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Meat Science 66 (2004) 567–577

MEAT SCIENCE

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Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef

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Received 17 March 2003; received in revised form 13 June 2003; accepted 13 June 2003

Abstract

Thirty Hereford steers were finished either on pasture ($n=10$) or concentrate ($n=20$) to determine dietary and antioxidant treatment effects on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. Half of the steers finished on concentrate were supplemented with 1000 I.U. vitamin E head^{-1} day^{-1} for 100 days. Postmortem vitamin C was added to ground beef (0.05% v/w) displayed for 8 days at 2 °C. Carcasses from steers finished on concentrate had greater ($P<0.05$) carcass weight, conformation, degree of finishing, fat depth, and ribeye area than pasture finished animals. Carcasses from pasture-fed steers showed darker ($P<0.05$) longissimus color and yellower ($P<0.05$) fat at 24 h postmortem than concentrate-fed. Initial longissimus Warner-Bratzler shear force (WBSF) values were similar ($P>0.05$) between pasture- and concentrate-fed animals. However, beef from pasture-fed cattle had lower ($P<0.05$) WBSF values at 7 and 14 days postmortem. Longissimus α-tocopherol concentrations were greater ($P<0.01$) for pasture- and concentrate-fed animals that were supplemented with vitamin E compared to concentrate-fed. Steaks from pasture-fed and vitamin E supplemented cattle had similar ($P>0.05$) TBARS values, which were lower ($P<0.05$) than steaks from concentrate-fed steers during 21 days of display. Ground beef from vitamin E supplemented steers had the lowest TBARS values; whereas samples from pasture-fed animals had the lowest lipid stability with higher TBARS levels than other treatments. Vitamin C addition to ground beef did not ($P>0.05$) reduce lipid oxidation. Vitamin E supplementation of concentrate-fed cattle had no effect ($P>0.05$) on color stability of ground beef or steaks. The a^* (redness) and b* (yellowness) values were higher ($P<0.05$) when vitamin C was added to ground beef. Longissimus fatty acid content of concentrate-fed animals was twofold greater ($P<0.01$) than pasture-fed. The percentages of C14:0, C16:0, and C18:1 fatty acids were higher ($P<0.01$) in the intramuscular fat of concentrate-fed steers, whereas pasture-fed cattle showed greater ($P<0.01$) proportions of C18:0, C18:2, C18:3, C20:4, C20:5, and C22:5. Total conjugated linoleic acid (CLA) and CLA isomer c9t11 were higher ($P<0.01$) for pasture- than concentrate-fed cattle. Vitamin E supplementation of concentrate-fed steers increased lipid stability of ground beef and steaks, but was unable to improve color stability; whereas vitamin C addition to ground beef increased color stability without altering lipid oxidation. Finishing cattle on pasture enhanced the unsaturated fatty acid profile of intramuscular fat in beef including CLA and omega-3 fatty acids.

Keywords: Beef; Pasture; Concentrate; Antioxidants

1. Introduction

Beef cattle production systems in Uruguay rely almost exclusively on grazed pastures. However, more recently intensive beef production systems have gained increased interest by some beef producers. The focus is to produce a differentiated product in a vertically integrated manner to target both domestic, but particularly international markets. This production system, however, differs from a typical feedlot grain-based diet in the United States, in that the rations are formulated with 50% corn silage, and 50% grain.

Dietary recommendations for humans promoting the consumption of less saturated fat have led to an increased interest in meats containing more unsaturated fatty acids. Consumption of saturated fatty acids (SFA) has been associated with increased serum low-density-lipoprotein cholesterol concentrations, and increased risk

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doi:10.1016/S0309-1740(03)00160-8

of coronary heart disease (Keys, 1970). Ruminant fat has a higher SFA and a lower polyunsaturated:saturated fatty acid (PUFA:SFA) ratio than non-ruminant fat, due to hydrogenation of dietary unsaturated fatty acids in the rumen (French, Stanton et al., 2000). However, the nutritional background of meat-producing animals may alter the fatty acid composition of ruminant tissue fat.

Recent research has focused on the nutritional importance of the n-6:n-3 fatty acid ratio in the human diet, and on conjugated linoleic acid (CLA) isomers because of their anticarcinogenic properties (Ha, Storkson, & Pariza, 1990; Ip, Singh, Thompson, & Scimeca, 1994). The nutritional value of n-3 PUFAs is well recognized, and increased consumption of these fatty acids has been recommended (Department of Health, 1994). Ruminant fats are among the richest natural sources of CLA, in particular the *cis*-9, *trans*-11 isomer, which arises from microbial hydrogenation of dietary linoleic acid in the rumen (Ha et al., 1990). In addition, CLA is synthesized from *trans*-11 octadecenoic acid by Δ^9-desaturase in adipose tissue (Bauman, Baumgard, Corl, & Griinari, 1999). Previous research has shown that including grass in the diet of dairy and beef cattle increased CLA concentration in milk and beef intramuscular fat, respectively (French, Stanton et al., 2000; Lawless, Murphy, Harrington, Devery, & Stanton, 1998; Yang, Lanari, Brewster, & Tume, 2002a).

Although an increase in the n-3 fatty acid concentration is desirable from a human health perspective, oxidative stability of meat is reduced. Lipid and muscle pigment oxidation are the major problems causing quality deterioration in meat. Thus, enrichment with antioxidants is necessary in order to prevent the risk of oxidative damage (Jakobsen, 1999).

The Uruguayan economy is strongly dependent on agriculture and the export of beef products, and there is no information available comparing the meat quality, fatty acid composition and product shelf life of beef from the traditional pasture-fed and the more intensive concentrate-based production systems. The objectives of this study were to compare carcass characteristics, beef quality, and longissimus fatty acid composition from cattle finished on pasture or on a concentrate-based diet; and to evaluate the effect of antioxidants, antemortem vitamin E and postmortem vitamin C, on product shelf life.

