Data were analyzed via PROC MIXED of SAS (SAS Inst., Inc., Cary, N.C.) with the fixed effect of treatment and the random effect of muscle as independent variables in the model. Day and the day x treatment interaction were included in the model for retail display variables. Panelist was included in the model for sensory color and taste data. Cooked and fresh fatty acid data were analyzed independently to directly assess treatment effects in the cooked or fresh state. For all variables, means were generated using LSMEANS and when significant ($P < 0.05$) F values were observed, were separated with the PDIFF option.

Results and Discussion

Untreated steaks (CNT) had the least ($P < 0.05$) whole muscle and retail purge, and Oil steaks had the greatest ($P < 0.05$) whole muscle purge, with steaks from the 2 CLA treatments having similar ($P > 0.05$) retail purge (Table 2). Steaks from both CLA treatments were similar ($P > 0.05$) in cooked losses, and both had higher ($P < 0.05$) cooked losses than CNT. There were no differences ($P > 0.05$) in muscle pH among the treatments. The increased purge from the solution-enhanced treatments was expected without the addition of phosphate, sodium chloride, or other binders to help retain the solution.

Artificial marbling was observed in steaks treated with the CLA sources. Marbling scores revealed that steaks from both CLA treatments increased ($P < 0.05$) marbling compared to CNT, and Powder steaks had higher ($P < 0.05$) marbling scores than Oil (Table 2). The CNT steaks had USDA Slight marbling scores, whereas Oil had USDA Small marbling scores and Powder had USDA Modest marbling scores, with Powder steaks having approximately 2 full marbling grade scores higher than CNT. This was a profound effect, particularly because all treatments were represented in each muscle, and also equally represented at the anterior, medial, and posterior positions of muscles.

Steaks from both CLA treatments required less ($P < 0.07$) shear force than CNT steaks (Table 2). The decreased shear force from the CLA treatments is probably an effect of the needles invoking mechanical tenderization on the muscles more so than the impact of lipid/solution incorporation. Likewise, steaks from both CLA treatments were rated more tender ($P < 0.05$) than CNT for myofibrillar, connective tissue, and overall tenderness (Table 3).

However, there was a trend ($P = 0.06$) for Powder steaks to be juicier than CNT or Oil steaks. The improved juiciness relative to CNT is probably due to the direct affect of solution addition, and improved juiciness for Powder relative to Oil is probably due to decreased whole-muscle purge with similar cooking losses.

Sensory appraisal of flavor indicated that Oil steaks had decreased ($P < 0.05$) beef flavor and increased ($P < 0.05$) off flavor compared to CNT or Powder, with CNT and Powder steaks being similar ($P > 0.05$) in flavor. The powder steaks having similar flavor as CNT and Oil having greater off flavors may be a result of the solution ingredients. The Powder treatment had a dried milk base that may have invoked milder flavor than the Oil treatment's oil and lecithin ingredients causing increased off flavor and diluted beef flavor. Flavor may also have been influenced by treatment impacts on lipid oxidation as is subsequently discussed for TBARS.

There was a significant ($P < 0.05$) day x treatment interaction for TBARS of steaks during display (Fig. 1). While there were no differences ($P > 0.05$) in TBARS at the beginning of display, Powder steaks had lower ($P < 0.05$) TBARS than CNT or Oil on days 3 and 6 of display, indicating decreased oxidation during display for steaks from this treatment. Likewise, the greater lipid oxidation for Oil steaks compared to Powder steaks may also be due to the addition of lecithin in the enhancement solution of the Oil treatment and the oxidation of polyunsaturated fatty acids from the phospholipid fraction of the lecithin.

Fatty acid profiles were obtained on fresh (Table 4) and cooked (Table 5) samples to assess the concentrations of the 2 CLA isomers post-injection for retention, and to assess the concentrations post-cooking that would be consumed. Fresh steaks from both CLA treatments had greater ($P < 0.05$) concentrations of the *cis*-9,*trans*-11 and *trans*-10,*cis*-12 isomers than untreated steaks, and Powder steaks had greater ($P < 0.05$) concentrations of these 2 isomers than Oil steaks. The increase in CLA was of large magnitude with Powder steaks and Oil steaks having approximately 1,600% and 2,500% increases in the *cis*-9,*trans*-11 isomer compared to CNT steaks, respectively. The increase in the *trans*-10,*cis*-12 isomer, compared to CNT steaks, was approximately 16,000% and 23,000% for Oil and Powder steaks, respectively.

