

Lipid stability and meat colour of beef from pasture- and grain-fed cattle with or without vitamin E supplement

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Abstract

Meat from pasture-fed cattle can have high contents of α -tocopherol and other anti-oxidants originating from naturally occurring compounds present in grasses. However, meat from pasture-fed cattle may have an increased demand for endogenous anti-oxidants because of its high content of polyunsaturated fatty acids, which in turn, may affect its colour and lipid stability. In the work described, we evaluated the effects of pasture-feeding alone and with vitamin E supplementation and compared the findings with those obtained for grain-fed cattle (predominantly sorghum) with and without supplementation. Within each nutritional background, vitamin E supplementation did not alter meat colour or colour stability of fresh or 47-day aged muscle during 7-day aerobic storage. However, both control and supplemented grain-fed product had better meat colour (more redness) compared with meat from grass-fed cattle. These differences in redness between pasture- and grain-fed fresh beef were not apparent after ageing. The treatments did not affect the lipid stability of fresh meat during aerobic storage; however, supplementation reduced ($P < 0.01$) lipid oxidation in grain-fed aged beef compared with pasture-fed aged beef, despite both having similar α -tocopherol contents. Pasture-fed beef had more linolenic acid, less linoleic acid and, overall, was more polyunsaturated than grain-fed beef ($P < 0.05$). In summary, vitamin E supplementation of pasture-fed cattle did not alter muscle tocopherol contents but pasture-fed beef (both control and supplemented) was more susceptible to lipid oxidation following ageing than vitamin E supplemented grain-fed beef. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Meat colour; Lipid oxidation; Vitamin E supplementation; Pasture- and grain-fed beef; Sorghum

1. Introduction

The effects of high concentrations of α -tocopherol in muscles of grain-fed cattle on their colour and lipid stabilities have been clearly demonstrated (Arnold, Arp, Scheller, Williams, & Schaefer, 1993; Arnold, Scheller, Arp, Williams, Buege, & Schaefer, 1992; Fautsman, Cassens, Schaefer, Buege, Williams, & Scheller, 1989). Cattle grazed on pasture can also achieve high concentrations of α -tocopherol in their tissues (Daly, Young, Graafhuis, & Moorhead, 1999) but its effect on lipid and pigment stabilities has been less well researched. In an associated study (Yang, Brewster, Lanari, & Tume, 2002) we observed that non-supplemented pasture-fed cattle had muscle concentrations of 4–6 μg α -tocopherol/g muscle. Supplementation with 2500 IU vitamin E/head/day for 132 days did not result in additional

increments in any of the three muscles investigated. Further, the α -tocopherol concentrations achieved on pasture were similar to those measured in muscles from grain-fed cattle supplemented with 2500 IU vitamin E/head/day.

In this study we investigate whether high muscle α -tocopherol concentrations alone result in the improved lipid stability as observed by others (Arnold et al., 1992; Arnold, Arp et al., 1993), or if there is an interaction with the content of unsaturated fatty acids. Studies have shown that pasture feeding can lead to increased concentrations of polyunsaturated fatty acids in muscles (Larick & Turner, 1989; Melton, Black, Davis, & Backus, 1982) compared with beef from grain-fed cattle. Meats containing greater contents of the highly unsaturated lipids are likely to be more prone to lipid oxidation than those more saturated and therefore may have an increased requirement for anti-oxidants. In addition, there may be differences in contents of other anti-oxidants (β -carotene) or pro-oxidants (low molecular weight iron) that affect these meat quality attributes.

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Thus, we proposed that there might be differences in meat colour and in lipid stabilities between muscles having similar concentrations of α -tocopherol but originating from differing nutritional backgrounds.

2. Materials and methods

2.1. Animals and diets

Details of animals, diets, carcass weights and fat measurements were presented in full previously (Yang et al., 2002). Briefly, thirty-two Hereford cross steers (mean 294 ± 9.5 kg live wt.) were divided into four equal-sized groups and assigned to one of the four treatments for 132 days prior to slaughter. The treatments were pasture-fed supplemented with 0 or 2500 IU *dl*- α -tocopheryl acetate/head/day (vitamin E, Roche Products Pty Ltd, Goodna, Queensland, Australia), or grain-fed on a sorghum-based feedlot ration supplemented with 0 or 2500 IU/head/day vitamin E. Intakes of α -tocopherol acetate were estimated to be 2200, 4700, 300 and 2800 IU/head/day for pasture-fed control and supplemented and for grain-fed control and supplemented cattle respectively (Yang et al., 2002).

As both pasture- and grain-feeding was for the same duration (132 days) there were large differences in growth rates of the groups. Vitamin E supplementation did not influence the average weight of the pasture-fed cattle, the mean carcass weights were 184.6 ± 1.6 kg for the non-supplemented and 185.0 ± 4.0 kg for the supplemented group. In the case of the grain fed steers, the average carcass weight of the control group was 14 kg higher than the supplemented animals (279.2 ± 9.8 kg versus 265.3 ± 4.6 kg).