2. Materials and methods

2.1. Animals and diets

Thirty Hereford steers backgrounded on pasture were finished either on pasture ($n = 10$) or concentrate ($n = 20$) during summer (November 2001–February 2002). Pasture- and concentrate-fed steers were fed in commercial operations run by the National Institute of Agricultural Research of Uruguay in conjunction with the Uruguayan Hereford Breeders Association, and the Uruguayan Association of Natural Intensive Beef Producers. The pasture consisted predominantly of perennial ryegrass (*Lolium perenne*), birdsfoot trefoil (*Lotus corniculatus*), white clover (*Trifolium repens*), and tall fescue (*Festuca arundinacea*) with presence of weeds. The concentrate ration consisted of 50% corn silage, 28% wheat hulls, 18% corn, and 5% supplement (predominantly wheat hulls, Rumensin®, and urea). Half of the steers finished on concentrate were supplemented with 1000 I.U. vitamin E head^{-1} day^{-1} for 100 days. Concentrate-fed steers were slaughtered in a commercial meat plant according to normal procedures after 100 days of finishing. Pasture-fed steers were slaughtered in the same commercial meat plant after a grazing period of 130 days.

2.2. Slaughter and sampling procedures

Carcasses were graded after slaughter using the Uruguayan grading system as specified by the National Meats Institute (I.N.A.C., 1997), and carcass data recorded (conformation, age, degree of finishing, dentition). Carcass conformation was based on visual assessment of muscle mass development and a lower number indicates better conformation (1: large muscle development to 6: lack of muscle development). Degree of finishing was based on amount and distribution of subcutaneous fat and a lower number indicates lack of finishing (0: lack of fat cover to 4: excessive finishing). Age was based on dentition and a lower number indicates a younger animal (1: baby teeth to 4: full teeth). Carcass temperature was measured at 1, 3, and 22 h postmortem in the longissimus muscle between the 12th and 13th ribs (Barnant 115, thermocouple type E). At 24 h postmortem, carcasses were ribbed between the 12th and 13th ribs and additional carcass data collected (ribeye area, fat depth and pH). The pistola cut was weighed and the ribeye roll (IMPS 112) and clod (IMPS 114) were removed from each carcass, vacuum-packaged and transported to a meat laboratory. Colorimeter measurements were taken on the ribeye roll after 1 h bloom time for subcutaneous fat and the exposed longissimus muscle between the 12th and the 13th ribs.

The ribeye roll was fabricated into steaks (2.5 cm) for fatty acid analysis, vitamin E determination, tenderness, and lipid and color stability measurements. Steaks for fatty acid analysis and vitamin E determination were individually vacuum packaged and frozen for subsequent analyses. Steaks for tenderness measurements were vacuum packaged, stored in a cooler at 2 °C for 1, 7 and 14 days of aging and frozen for subsequent Warner-Bratzler shear force determination. Steaks for lipid and color stability measurements were individually

placed on Styrofoam trays, over-wrapped with oxygen permeable film, and displayed for 21 days at 2 °C in a lighted cooler. The clod was stored anaerobically in a cooler at 2 °C for 1 week. After storage in order to reduce sample numbers for TBARS analyses the clod was trimmed and ground (0.635 cm). Each ground beef sample was divided into two equal sub-samples. Sodium ascorbate (0.05% v/w; vitamin C) was added to one sub-sample, mixed, and formed into 114-g patties. The remaining sub-sample did not receive a postmortem vitamin C treatment and was formed into 114-g patties. Hamburger patties were placed on Styrofoam trays, overwrapped with oxygen permeable film and stored for 8 days in a 2 °C lighted cooler.

2.3. Lipid oxidation analysis

Lipid stability was evaluated in the steaks and ground beef that were displayed for instrumental color. Lipid oxidation was determined by measuring 2-thiobarbituric acid reactive substances (TBARS, Jo & Ahn, 1998) at 0, 5, 13 and 21 days of display for steaks, and at 0, 3, and 8 days of display for ground beef.

2.4. Instrumental color

Instrumental color measurements were recorded for L^* (lightness; 0: black, 100: white), a^* (redness/greenness; positive values: red, negative values: green), and b^* (yellowness/blueness; positive values: yellow, negative values: blue) using a Minolta chromameter (CR-210, Minolta Inc., Osaka, Japan). Steak and ground beef color measurements were obtained at 0, 5, 13, and 21 days, and 0, 3, 6, and 8 days of display for each sample, respectively. Values were recorded from three locations of the upper surface of each patty and steak randomly selected to obtain a representative reading of the surface color.

2.5. Fatty acid composition

Steaks were submerged in liquid nitrogen (−196 °C), pulverized and stored anaerobically at −20 °C. Total lipid was determined following the chloroform–methanol procedure of Folch, Lees, and Sloane Stanley (1957), modified by using a 10:1 ratio of chloroform-methanol to sample. Extract containing approximately 25 mg of lipid was converted to fatty acid methyl esters (FAME) following the method of Duckett, Andrae, and Owens (2002). The FAME were analyzed using a HP6890 (Hewlett-Packard) gas chromatograph, and separated using a 100-m SP 2560 capillary column (0.25 mm i.d. and 0.20 μm film thickness, Supelco, Bellefonte, PA). Column oven temperature was programmed at 150–165 °C at 1 °C/min, 165–167 °C at 0.2 °C/min, 167–225 °C at 1.5 °C/min and held at 225 °C for 15 min with 1:100 split. The injector and detector were maintained at 250 °C. Hydrogen was the carrier gas at a flow rate of 1 ml/min. Individual fatty acids were identified by comparison of retention times with standards (Sigma, St. Louis, MO; Supelco, Bellefonte, PA; Matreya, Pleasant Gap, PA).