Cooked samples from CNT and Oil treatments had numerically higher concentrations of both CLA isomers than their respective fresh samples, indicating retention of CLA combined with water losses for greater concentration expressions per unit of wet sample weight. However, cooked Powder steaks had numerically similar concentrations of both CLA isomers as fresh Powder steaks. This may have resulted from the Powder CLA source being water dispersible and being lost with the water fraction during cooking. While cooked steaks from both CLA treatments had greater ($P < 0.05$) concentrations of both CLA isomers than cooked CNT steaks, the loss of CLA with moisture during cooking for Powder steaks caused cooked Oil steaks to have greater ($P < 0.05$) concentrations of both CLA isomers than cooked Powder steaks. Even so, both CLA treatments substantially increased concentrations of the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers.

Implications

Injection of either a powderized CLA source or an oil CLA source dramatically increased the proportions of the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers of CLA. This effect would allow for the levels of CLA utilized for potential health benefits in medical studies to be consumed by individuals in relatively small portions, as opposed to complete dietary adjustments. Additionally, injection of the powderized CLA source created artificial marbling in steaks that increased visual appraisal of marbling by 2 full USDA marbling scores. Injection of CLA could have potential as a value-addition/fortification tool for beef products in terms of health implications and/or artificial marbling, and warrants further research.

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Table 1. Fatty acid profile of Oil and Powder commercial sources of conjugated linoleic acid (CLA).

Fatty acid, % sample	Commercial CLA Oil product	Commercial CLA Powder product
16:0	0.122	0.487
18:0	2.601	2.023
18:1*cis*-9	14.84	11.64
18:1*cis*-11	0.852	0.677
18:2*cis*-9,*trans*-12	0.407	0.326
18:2*cis*-9,*trans*-11	40.55	30.53
18:2*trans*-10,*cis*-12	40.69	30.699
18:2*trans*-9,*trans*-11	0.696	0.517
18:2*cis*-9,*cis*-11	1.159	0.802
20:0	0.00	0.019
21:0	0.994	0.725

Table 2. Treatment effects for *longissimus* pH, purge, marbling, Warner-Bratzler shear force, cooking loss and retail purge traits.

	Post pH[a]	Purge[b]	Marbling[c]	Warner-Bratzler shear force (N)	Cooking loss[d]	Retail purge[e]
Untreated	5.71	0.68^{y}	394.7^{y}	29.56	24.54^{x}	5.75^{x}
CLA Oil	5.70	2.61^{w}	478.9^{x}	22.61	28.64^{w}	6.90^{w}
CLA Powder	5.72	1.76^{x}	586.2^{w}	24.52	28.51^{w}	6.64^{w}
SEM	0.01	0.14	14.0	2.24	0.66	0.30

[a]Muscle pH post-equilibration.
[b]Whole muscle equilibration purge: (pre-equilibration wt-post-equilibration wt)/pre-equilibration wt x 100.
[c] 300-399 = Slight; 400-499 = Small; 500-599 = Modest.
[d]Cooking loss = (pre-cooked wt - cooked wt)/pre-cooked wt x 100.
[e]Retail purge = (day 0 steak wt - day 6 steak wt)/day 0 steak wt x 100.
[wxy]Trait means with different superscripts differ ($P < 0.05$).

Table 3. Treatment effects for sensory taste panel characteristics.

	Myofibrillar Tenderness[a]	Connective tissue amount[a]	Overall Tenderness[a]	Juiciness[a]	Beef flavor[b]	Off flavor[c]
Untreated	6.55^{x}	6.70^{x}	6.65^{x}	6.55	7.25^{w}	4.69^{w}
CLA Oil	7.12^{w}	6.98^{w}	7.07^{w}	6.61	6.96^{x}	4.25^{x}
CLA Powder	7.17^{w}	6.98^{w}	7.08^{w}	6.85	7.13^{wx}	4.55^{w}
SEM	0.13	0.11	0.12	0.15	0.09	0.07

[a] 1-8: 1 = extremely tough, abundant, extremely dry; 8 = extremely tender, none, extremely juicy.
[b] 1-8: 1 = extremely non-beef like; 8 = extremely beef like.
[c] 1-5: 1 = extreme off-flavor; 5 = no off-flavor.
[wxy]Trait means with different superscripts differ ($P < 0.05$).