2.2. Sample collections

The muscles *m. longissimus dorsi* (LD), *m. semimembranosus* (SM) and *m. gluteus medius* (GM), selected because of their known differences in colour stabilities (Renner, 1984) were removed from each carcass 20 h post-mortem. This is referred to as day 1. Each muscle was cut into sections, used immediately or vacuum-packaged and stored at 0°C for 47 days until required for analysis. In addition, small samples (25 g) of muscles were taken and stored frozen at -20°C for later analyses. Subcutaneous fat was removed at the same time from above the LD muscle and was also stored frozen at -20°C .

2.3. Meat colour measurement and chemical analysis

At each storage time (1 or 47 days), three cores from each muscle (10 mm thick and 35 mm in diameter) were

cut, wrapped in oxygen permeable film and kept in the dark at 4°C for 7 days. Meat colour (CIE $L^*a^*b^*$) was measured daily using a Minolta CR200 Chroma Meter (Minolta Co., Ltd, Osaka, Japan). Reflectance measurements were collected from a 0° -viewing angle with Commission Internationale de l'Eclairage (CIE) illuminant C lighting conditions. Each data point is the mean of three replications.

The lipid stability of muscles was investigated in the same meat samples under display for meat colour. Lipid oxidation was determined by measuring 2-thiobarbituric acid reactive substances (TBARS) using a modified method of Witte, Krause, and Bailey (1970) at the beginning and the end of display (days 1 and 7) and was expressed as nmol malondialdehyde produced per kg muscle.

Total lipids were extracted from fresh and aged muscles (Folch-Pi, Lees, and Sloane-Stanley, 1957) at days 1 and 7. The phospholipid fraction of the lipid extract was separated with a Sep-Pak[®] silica cartridge (Waters Corporation, Milford, MA) using a modified method of Larick, Turner, Koch, and Crouse (1989) in conjunction with that of Juaneda and Rocquelin (1985). Fatty acids in both lipid fractions were methylated with 1 ml 5% sulphuric acid in methanol overnight at 60°C and the methyl esters were extracted with petroleum ether. Fatty acid methyl esters were separated by gas chromatography (Shimadzu GC17, Kyoto, Japan, with AOC17 auto-injector) using a $50 \text{ m} \times 0.25 \text{ mm}$ glass capillary column (CP-Sil-88, ChromPak, Middleburg, The Netherlands) with nitrogen as carrier gas. The initial temperature was set at 150°C , incrementing at $5^\circ\text{C}/\text{min}$ to 235°C and held at that temperature for 8 min. Fatty acids were identified by comparison of retention times with standards (Alltech, Sydney, Australia).

2.4. Statistical analysis

Meat redness, as denoted by the a^* value, was subjected to the Mixed Procedure of SAS (SAS, 1998) as a split plot design with repeated measures. Feed type (pasture or grain), vitamin E dose and their interactions, were considered as the main plot while muscle type and its interactions with the factors previously named were analysed as subplot variables. The effect of storage time and its interactions was analysed as a sub-subplot variable. As carcass weight and fat thickness can affect meat colour by altering the carcass-chilling rate (Mallikarjunan & Mittal, 1994), these parameters were included as covariates in the analysis in order to determine the extent of their significance. Data from all other measurements were subjected to analysis of variance, using the Mixed Procedure (SAS, 1998), testing for differences resulting from dietary treatment.

3. Results and discussion

3.1. α -Tocopherol concentrations in muscle

Table 1 presents the α -tocopherol concentrations in fresh (Yang et al., 2002) and 47 days aged GM, LD and SM. In accordance with previous publications (Liu et al., 1996), ageing did not change the α -tocopherol content of the muscles.

3.2. Meat colour

The colour stabilities of the fresh and aged muscles are presented in Fig. 1. Supplementation of pasture-fed cattle with vitamin E had no effect ($P > 0.20$) on meat redness (a^* value) of fresh or 47-day aged meat when measured over a 7-day period of aerobic storage. Clearly, in this study, pasture feeding provided adequate α -tocopherol to saturate the muscles with or without supplement (Table 1), and therefore redness and colour stabilities were not affected.

In contrast with previous publications (Arnold, Scheller, Arp, Williams, & Schaefer, 1993; Faustman et al., 1989; Lynch, Kerry, Buckley, Faustman, & Morrissey, 1999), supra-nutritional supplementation of grain-fed cattle with vitamin E did not affect meat redness or stability, compared with that from non-supplemented cattle, when viewed over a 7-day period of aerobic storage. This behaviour could be partly attributed to the relatively high levels of α -tocopherol (1.8–2.4 $\mu\text{g/g}$) present at the start of the experiment, and to the protective action of other anti-oxidants in muscles from non-supplemented grain-fed animals. Eikelenboom, Hoving-Bolink, Houben, and Klont (2000) suggested that α -tocopherol concentrations between 2.1 and 4.4 $\mu\text{g/g}$ in unsupplemented muscle may have reduced the response of the LD muscle to the vitamin E treatment. Hill and Williams (1993) reported little or no benefit from vitamin E supplementation on the colour stability of fresh beef from cattle fed with good quality pasture immediately before grain feeding. The depletion of α -tocopherol in muscle is slow (Arnold, Arp et al., 1993) so when cattle have access to good quality grass prior to