2.6. Tenderness (Warner-Bratzler shear force)

Steaks (2.5 cm) were vacuum packaged, stored in a cooler at 2 °C and frozen after 1, 7 and 14 days of aging for subsequent Warner-Bratzler shear force determination. Steaks were thawed for 24 h at 2 °C, and boiled in a water bath to an internal temperature of 71 °C (AMSA, 1995). Steaks were allowed to come to room temperature before six 1.27-cm cores were removed per steak parallel to the longitudinal orientation of the muscle fibers. All cores were sheared perpendicular to the long axis of the core using a Warner-Bratzler meat shear machine (Standard Shear model 2000 D, G-R Manufacturing Co; Manhattan, Kansas).

2.7. Vitamin E analysis

Muscle α-tocopherol concentrations were measured according to Koprivnjak, Lum, Sisak, and Saborowski (1996) with modifications, using reverse phase high-pressure liquid chromatography (HPLC AKTA Purified System, Amersham Pharmacia Biotech) with fluorescence detection (Shimadzu RF-10A XL). Duplicate 25 mg muscle samples free of marbling fat were weighed, combined with 400 μl of methanol, and mixed vigorously using a pestle for 15 s. The homogenate was then vortexed for 30 s, and centrifuged for 10 min at 14 000 rpm (microcentrifuge Eppendorf 5415C). An aliquot of the supernatant was transferred into a vial and 30 μl were injected into the HPLC. Wavelength settings were 295 and 325 nm for excitation and emission, respectively. The mobile phase consisted of methanol with a flow rate of 1.0 ml min^{-1}. The column used was Sephasil Peptide C18 5u ST 4.6/100. The α-tocopherol concentrations were calculated based on peak area of external standards (Sigma, St. Louis, MO).

2.8. Statistical analysis

Results were analyzed by analysis of variance using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Pre-planned, non-orthogonal contrasts were used to compare means from cattle finished on pasture, concentrate-fed steers with or without vitamin E supplemention, and from ground beef samples treated with vitamin C. Variables measured over time were analyzed as repeated measures. Vitamin E supplementation did not alter any carcass characteristic, Warner-Bratzler shear force, or fatty acid composition, and data were pooled across vitamin E treatment for concentrate-fed cattle.

3. Results and discussion

3.1. Carcass characteristics

Vitamin E supplementation did not alter ($P > 0.05$) any of the carcass characteristic measured. The effect of finishing beef cattle on pasture or concentrate on carcass characteristics is shown in Table 1. Carcasses from cattle finished on concentrate were heavier ($P < 0.05$) than those finished on pasture. Conformation scores tended to be lower ($P < 0.10$) indicating better conformation from carcasses finished on concentrate than pasture. Carcasses from concentrate-finished animals had greater ($P < 0.05$) fat depth, ribeye area, and degree of finishing than pasture-finished animals. Dietary treatment did not alter ($P > 0.05$) age at slaughter, pistola cut weight, or longissimus muscle pH values. Similarly, Bidner et al. (1986) and Morris, Purchas, and Burnham (1997) observed no change in muscle pH between pasture- and concentrate-fed cattle.

3.2. Instrumental longissimus and fat color

Objective color measurements of longissimus muscle and subcutaneous fat at the 12/13th rib interface taken after 1 h bloom time are shown in Table 2. Longissimus muscle of animals finished on pasture had lower ($P < 0.05$) L^* values indicating a darker colored lean than concentrate-finished animals. Others (Bidner et al., 1986; McCaughey & Cliplef, 1996; Schroeder, Cramer, Bowling, & Cook, 1980) have shown darker muscle color in pasture-fed than grain-fed beef. There were no differences ($P > 0.05$) in longissimus a^* or b^* among treatments.

For subcutaneous fat, carcasses from pasture-fed cattle had higher ($P < 0.05$) L^* values than carcasses from concentrate-fed animals that were supplemented with vitamin E, with control concentrate-fed steers being intermediate. Finishing cattle on pasture increased ($P < 0.05$) subcutaneous fat b^* values indicating more yellowness compared with fat from concentrate finished animals not supplemented with vitamin E. However, subcutaneous fat b^* values for concentrate-fed steers that were supplemented with vitamin E did not differ ($P > 0.05$) compared with pasture- and concentrate-fed cattle. Numerous studies have consistently shown that feedlot-finished cattle have whiter fat color scores than pasture-fed animals (Bennett et al., 1995; Schaake et al., 1993; Simonne, Green, & Bransby, 1996). Fat color is largely dependent on its carotenoid content derived from plants. Green, fresh pastures usually contain high quantities of carotenoids (up to 500 ppm of dry matter); dry or cut hay may have considerably less (< 50 ppm), whereas most grains contain only small concentrations of carotenoids (usually < 5 ppm, Tume & Yang, 1996).

3.3. Beef tenderness (Warner-Bratzler shear force)

Warner-Bratzler shear force (WBSF) values over 14 days of aging are presented in Fig. 1. Initial tenderness did not differ ($P > 0.05$) between pasture- and grain-fed cattle (4.7 vs. 4.5 kg, respectively). Studies comparing forage vs. concentrate finishing of beef have produced mixed results on palatability attributes. Some studies found a negative effect of forage finishing on meat tenderness (Mitchell, Reed, & Rogers, 1991; Smith, 1990), while others showed that pasture-fed beef can be produced with no deleterious effects on meat quality including tenderness (French et al., 2001; Mandell, Buchanan-Smith, & Campbell, 1998). In many experiments, dietary effects are confounded with animal age, growth rate or carcass weight and fatness at slaughter.

Table 1
Mean (±SE) carcass characteristics of steers

Characteristic	Pasture ($n = 10$)	Concentrate ($n = 20$)
Hot carcass wt., kg	225.6a ± 4.405	240.1b ± 3.115
Age[a,b]	1.9 ± 0.121	1.8 ± 0.086
Conformation[a,c]	3.0c ± 0.123	2.7d ± 0.087
Degree of finishing[a,d]	1.5a ± 0.095	2.0b ± 0.067
Pistola cut wt, kg[e]	46.5 ± 0.911	47.4 ± 0.645
Fat depth, mm	3.8a ± 0.614	6.1b ± 0.434
Ribeye area, cm^2	55.2a ± 2.168	62.9b ± 1.533
pH	5.7 ± 0.039	5.7 ± 0.028

Means within the same row with different letters (a,b) differ ($P < 0.05$). Means within the same row with different letters (c,d) differ ($P < 0.10$).