Table 4. Treatment effects for fresh, uncooked *longissimus* fatty acid profiles.

Fatty acid , % wet tissue	Untreated	CLA Oil	CLA Powder	SEM
10:0	0.003	0.002	0.002	0.0003
12:0	0.004	0.003	0.003	0.0006
14:0	0.161	0.142	0.143	0.021
14:*cis*-9	0.038	0.033	0.033	0.006
15:0	0.021	0.018	0.018	0.003
16:0	1.276	1.187	1.151	0.117
16:1*trans*-9	0.012	0.01	0.01	0.001
16:1*cis*-9	0.196	0.183	0.176	0.022
17:0	0.053	0.046	0.046	0.006
17:1*trans*-10	0.000	0.001	0.001	0.0002
18:0	0.626	0.618	0.611	0.051
18:1*trans*[a]	0.169	0.140	0.140	0.029
18:1*cis*-9	1.803	1.82	1.836	0.159
18:1*cis*-11	0.09	0.09	0.092	0.008
18:2*cis*-9,*trans*-12	0.207^{x}	0.25^{w}	0.206^{x}	0.015
18:2*cis*-9,*trans*-11	0.019^{y}	0.32^{x}	0.467^{w}	0.031
18:2*trans*-10,*cis*-12	0.002^{y}	0.315^{x}	0.462^{w}	0.032
18:2*trans*-9,*trans*-11	0.000^{y}	0.008^{x}	0.017^{w}	0.002
18:2*cis*-9,*cis*-11	0.000^{y}	0.013^{x}	0.019^{w}	0.001
18:3*cis*-9,12,15	0.014	0.012	0.015	0.001
20:0	0.001	0.001	0.001	0.0003
20:1*cis*-11	0.004^{x}	0.01^{w}	0.003^{x}	0.001
20:3*cis*-8,11,14	0.010	0.011	0.010	0.001
20:4*cis*-5,8,11,14	0.037	0.038	0.037	0.002
20:5*cis*-5,8,11,14,17	0.002	0.001	0.002	0.0007
22:5*cis*-7,10,13,16,19	0.008	0.007	0.008	0.0008
n-6/n-3[b]	1.169^{x}	1.513^{w}	1.143^{x}	0.126
Saturates[c]	2.143	2.017	1.974	0.195
Monounsaturates[d]	2.312	2.285	2.292	0.215
Polyunsaturates[e]	0.300^{y}	0.978^{x}	1.24^{w}	0.071
Total *trans*[f]	0.182	0.160	0.169	0.030

[a]Comprises all 18:1*trans* isomers.
[b]n-6/n-3: (18:2*cis*-9,*trans*-12+20:3*cis*-8,11,14+20:4*cis*-5,8,11,14) / (18:3*cis*-9,12,15+20:5*cis*-5,8,11,14,17+ 22:5*cis*-7,10,13,16,19).
[c]Saturates= Fatty acids with no double bonds.
[d]Monosaturates= Fatty acids with one double bond.
[e]Polyunsaturates= Fatty acids with 2 or more double bonds.
[f]Total *trans*= 16:1*trans*-9+17:1*trans*-10+18:1*trans*+18:2*trans*-9,*trans*-11.
[wxy]Within a row, means with different superscripts differ ($P < 0.05$).

Table 5. Treatment effects for cooked *longissimus* fatty acid profiles.