grain feeding, as was the case in the current study, the meat from non-supplemented cattle will have a high content of α -tocopherol and other antioxidants (e.g. polyphenols) from pasture (Aerts, Barry, & McNabb, 1999). The cattle used in the current study were fed with red sorghum while the animals used in previous publications (Arnold et al., 1993; Faustman et al., 1989; Liu et al., 1996; Lynch et al., 1999) were fed with corn. Although both corn and sorghum are rich in polyphenols such as pro-anthocyanidins and phytic acid with a strong anti-oxidant activity, Jood, Kapoor, and Singh (1995) reported anti-oxidant concentrations in sorghum 30% higher than in corn. The presence of high concentrations of anti-oxidants from the grass and from the sorghum in the muscle may have reduced the potential differences in colour stability between non-supplemented and supplemented grain-fed beef as a result of vitamin E supplementation.

Faustman, Chan, Schaefer, and Havens (1998) reported that the ability of vitamin E to suppress low pO_2 -induced metmyoglobin formation was diminished in day 2 versus day 10 post-mortem beef. In the current study, the fresh meat was stored for 2 days post-mortem while most of the previous works (Arnold et al., 1992; Arnold, Arp et al., 1993; Arnold, Scheller et al., 1993; Faustman et al., 1989; Liu et al., 1996) were done in meat stored for at least 14 days post-mortem. Therefore, the differences in post-mortem time could have affected the efficacy of dietary vitamin E on improving colour stability.

The results from Liu, Scheller, Arp, Schaefer, and Frigg (1996) suggested that, for muscle with α -tocopherol contents between 1.4 and 4.5 $\mu\text{g/g}$, significant differences in discolouration rate were not apparent for at least 9 days of aerobic storage for colour-stable muscles such as LD. However, for less colour-stable muscles like SM and GM, differences in discolouration were obvious in shorter periods. In our study, the samples were viewed for 7 days, which may not have been long enough to show the benefits of the high α -tocopherol content in the meat from supplemented cattle on meat colour stability.

a^* Values were lower ($P < 0.02$) in meat from fresh pasture-fed than from grain-fed beef with or without

Table 1
Mean concentrations (with pooled S.E.) of α -tocopherol in fresh (day 0) and aged (day 47) muscles ($\mu\text{g/g}$ tissue) from pasture- and grain-fed cattle with or without vitamin E supplement ($n = 8$)

Muscle	Pasture				Grain				Pooled S.E.
	Control		Supplemented		Control		Supplemented		
	Day 0	Day 47	Day 0	Day 47	Day 0	Day 47	Day 0	Day 47	
LD	4.5a	4.8a	4.6a	4.6a	1.8b	1.7b	4.3a	4.9a	0.231
SM	4.4a	4.0a	4.3a	4.0a	2.0b	2.0b	5.3a	5.6a	0.231
GM	5.8a	4.9a	6.1a	5.3a	2.4b	2.3b	6.0a	6.7a	0.231

Means within the same row with different letters are statistically different ($P < 0.05$).

supplementation. Renerre and Bonhomme (1991) reported that an increase in the chilling rate significantly reduced the a^* values; Mallikarjunan and Mittal (1994) showed that carcass weight and subcutaneous fat thickness might significantly alter the chilling rate and meat colour. As the carcasses from pasture-fed cattle were significantly lighter than those from the grain-fed animals, the differences in colour and colour stability could be also due to variations in the chilling rate across treatments. Analysis of covariance indicated that the differences in weight between pasture and grain-fed carcasses had a significant effect ($P < 0.05$) on a^* values of the LD and SM but not in the GM. Although fat depth was 14 mm less in carcasses from pasture- than in grain-fed cattle (Yang et al., 2002), this factor did not affect ($P > 0.30$) a^* values. In our study, the dark appearance of pasture-fed LD and SM compared with the grain-fed muscles was caused by the combined effect of pasture feeding ($P < 0.01$) and rapid chilling rates ($P < 0.05$). However, when both factors were statistically compared, the influence of the nutritional background on colour was stronger. If pasture- and grain-fed cattle are slaughtered at the same age, then usually pasture-fed carcasses will be the lightest weight. Therefore, rates of

chilling carcasses from pasture-fed cattle should be slowed in order to avoid or reduce meat darkening.

Vestergaard, Oksbjerg, and Henckel (2000) showed that pasture feeding produced muscles with a higher proportion of oxidative fibres and a darker colour when compared to muscles from grain-fed cattle. The authors concluded that difference in feeding level and physical activity between pasture- and grain-fed cattle can change the metabolic characteristics and the colour stability of the muscles. Although the relationship between production system, muscle metabolic type and colour stability was not analysed in the current study, changes in muscle metabolism could also be a contributing factor to the darker appearance of pasture-fed beef.