[a] Carcass characteristics were evaluated according to the procedures of the Uruguayan National Meats Institute (INAC, 1997).

[b] Based on dentition, a lower number indicates younger animal (1: baby teeth to 4:full teeth).

[c] A lower number indicates better conformation (1–6).

[d] A lower number indicates lack of finishing (0–4).

[e] Pistola cut (round and loin).

Table 2
Lightness (L^*), redness (a^*), and yellowness (b^*) of longissimus and subcutaneous fat at 24 h postmortem

	Diet			
	Pasture ($n = 10$)	Concentrate ($n = 10$)	Concentrate ($n = 10$)	
	Vitamin E (I.U. $head^{-1}$ day^{-1})			
	0	0	1000	SE
Longissimus color				
L^*	33.80b	35.56a	36.34a	0.692
a^*	20.45	20.42	20.95	0.520
b^*	8.77	8.44	9.22	0.313
Fat color				
L^*	72.44a	71.81ab	69.78b	0.858
a^*	5.94	5.15	5.51	0.302
b^*	15.23a	13.53b	14.48ab	0.540

Means within the same row with different letters (a,b) differ $P < 0.05$.

In this study, initial shear force values were similar between steaks from pasture- and concentrate-fed steers despite differences ($P<0.05$) in carcass weight (226 vs. 240 kg), fatness (fat depth: 3.8 vs. 6.1 mm), and temperature during chilling (Table 3). Carcass temperature during chilling was lower ($P<0.01$) for pasture- than concentrate-fed cattle. More extensive aging was evident in steaks from pasture-fed steers, which had WBSF values approximately 1 kg ($P<0.01$) and 0.6 kg ($P<0.05$) lower at 7 and 14 days of aging, respectively than steaks from concentrate-fed animals. French, O'Riordan et al. (2000) found that supplementing grass with low levels of concentrate produced the most tender and acceptable meat at 2 days postmortem, but that further aging eliminated all treatment effects on eating quality of beef.

3.4. Muscle α-tocopherol concentrations

Longissimus concentrations of α-tocopherol were greater ($P<0.01$, Fig. 2) for pasture- and concentrate-fed cattle supplemented with vitamin E (3.91 and 3.74 μg/g, respectively), compared with concentrate-fed control animals (2.92 μg/g). Faustman, Cassens, Schaefer, Buege, Williams, and Scheller (1989) reported minimum tissue levels of 3.0 μg α-tocopherol/g muscle, whereas Arnold, Arp, Scheller, Williams, and Schaefer (1993) proposed 3.5 μg/g as the target concentration to have a significant impact on the reduction of pigment and lipid oxidation. Liu, Scheller, Arp, Schaefer, and Williams (1996) concluded that these critical α-tocopherol concentrations might be the minimal critical levels that need to be achieved in order to enhance meat quality. Results from different field studies reported that 500–1000 I.U. animal^{-1} day^{-1} of vitamin E for 90–100 days prior to harvest is efficacious for beef marketed in both domestic and export trades (Smith, Morgan, Sofos, & Tatum, 1996). Roeber, Belk, Tatum, Wilson, and Smith (2001) evaluated the effect of three supplementation levels with α-tocopherol on product shelf life, and concluded that 1000 I.U. animal^{-1} day^{-1} of α-tocopherol for at least 100 days can be used to increase retail caselife and to improve the overall color acceptability of steaks and ground beef products. In the present study, supplementation of α-tocopherol to concentrate-fed cattle with 1000 I.U. animal^{-1} day^{-1} for 100 days was sufficient to achieve similar ($P>0.05$) muscle α-tocopherol content to grass-fed cattle, at levels beyond the proposed critical concentrations for improving shelf life.

Vitamin E supplementation of pasture-fed cattle was not considered in this research. Faustman, Chan, Schaefer, and Havens (1998) suggested that if a nutritional program delivers sufficient vitamin E to obtain the threshold level in muscle, then additional supplementation is unnecessary. α-tocopherol concentrations in fresh forage can theoretically result in muscle saturation with α-tocopherol, since green forage may be a good dietary source of α-tocopherol when pasture quality allows for high levels of α-tocopherol consumption (Faustman et al., 1998). Research conducted recently in Australia (Yang et al., 2002) showed that vitamin E supplementation of pasture-fed cattle did not alter muscle tocopherol contents.

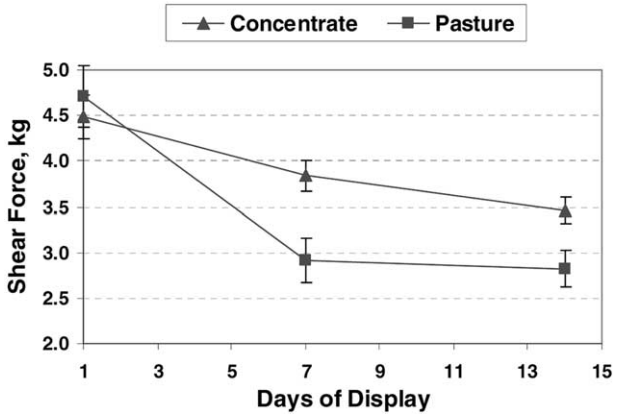

Fig. 1. Effect of postmortem aging on shear force of longissimus steaks from pasture ($n=10$) and concentrate ($n=20$).