Fatty acid, % wet tissue	Untreated	CLA Oil	CLA Powder	SEM
10:0	0.004	0.004	0.004	0.001
12:0	0.005	0.005	0.005	0.0007
14:0	0.252	0.225	0.238	0.029
14:*cis*-9	0.057	0.051	0.055	0.007
15:0	0.033	0.029	0.031	0.004
16:0	2.037	1.922	1.969	0.181
16:1*trans*-9	0.021	0.019	0.019	0.002
16:1*cis*-9	0.310	0.284	0.297	0.030
17:0	0.086	0.079	0.081	0.009
17:1*trans*-10	0.003	0.002	0.001	0.0008
18:0	1.067	1.045	1.049	0.097
18:1*trans*[a]	0.273	0.243	0.248	0.042
18:1*cis*-9	2.999	3.037	3.004	0.281
18:1*cis*-11	0.143	0.152	0.145	0.013
18:2*cis*-9,*trans*-12	0.331^{x}	0.417^{w}	0.340^{x}	0.020
18:2*cis*-9,*trans*-11	0.033^{y}	0.646^{w}	0.466^{x}	0.039
18:2*trans*-10,*cis*-12	0.001^{y}	0.635^{w}	0.452^{x}	0.039
18:2*trans*-9,*trans*-11	0.000^{y}	0.021^{w}	0.012^{x}	0.003
18:2*cis*-9,*cis*-11	0.000^{y}	0.023^{w}	0.015^{x}	0.001
18:3*cis*-9,12,15	0.024	0.020	0.024	0.003
20:0	0.003	0.003	0.002	0.0008
20:1*cis*-11	0.008^{x}	0.020^{w}	0.007^{x}	0.001
20:3*cis*-8,11,14	0.017	0.017	0.018	0.001
20:4*cis*-5,8,11,14	0.056	0.056	0.060	0.003
20:5*cis*-5,8,11,14,17	0.003	0.003	0.004	0.0012
22:5*cis*-7,10,13,16,19	0.013	0.012	0.014	0.001
n-6/n-3[b]	1.161^{x}	1.529^{w}	1.142^{x}	0.13
Saturates[c]	3.486	3.312	3.380	0.30
Monounsaturates[d]	3.814	3.810	3.776	0.363
Polyunsaturates[e]	0.477^{y}	1.853^{w}	1.403^{x}	0.088
Total *trans*[f]	0.296	0.285	0.280	0.044

[a]Comprises all 18:1*trans* isomers.
[b]n-6/n-3: (18:2*cis*-9,*trans*-12+20:3*cis*-8,11,14+20:4*cis*-5,8,11,14) / (18:3*cis*-9,12,15+20:5*cis*-5,8,11,14,17+ 22:5*cis*-7,10,13,16,19).
[c]Saturates= Fatty acids with no double bonds.
[d]Monosaturates= Fatty acids with one double bond.
[e]Polyunsaturates= Fatty acids with 2 or more double bonds.
[f]Total *trans*= 16:1*trans*-9+17:1*trans*-10+18:1*trans*+18:2*trans*-9,*trans*-11.
[wxy]Within a row, means with different superscripts differ ($P < 0.05$).

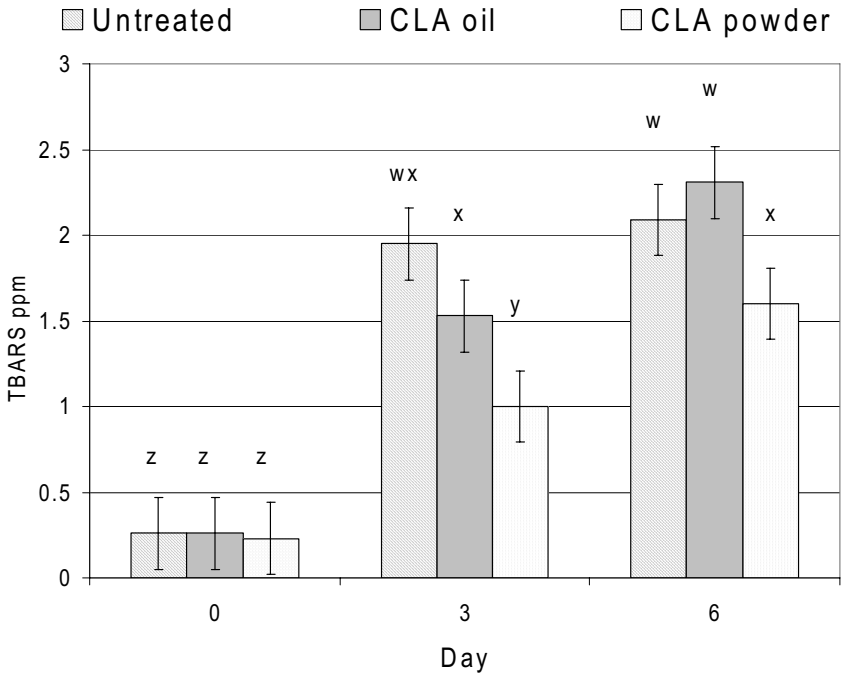

Fig. 1. Treatment x day interaction for TBARS (lipid oxidation; thiobarbituric acid reactive substances) of *longissimus* steaks during simulated retail display. Columns with different superscripts differ (P < 0.05).