The between-muscle differences in fresh meat colour were highly significant ($P < 0.003$) and the mean a^* values for grain-fed beef over time were 19.0 for GM, 20.9 for SM and 21.8 for LD. These results indicated that the relative colour stabilities of the three muscles were LD > SM > GM, in agreement with previous publications (O'Keefe & Hood, 1982; Renerre, 1984). In contrast, the colour stabilities of the three muscles from fresh pasture-fed beef were similar ($P > 0.28$) with a^* values being 18.2, 18.1 and 18.4 for GM, LD and SM, respectively. Within each muscle type, colour stability of aged meat from pasture- and grain-fed beef was similar ($P > 0.33$) and, as in the case with fresh meat, vitamin E supplementation did not improve colour stability ($P > 0.25$).

3.3. Lipid stability (TBARS) of muscles

Lipid oxidation in all fresh muscles, as indicated by TBARS, was not affected by the dietary treatments (Fig. 2). Ageing under vacuum for 47 days did not influence the TBARS values at day 1 of aerobic storage. The values increased dramatically ($P < 0.01$) however, during the following 7 days storage for all the treatments except for the supplemented grain-fed group in which there was only a slight but not significant increase. This was true for each muscle type investigated. Thus, although pasture and supplemented grain-fed groups had similar amounts of α -tocopherol in their muscles, in both fresh and aged (Table 1), the meat from the supplemented grain-fed group had higher lipid stability after storage than that from pasture-fed animals. The results for grain-fed beef were in agreement with previous publications which showed that supplementing grain-fed cattle with 500–3600 IU/head/day of vitamin E markedly inhibited lipid oxidation in beef during retail display or frozen and vacuum-packaged storage (Arnold et al., 1992; Arnold, Arp et al., 1993; Arnold, Scheller et al., 1993; Faustman et al., 1989; Houben, van Dijk, Eikelenboom, & Hoving-Blink, 2000; Lynch et al., 1999; Mitsumoto, Cassens, Schaefer, Arnold, & Scheller, 1991; Sherbeck, Wulf, Morgan, Tatum, Smith, & Williams, 1995).

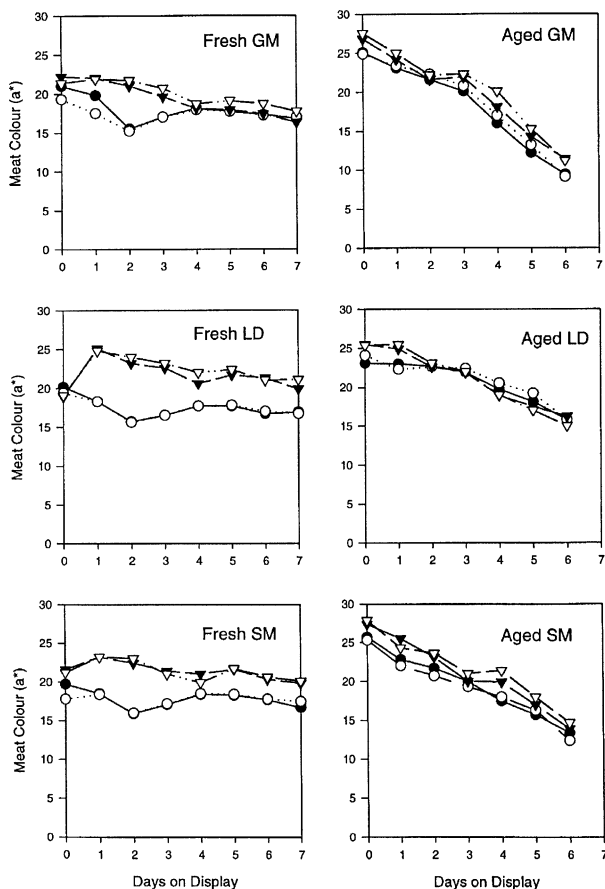


Fig. 1. Meat colour (a^*) of fresh or aged LD, SM and GM from pasture (P)- and grain (G)-fed cattle with or without vitamin E supplement during retail display ($n = 8$), (● P0, ○ P2500, ▼ G0, ▽ G2500).

The effect of muscle type on the lipid stability of aged beef was significant. A comparison of the TBARS values after 7 days display showed that the lipid stability of GM was much lower ($P < 0.0001$) than that of LD or SM for the control beef. No significant difference in lipid stability was detected between the LD and SM. This result is interesting because the GM had the highest mean content of α -tocopherol compared with LD and SM (Table 1). Lynch et al. (1999) also reported that grain-fed LD, either fresh supplemented or fresh and vacuum-packaged, non-supplemented, was more resistant to lipid oxidation than GM.