Table 3
Temperature (means±SE) change during chilling from pasture- and concentrate-fed carcasses measured in the longissimus muscle

Chilling time (h)	Temperature, °C	
	Pasture ($n=10$)	Concentrate ($n=20$)
1	36.63a±0.422	39.25b±0.298
3	22.14a±0.599	26.65b±0.423
22	0.73a±0.154	1.77b±0.109

Means within the same row with different letters (a,b) differ $P<0.01$.

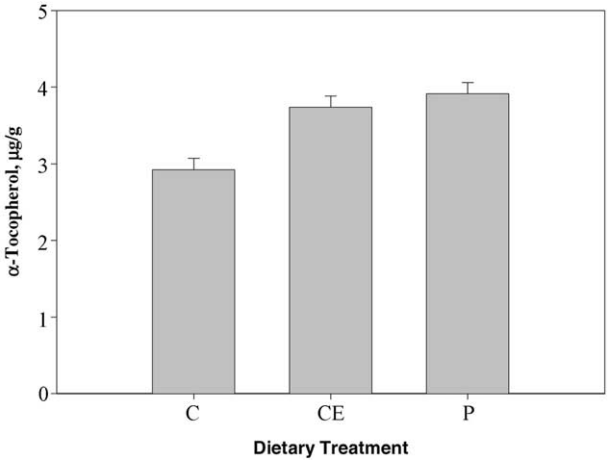

Fig. 2. Muscle α-tocopherol concentrations from pasture (P, $n=10$), concentrate (C, $n=10$), and concentrate–vitamin E (CE, $n=10$).

3.5. Lipid oxidation

Fig. 3a shows lipid oxidation values, as determined by TBARS, for longissimus steaks at different storage times during 21 days of lighted display at 2 °C. Steaks from pasture-fed animals had lower ($P<0.01$) initial TBARS values than steaks from concentrate-fed cattle. With increasing display time, lipid oxidation was lower ($P<0.05$) for steaks from pasture-fed and vitamin E supplemented cattle than from control concentrate-fed steers. This is in contrast to the results of Yang et al. (2002) who found that pasture feeding increased lipid oxidation of aged beef compared with vitamin E supplemented grain-fed beef, despite similar muscle α-tocopherol concentrations. In the present study, pasture-fed beef achieved similar muscle α-tocopherol concentrations as well as similar lipid stability to steaks from concentrate-fed cattle that were supplemented with vitamin E. The results for concentrate-fed cattle are consistent with previous research findings which showed that supplementing feedlot cattle with vitamin E improved lipid stability of beef during retail display (Houben, van Dijk, Eikelenboon, & Hoving-Bolink, 2000; Roeber et al., 2001; Stubbs, Morgan, Ray, & Dolezal, 2002).

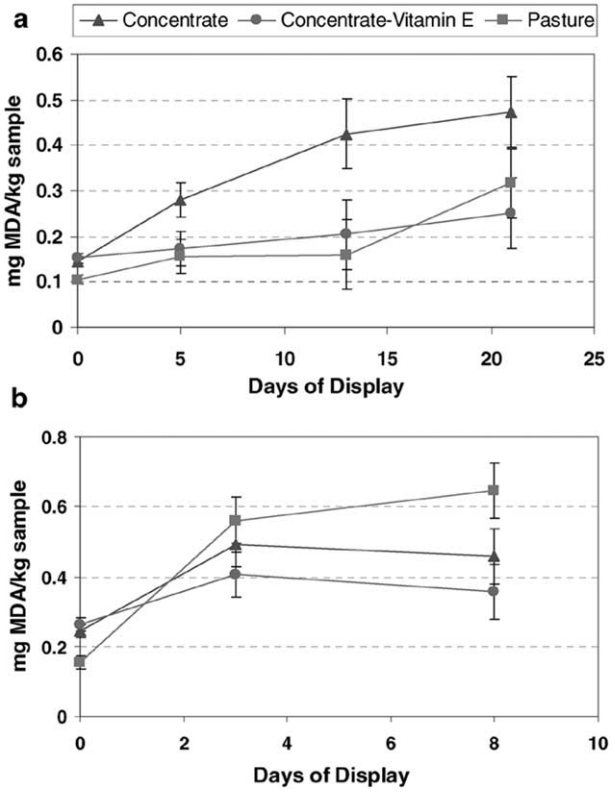

Fig. 3. Levels of TBARS (mg malonaldehyde/kg sample) values during display at 2 °C of (a) longissimus steaks and (b) ground beef from pasture ($n=10$), concentrate ($n=10$), and concentrate–vitamin E ($n=10$).

Vitamin C addition to ground beef did not alter ($P>0.05$) lipid oxidation (data not shown). There was no interaction ($P>0.05$) between dietary treatment (pasture, concentrate, and concentrate–vitamin E) and vitamin C addition to ground beef indicating the lack of a synergistic effect between vitamin E and C on lipid oxidation. These results are in disagreement with Schaefer, Liu, Faustman, and Yin (1995) who pointed out that myoglobin and lipid are less prone to lipid oxidation, provided α-tocopherol is present with ascorbic acid. Parker (1989) proposed that once the tocopheryl radical is formed, the molecule is no longer an active antioxidant, but ascorbic acid can reduce the radical regenerating its antioxidant activity. Previous studies also showed that steaks and ground beef from α-tocopherol acetate-supplemented LD had even greater color and lipid stability when dipped in L-ascobic acid solution (Mitsumoto, Cassens, Schaefer, Arnold, & Scheller, 1991; Mitsumoto, Faustman, Cassens, Arnold, Schaefer, & Scheller, 1991).

Fig. 3b shows the TBARS values for ground beef samples displayed during 8 days at 2 °C. Ground beef from cattle finished on concentrate showed higher ($P<0.05$, day 0) initial lipid oxidation values than pasture-fed. At 3 days of display, there were no differences ($P>0.05$) among dietary treatments in lipid oxidation. However, at 8 days of display ground beef from vitamin E supplemented cattle had lower ($P<0.05$) TBARS values, exhibiting greater lipid stability as a consequence of the vitamin E antioxidant activity, than ground beef from pasture-fed animals, with ground beef from non-supplemented cattle being intermediate. Mincing muscle tissue disrupts cellular integrity and exposes more of the lipids to the oxidative catalysis; it also dilutes the antioxidants and increases the exposure of the tissue to oxygen (Hultin, 1988). Animal adipose tissues from pasture-based diets have greater concentrations of n-3 PUFA compared with adipose tissues from concentrate-fed cattle. Increasing n-3 PUFA content increases susceptibility to lipid oxidation in displayed products, more so in minced beef than steaks because of the extra processing involved (Vatansever et al., 2000). This may explain the greater lipid oxidation observed in ground beef compared with steaks from pasture-fed animals.

3.6. Instrumental color of longissimus steaks and ground beef

The changes in longissimus steak color (L^*, a^*, b^*) over 21 days of illuminated display at 2 °C are shown in Fig. 4. Steaks from pasture-fed cattle had higher ($P<0.05$) L^* values than concentrate-fed cattle during 13 days of display. This is in contrast to the results from longissimus color recorded at 24 h postmortem, which showed that pasture-fed steers had lower L^* values

indicating a darker color. Pasture-fed beef was redder ($P<0.05$) and yellower ($P<0.05$) than concentrate-fed beef after 5 days of display regardless of vitamin E supplementation. Vitamin E supplementation of concentrate-fed cattle did not alter ($P>0.05$) L^*, a^*, or b^* lean color values. a^* values reported in this study are higher than those reported in the literature. However, the rate of decline during display is similar to that observed in other studies.

Dietary treatment (pasture, concentrate, and concentrate–vitamin E) did not alter ($P>0.05$) L^*, a^* or b^* values of ground beef during display (data not shown). Vitamin C addition to ground beef did not alter ($P>0.05$) L^* values (data not shown). However, in contrast to vitamin E, vitamin C addition to ground beef showed a clear effect on redness by delaying metmyoglobin formation and retaining a redder ($P<0.05$) color during display (Fig. 5a). Addition of vitamin C also had a clear effect on yellowness (b^* value) of ground beef showing higher b^* values ($P<0.05$) during display than control samples (Fig. 5b).

The lack of response to vitamin E supplementation in color stability of whole muscle as well as ground beef is in agreement to Yang et al. (2002), who reported that supra-nutritional supplementation of grain-fed cattle with vitamin E did not affect meat redness or stability compared with non-supplemented cattle. However, these results were only evaluated over a 7-day period of aerobic storage. In contrast to the results in this study, previous publications have shown important responses in meat color stability to vitamin E supplementation of grain-fed cattle (Houben et al., 2000; Roeber et al., 2001; Stubbs et al., 2002). Yang et al. (2002) attributed the absence of response to vitamin E supplementation in color stability to the relatively high levels of muscle α-tocopherol (1.8–2.4 μg/g) present in non-supplemented grain-fed animals. Eikelenboom, Hoving-Bolink, Houben, and Klont (2000) suggested that α-tocopherol concentrations between 2.1 and 4.4 μg/g in unsupplemented muscle may have reduced the response of the LD muscle to the vitamin E treatment. Results from this research

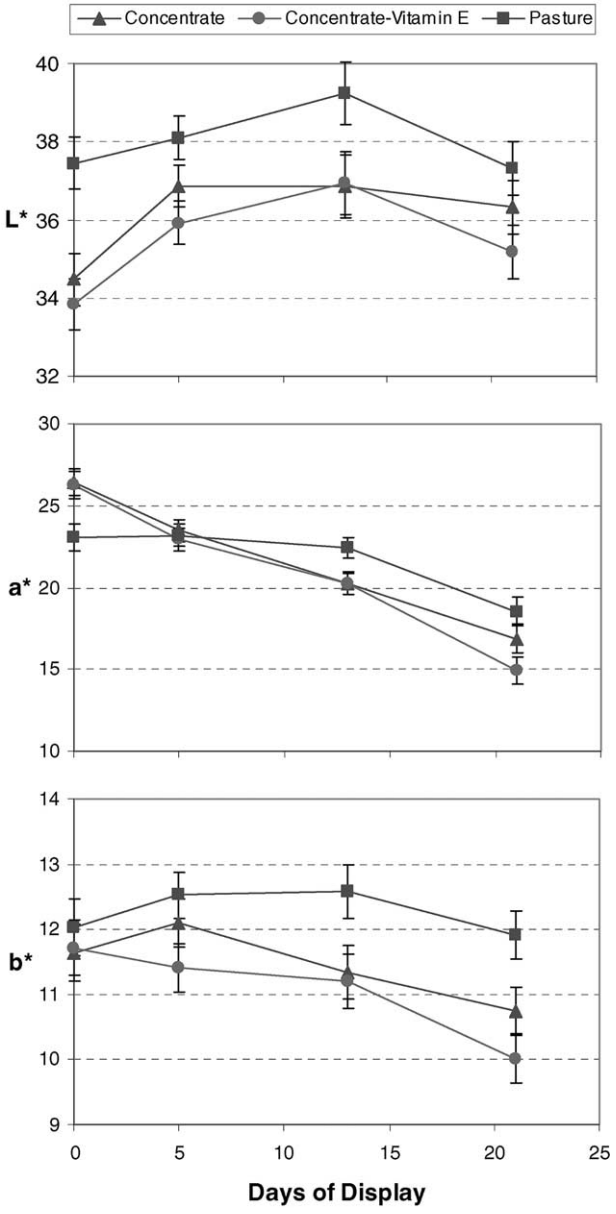

Fig. 4. Color L^*, a^*, and b^* values during display of longissimus steaks at 2 °C from pasture ($n=10$), concentrate ($n=10$), and concentrate–vitamin E ($n=10$).