3.4. Fatty acid composition of total lipid and phospholipid in muscles

The mean fat contents (g lipid/100 g muscle, wet wt., $n = 8$) of the muscles investigated from pasture- and

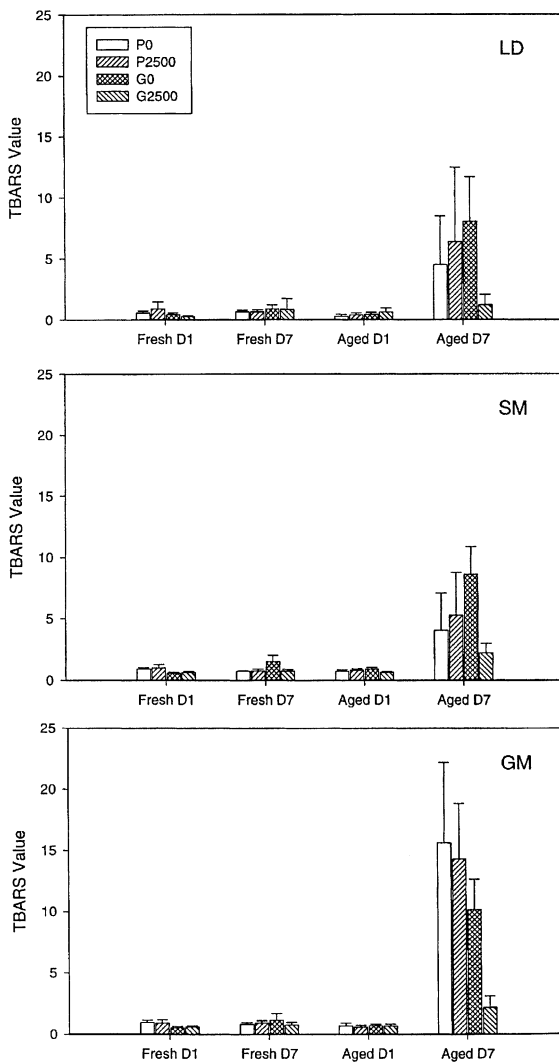


Fig. 2. Lipid stability of muscles (TBARS Value, nmol malonaldehyde produced/kg muscle) from pasture- and grain-fed cattle with or without vitamin E supplement ($n = 8$).

grain-fed groups were as follows: LD 1.71 and 3.63 ($P < 0.05$); SM 1.92 and 1.52 ($P > 0.1$); and GM 1.17 and 2.60 ($P < 0.05$), respectively. As a result of these differences in fat contents, interpretation of fatty acid analyses on total lipid fractions of meat should be treated cautiously because of the varying proportions of phospholipids and triacylglycerols. Triacylglycerols tend to be more saturated and much less polyunsaturated than phospholipids. Although the highly unsaturated phospholipid-fatty acids are most likely to impact on lipid stability, fatty acid analyses on total lipid extracts should be considered to give an overall assessment of the oxidative stability of a particular muscle. The fatty acid profiles of both the total lipids and of the phospholipids are presented in Tables 2–4 for LD, SM and GM, respectively.

There were significant differences in the percentages of many of the fatty acids in both the total lipid and the phospholipid fractions of muscles from the pasture- and grain-feeding systems (Tables 2–4). Differences in fatty acid percentages resulting from muscle type, vitamin E supplementation, 47-day ageing or 7-day aerobic storage were not significant, therefore, only the results for total lipids and phospholipids of freshly isolated muscles from each muscle are presented.

For total lipids of LD and GM, grain-fed beef contained the highest percentage of saturated and mono-unsaturated fatty acids while pasture-fed beef had the highest percentage of polyunsaturated fatty acids for all muscles. With beef from pasture-fed cattle, the percentage of polyunsaturation ranged from 12.5–17.9% but was only 5.6 to 12.5% for grain-fed beef ($P < 0.05$). There was also a trend for differences in polyunsaturation with LD < SM < GM. However, for grain-fed cattle, there were marked differences in percentage polyunsaturation with LD being only half that of GM muscle ($P < 0.05$).

Major changes in individual fatty acids were found for palmitic (16:0), oleic [18:1c(9)] and linolenic (18:3) acid (Tables 2–4). For LD and GM muscles, the percentage of palmitic acid was significantly ($P < 0.05$) higher in grain-fed cattle than pasture-fed and there was a similar trend for SM ($P > 0.05$). The percentage of oleic acid was also higher in the muscles from grain-fed cattle than in muscles from pasture-fed, but linolenic was highest in the pasture group.

All of the highly unsaturated fatty acids, 18:3, arachidonic (20:4), icosapentaenoic (20:5) and docosapentaenoic (22:5) were significantly more prevalent in each of the muscles from pasture-fed cattle (Tables 2–4). Differences in the contents of the n -3 fatty acids between feeding systems were particularly large. Although these highly unsaturated fatty acids represent only a small percentage of the total lipid, small differences in their contents can account for quite large effects in terms of oxidation (Shahidi, 1992). Thus, the unsaturation ratio

is not necessarily a good indicator of relative oxidative stability.