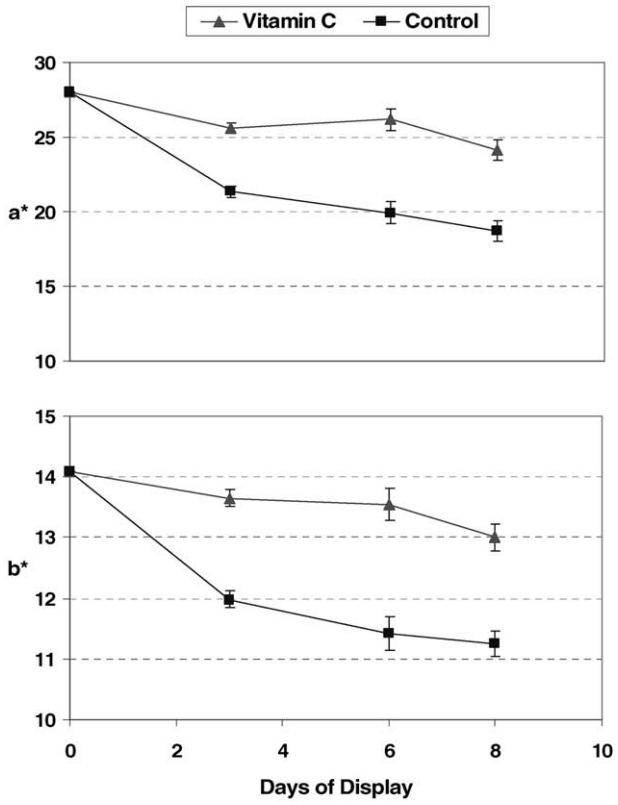

Fig. 5. Color a^* and b^* values of ground beef during display at 2 °C from vitamin C treatment and control.

showed that the mean α-tocopherol level for longissimus muscle of unsupplemented concentrate-fed cattle (2.92 μg/g) was within this concentration range. The steers used in this research were backgrounded on good quality pastures before the differential dietary treatments. Hill and Williams (1993), and Yang et al. (2002) reported limited benefit from vitamin E supplementation on color stability of fresh beef from cattle fed good quality pasture immediately before grain feeding. The composition of the concentrate ration fed to cattle in the present study, is different from the corn- or sorghum-based feedlot rations used in the finishing production systems of USA or Australia. The depletion of α-tocopherol in muscle as a consequence of a feedlot finishing period would be slower when the ration is predominantly corn silage with corn and wheat hulls compared with a grain-based ration.

3.7. Intramuscular fatty acid composition

The lipid content and fatty acid composition of longissimus intramuscular fat for pasture- and concentrate-fed cattle are presented in Table 4. Vitamin E supplementation had no effect ($P > 0.05$) on the fatty acid content or composition of intramuscular fat. Longissimus fatty acid content of concentrate-fed steers was twofold greater ($P < 0.01$) than pasture-fed animals (3.18 vs. 1.68%, respectively). These values are similar to the mean fat contents reported by Yang et al. (2002) in LD from concentrate- and pasture-fed animals (3.63 vs. 1.71%, respectively). The main fatty acids in the intramuscular fat from pasture- and concentrate-fed cattle were oleic (C18:1), palmitic (C16:0) and stearic (C18:0), which acounted for 71 and 77% of the total fatty acids, respectively.

The percentages of myristic (C14:0), myristoleic (C14:1), palmitic (C16:0), palmitoleic (C16:1) and oleic (C18:1) acids were higher ($P < 0.01$) in the intramuscular fat of concentrate finished cattle than pasture-fed animals. Pasture-fed cattle had higher ($P < 0.01$) concentrations of stearic (C18:0), linoleic (C18:2) linolenic (C18:3), arachidonic (C20:4), eicosapentaenoic (C20:5, EPA), and docosapentaenoic (C22:5, DPA) acids than concentrate-fed cattle. Dietary treatment did not alter ($P > 0.05$) the concentration of docosahexaenoic acid (C22:6, DHA). Similarly, others (Brown, Melto, Riemann, & Backus, 1979; Melton, Black, Davies, & Backus, 1982) have shown greater concentrations of stearic, linolenic and arachidonic acids in pasture-fed vs. concentrate-fed animals.

Intramuscular fat from pasture-fed cattle had greater ($P < 0.05$) concentrations of total CLA and CLA isomer *cis*-9, *trans*-11 than concentrate-fed (5.3 vs. 2.5 and 4.1 vs. 2.3 mg CLA/g lipid, respectively). Previous research has shown that including pasture in the diet of dairy and beef cattle increased CLA concentration in milk and beef intramuscular fat, respectively (French, Stanton et al., 2000; Lawless et al., 1998; Yang, Lanari et al., 2002). French, Stanton et al. (2000) reported 10.8 and 3.7 mg total CLA/g lipid in longissimus muscle for grass-fed and concentrate supplemented grass-fed beef, respectively. Shantha, Moody, and Tabeidi (1997) reported 7.7 and 5.2 mg total CLA/g lipid in semimembranosus muscle for grass-fed and corn supplemented grass-fed beef, respectively. Rule, Broughton, Shellito, and Maiorano (2002) reported 4.1 and 2.6 mg CLAc9t11/g lipid in longissimus muscle for pasture-fed cows and feedlot steers, respectively.