Several reports (Brown, Melton, Riemann, & Backus, 1979; Melton et al., 1982; Miller, Masor, & Riley, 1981; Westerling & Hedrick, 1979) showed that beef from steers grazed on pasture have more 18:0, 18:3, 20:3, 20:4 and 22:5 and less 16:0 and 17:0 than beef produced by steers fed grain. Garcia, Pensel, Margaria, and Olga Rosso (1999) also found that the percentage of 18:3 increased and the ratio of 18:2 and 18:3 decreased as the amount of corn grain diminished in the diet of pasture-fed beef. It has been estimated that 18:3 is twice as prone to lipid oxidation as 18:2 (Shahidi, 1992) and this may partly explain why the vitamin E supplemented grain-fed beef had better lipid stability after ageing than pasture-fed beef despite their similar muscle α -tocopherol contents. These findings were in agreement with the results of Wichtel, Freeman, Craigie, Varela-Alvarez, and Williamson (1996) who reported that serum from dairy heifers grazed on pasture had

increased peroxidisable polyunsaturated fatty acid concentrations but also tended to have increased protective α -tocopherol concentrations.

Whereas variations in the overall fat content of the individual muscles affected the fatty acid composition of the total lipids, it has negligible effect on the isolated phospholipids. Therefore, comparisons between different muscle types and feeding backgrounds can be considered directly. Linolenic acid (18:3) has been shown to be a major constituent of the total lipid content of forages (Harfoot, 1981) while the lipid component of sorghum is high in 18:1 (34%) and 18:2 (50%) and low in 18:3 (3%) (Becker, 1992). In our study, compared with beef from pasture-fed cattle, the grain-fed beef had a significantly increased mean percentage of 18:2 in the muscle phospholipid fraction, accounting for nearly all the difference in the total polyunsaturated fatty acids between the two feeding systems, and a significantly decreased 18:3 content. As found for total lipids, the *n*-3 fatty acids were significantly higher in the phospholipids

Table 2

Fatty acid profile (means of percent of distributions with pooled S.E.) of total lipids and phospholipids of fresh LD muscles from pasture- and grain-fed cattle with or without vitamin E supplement

Fatty acid	Total lipids				Pooled S.E.	Phospholipids				Pooled S.E.
	Pasture		Grain			Pasture		Grain		
	Control <i>n</i> = 8	Supplemented <i>n</i> = 8	Control <i>n</i> = 8	Supplemented <i>n</i> = 8		Control <i>n</i> = 8	Supplemented <i>n</i> = 8	Control <i>n</i> = 4	Supplemented <i>n</i> = 4	
14:0	1.74 ^{ca}	1.99 ^{bc}	2.62 ^{ab}	2.99 ^a	0.216	0.90	0.93	0.78	0.81	0.085
14:1	0.26	0.24	0.50	0.59	0.175					
15:0	0.41 ^a	0.41 ^a	0.21 ^b	0.21 ^b	0.047					
16:0	22.30 ^b	23.80 ^b	27.80 ^a	29.00 ^a	0.730	19.70	20.66	19.93	19.08	0.873
16 DMA ^b	3.74 ^a	3.06 ^a	1.41 ^b	1.52 ^b	0.288	4.09	4.00	3.73	4.87	0.539
16:1, <i>n</i> -7	2.39 ^b	2.70 ^{ab}	3.56 ^a	3.51 ^a	0.216	1.73	1.61	1.55	1.46	0.115
17:0	0.83 ^{ab}	0.87 ^a	0.55 ^{bc}	0.51 ^c	0.075					
17:1	0.69	0.67	0.46	0.40	0.119	0.87 ^a	0.84 ^a	0.54 ^b	0.51 ^b	0.062
18:0	16.30	16.20	15.00	15.20	0.619	16.39	17.00	16.95	16.88	0.717
18 DMA	2.03 ^a	1.58 ^a	0.82 ^b	0.84 ^b	0.171	2.21	2.05	2.27	3.16	0.316
18:1, <i>n</i> -7, <i>t</i>	2.01	2.06	1.15	1.22	0.370	1.70	2.10	1.73	1.34	0.420
18:1, <i>n</i> -9	29.00 ^b	30.40 ^b	37.60 ^a	35.10 ^a	1.194	28.08	27.02	26.02	26.14	1.293
18:1, <i>n</i> -7	1.46	1.46	1.42	1.31	0.097	1.68	1.78	1.59	1.63	0.136
18:2, <i>n</i> -6	6.48 ^a	5.52 ^{ab}	3.59 ^b	3.67 ^b	0.643	8.68 ^b	8.39 ^b	12.65 ^a	12.24 ^a	0.809
18:3, <i>n</i> -3	1.80 ^a	1.55 ^a	0.38 ^b	0.52 ^b	0.110	2.19 ^a	1.98 ^a	0.76 ^b	0.81 ^b	0.209
CLA ^c	0.22	0.21	0.06	0.12	0.043					
22:0	0.44 ^a	0.40 ^a	0.08 ^b	0.11 ^b	0.049	0.63	0.60	0.48	0.47	0.081
22:1	0.80	0.69	0.45	0.44	0.143	1.63	1.41	1.56	1.46	0.243
20:4, <i>n</i> -6	2.79	2.46	1.22	1.31	0.526	3.75	3.63	4.89	4.61	0.411
20:5, <i>n</i> -3	1.27 ^a	1.13 ^a	0.33 ^b	0.23 ^b	0.155	1.62 ^a	1.53 ^a	0.87 ^b	0.76 ^b	0.208
22:5, <i>n</i> -3	1.84 ^a	1.61 ^a	0.00 ^b	0.00 ^b	0.153	2.28	2.19	1.83	1.89	0.264
Saturated (S)	42.60 ^b	44.10 ^{ab}	46.60 ^{ab}	48.40 ^a	1.210	38.62	40.36	38.96	38.33	1.666
Monounsaturated (M)	36.60 ^c	38.20 ^{bc}	45.10 ^a	42.50 ^{ab}	1.283	35.68	34.77	32.99	32.54	1.325
Polyunsaturated (P)	14.40 ^a	12.50 ^a	5.60 ^b	5.80 ^b	1.292	18.52	17.72	21.00	20.32	1.556
(M+P)/S	1.21	1.16	1.09	1.02	0.051	1.40	1.31	1.39	1.38	0.081
Total peroxidisable ^d	7.71 ^a	6.75 ^a	1.93 ^b	2.05 ^b	0.767	9.94	9.33	8.35	8.07	0.938

^a Of the same lipid fraction, means within the same row with a different letter are statistically different ($P < 0.05$).

^b DMA dimethyl acetals formed from fatty aldehydes during methylation.

^c CLA conjugated linoleic acid.

^d Fatty acids with three or more unsaturated bonds.

of meat from pasture-fed cattle than in the meat of grain-fed cattle. Larick and Turner (1990) also reported an increase in the concentrations of 18:2 and total polyunsaturated fatty acids and a decrease in the concentration of 18:3 in the phospholipid fraction of LD after 54 days of grain feeding compared with forage feeding. These results agreed with several researchers who have previously demonstrated that the polar lipid fraction of minced beef prepared from cattle fed high-forage diets has an increased percentage of 18:3 (Brown et al., 1979; Larick & Turner, 1989; Melton et al., 1982).

3.5. Interaction between feeding systems and colour and lipid stabilities

The dietary treatments (pasture versus grain) significantly affected the total fat content, the proportion of total PUFA in the lipids, the content of *n*-3 fatty acids and the α -tocopherol and β -carotene content of fresh and aged beef meat (Tables 1–4). Although the ratios of fatty acid unsaturation to saturation were

similar, there were significant differences in the concentration of highly unsaturated and *n*-3 fatty acids in each muscle. As lipid oxidation increases with the degree of unsaturation and the absolute concentration of peroxidisable lipids (fatty acids with three or more unsaturated bonds), we defined the Peroxidation Capacity (PC) of the meat as:

$$\text{PC} = (\text{g peroxidisable lipids}/100 \text{ g muscle}) \\ \times \text{degree of unsaturation}$$

Pasture and grain-fed meat had a PC of 42 and 28, respectively, indicating that pasture-fed meat is more susceptible towards lipid oxidation. This reduction in oxidative stability will exhaust the antioxidant capacity of the α -tocopherol and other antioxidants present in the tissue. Meat from pasture-fed cattle had a high content of α -tocopherol, similar to that from supplemented grain-fed steers. However, following vacuum-pack storage (47 days), it seems that the high α -tocopherol (and other anti-oxidants) present were not sufficient to

Table 3

Fatty acid profile (means of percent of distributions) of total lipids and phospholipids of fresh SM muscles from pasture- and grain-fed cattle with or without vitamin E supplement. Pooled S.E. are as presented in Table 2