Pasture-fed beef contained a similar ($P > 0.05$) proportion of saturated fatty acids (SFA), a lower ($P < 0.05$) concentration of monounsaturated fatty acids (MUFA) and a higher ($P < 0.01$) percentage of polyunsaturated fatty acids (PUFA) than concentrate-fed cattle. Current recommendations are that the PUFA:SFA (P:S) ratio should be around 0.45 (Department of Health, 1994). The P:S ratios in this study were lower than the recommended ratio, being 0.20 for pasture-fed and 0.13 for concentrate-fed cattle. Duckett,

Table 4
Intramuscular fatty acid composition (lsmean ± SE) from pasture-fed ($n = 10$), and concentrate-fed ($n = 20$) cattle

Fatty acid,%	Pasture ($n = 10$)	Concentrate ($n = 20$)
Total lipid	1.68a ± 0.245	3.18b ± 0.173
14:0, *myristic*	1.64a ± 0.104	2.17b ± 0.073
14:1, *myristoleic*	0.23a ± 0.025	0.41b ± 0.017
16:0, *palmitic*	21.61a ± 0.530	24.26b ± 0.375
16:1, *palmitoleic*	2.50a ± 0.140	3.38b ± 0.099
18:0, *stearic*	17.74a ± 0.507	15.77b ± 0.358
18:1, *n-9 oleic*	31.54a ± 0.771	37.28b ± 0.545
18:2, *n-6 linoleic*	3.29c ± 0.217	2.84d ± 0.154
18:3, *n-3 linolenic*	1.34a ± 0.055	0.35b ± 0.039
CLA[a] *c9t11*	0.41a ± 0.023	0.23b ± 0.016
Total CLA[b]	0.53a ± 0.031	0.25b ± 0.022
20:4, *n-6 arachidonic*	1.28a ± 0.097	0.95b ± 0.069
20:5, *n-3 EPA*[a]	0.69a ± 0.053	0.30b ± 0.037
22:5, *n-3 DPA*[a]	1.04a ± 0.070	0.56b ± 0.047
22:6, *n-3 DHA*[a]	0.09 ± 0.016	0.09 ± 0.012
Unidentified	16.49a ± 0.603	11.41b ± 0.426
SFA[a]	49.08 ± 0.723	47.62 ± 0.511
MUFA[a]	40.96a ± 0.796	46.36b ± 0.563
PUFA[a]	9.96a ± 0.607	6.02b ± 0.429
PUFA:SFA	0.20a ± 0.013	0.13b ± 0.009
n-6:n-3 ratio	1.44a ± 0.109	3.00b ± 0.077

Means within the same column with different letters (a,b) differ $P < 0.01$. Means within the same column with different letters (c,d) differ $P < 0.10$.

[a] CLA: conjugated linoleic acid, EPA: eicosapentaenoic acid, DPA: docosapentaenoic acid, DHA: docosahexaenoic acid, SFA: saturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids.

[b] Total CLA includes: c9t11, t10c12, t9t11, and other isomers that were unable to be identified specifically.

Wagner, Yates, Dolezal, and May (1993) also reported a higher P:S ratio (0.26) for muscle from grass-finished steers than for that from concentrate-finished animals (0.07). Similar P:S ratios to concentrate-fed cattle from this study have been reported for typical retail beef in the UK (0.11, Enser, Hallet, Hewett, Fursey, & Wood, 1996) and fish-meal-supplemented Charolais steers (0.11–0.13, Mandell, Gullett, Buchanan-Smith, & Campbell, 1997).

Intramuscular fat from pasture-fed cattle had a more favorable n-6:n-3 fatty acids ratio than concentrate-fed animals (1.4 vs. 3.0, respectively). An increase in the consumption of n-3 fatty acids is recommended (Department of Health, 1994) to overcome the imbalance in the ratio of n-6:n-3 PUFA in the current diets (10:1) compared with primitive man (1:1, Eaton, Eaton, Konner, & Shostak, 1996). Enser, Hallett, Hewett, Fursey, Wood, and Harrington (1998) and Mitchell et al. (1991) reported that adipose tissues from pasture-based diets had higher concentrations of n-3 PUFA in body tissues, while concentrate-based diets had higher concentrations of n-6 PUFA. These differences are a consequence of the fatty acid composition of the diet, α-linolenic acid (C18:3, the n-3 series precursor) being the major fatty acid in grass lipids, and linoleic acid (C18:2, the n-6 series precursor) being a major component in grains (Marmer, Maxwell, & Williams, 1984). Previous research similarly found a lower n-6:n-3 PUFA ratio in pasture-fed cattle than in concentrate-fed cattle. Rule et al. (2002) reported n-6:n-3 ratios of 1.95 and 6.38 for pasture-fed cows and feedlot steers, respectively; while French, Stanton et al. (2000) reported ratios of 2.33 and 4.15 for grass-fed and concentrate-fed steers.

4. Conclusions

Pasture-fed carcasses from Uruguayan cattle showed darker longissimus color and yellower fat at grading than concentrate-fed. Although pasture-fed carcasses were lighter and leaner than concentrate-fed, there were no differences in initial tenderness between the groups. Moreover, pasture-fed beef showed a greater potential for postmortem tenderization through aging, becoming more tender than concentrate-fed beef after 7 days of storage. Supplementation of α-tocopherol to cattle finished on concentrate with 1000 I.U. animal^{-1} day^{-1} for 100 days was sufficient to achieve similar muscle α-tocopherol content to pasture-fed cattle, at levels beyond the proposed critical concentrations for improving shelf life. Vitamin E supplementation of concentrate-fed steers increased lipid stability of ground beef and steaks, but was unable to improve color stability. Vitamin C addition to ground beef increased color stability without altering lipid oxidation. Finishing cattle on pasture enhanced the unsaturated fatty acid profile of intramuscular fat in beef including conjugated linoleic acid and omega-3 fatty acids. Results from this study suggest that the negative image of beef attributed to its highly saturated nature may be overcome by enhancing the fatty acid profile of intramuscular fat in beef through pasture feeding from a human health perspective.

Acknowledgements

This research was funded by the Uruguayan National Institute of Agricultural Research (INIA), Inter-American Development Bank (IDB) and the Uruguayan Ministry of Livestock, Agriculture and Fishery (MGPA). We wish to thank the Uruguayan Hereford Breeders Association, the Uruguayan Association of Natural Intensive Beef Producers (AUPCIN), the Uruguayan Technological Laboratory (LATU), Roche Ltd., and Dr. R. Radi and Dr. H. Botti for their support and cooperation in this project.

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