Fatty acid	Total lipids				Phospholipids			
	Pasture		Grain		Pasture		Grain	
	Control <i>n</i> =8	Supplemented <i>n</i> =8	Control <i>n</i> =8	Supplemented <i>n</i> =8	Control <i>n</i> =8	Supplemented <i>n</i> =8	Control <i>n</i> =4	Supplemented <i>n</i> =4
14:0	1.46c ^a	1.94bc	2.53ab	3.13a	0.90	0.78	0.70	0.87
14:1	0.31	0.31	0.63	0.72				
15:0	0.30ab	0.42a	0.21b	0.25ab				
16:0	22.30b	24.00b	26.30ab	28.20a	23.07	21.24	19.42	19.70
16 DMA ^b	3.26a	2.53ab	1.79bc	1.01c	2.74	3.40	3.99	3.88
16:1, <i>n</i> -7	2.78b	2.96b	4.04a	3.94a	1.21	1.47	1.43	1.53
17:0	0.85b	1.46a	0.52c	0.55bc				
17:1	2.47a	2.48a	0.51b	0.45b	0.77a	0.76a	0.52b	0.51b
18:0	12.30	14.60	12.80	14.20	19.34	18.67	16.38	17.23
18 DMA	1.95a	1.54ab	1.20bc	0.67c	1.69	2.02	2.54	2.68
18:1, <i>n</i> -7, t	1.73	2.24	0.85	1.60	3.55a	2.31b	1.24b	1.12b
18:1, <i>n</i> -9	32.00	32.70	36.50	35.70	23.80	26.86	25.17	27.22
18:1, <i>n</i> -7	1.69ab	1.78a	1.73ab	1.37b	1.65	1.77	2.08	1.87
18:2, <i>n</i> -6	5.97	4.95	5.34	4.24	6.89b	7.66b	13.54a	12.31a
18:3, <i>n</i> -3	1.73a	1.46a	0.30b	0.27b	1.73a	1.86a	0.81b	0.77b
CLA ^c	0.22	0.16	0.07	0.09				
22:0	0.44a	0.36ab	0.17bc	0.10c	0.48	0.61	0.51	0.41
22:1	0.67	0.53	0.65	0.49	0.84b	0.92b	2.48a	1.89a
20:4, <i>n</i> -6	3.07	2.36	1.89	1.32	3.47	3.67	4.95	4.05
20:5, <i>n</i> -3	1.34a	1.00a	0.36b	0.26b	1.49a	1.59a	0.93b	0.62b
22:5, <i>n</i> -3	1.89a	1.49a	0.66b	0.50b	2.08	2.31	1.73	1.52
Saturated (S)	38.40b	43.20ab	43.10ab	47.70a	46.11a	42.24ab	37.83b	39.25b
Monounsaturated (M)	41.70	43.00	44.90	44.20	31.64	34.09	32.91	34.15
Polyunsaturated (P)	14.20a	11.40ab	8.60b	6.70b	15.82b	17.11ab	22.05a	19.26ab
(M+P)/S	1.48a	1.27b	1.25b	1.10b	1.10	1.23	1.46	1.36
Total peroxidisable ^d	8.04a	6.31a	3.21b	2.35b	8.77	9.43	8.42	6.96

^a Of the same lipid fraction, means within the same row with a different letter are statistically different ($P < 0.05$).

^b DMA dimethyl acetals formed from fatty aldehydes during methylation.

^c CLA conjugated linoleic acid.

^d Fatty acids with three or more unsaturated bonds.

Table 4

Fatty acid profile (means of percent of distributions) of total lipids and phospholipids of fresh GM muscles from pasture- and grain-fed cattle with or without vitamin E supplement. Pooled S.E. are as presented in Table 2

Fatty acid	Total lipids				Phospholipids			
	Pasture		Grain		Pasture		Grain	
	Control <i>n</i> =8	Supplemented <i>n</i> =8	Control <i>n</i> =8	Supplemented <i>n</i> =8	Control <i>n</i> =8	Supplemented <i>n</i> =8	Control <i>n</i> =4	Supplemented <i>n</i> =4
14:0	1.15b ^a	1.29b	2.01ab	2.22a	0.72	0.88	0.68	0.60
14:1	0.14	0.14	0.30	0.38				
15:0	0.48a	0.51a	0.19b	0.22b				
16:0	22.70b	22.70b	27.30a	27.40a	20.06	20.20	18.48	17.54
16 DMA ^b	0.03	0.03	0.03	0.07	4.32	4.04	4.31	4.85
16:1, <i>n</i> -7	1.65b	1.65b	2.65a	2.89a	1.83	1.73	1.62	1.48
17:0	1.10a	1.08a	0.70b	0.61b				
17:1	0.85	0.76	0.50	0.48	0.99a	0.88a	0.53b	0.53b
18:0	17.40a	16.70ab	15.20ab	14.90b	17.61	17.94	16.09	15.97
18 DMA	0.00	0.00	0.00	0.00	2.54	2.36	2.78	3.56
18:1, <i>n</i> -7, t	1.86	1.89	2.87	1.98	2.09ab	2.52a	1.06b	1.02b
18:1, <i>n</i> -9	27.20bc	24.80c	32.10a	31.20ab	27.67	27.29	24.93	24.81
18:1, <i>n</i> -7	1.83	1.59	1.59	1.76	2.00	1.78	1.84	1.81
18:2, <i>n</i> -6	6.99	5.59	6.34	7.14	8.45b	8.18b	14.49a	14.19a
18:3, <i>n</i> -3	1.64a	1.29a	0.32b	0.39b	1.68a	1.68a	0.80b	0.77b
CLA ^c	0.26	0.22	0.13	0.15				
22:0	0.62a	0.40b	0.24b	0.29b	0.49	0.47	0.54	0.56
22:1	1.38	1.23	0.80	0.91	1.12	1.66	1.71	1.75
20:4, <i>n</i> -6	5.50	4.73	2.50	3.11	3.15b	3.34b	5.51a	5.70a
20:5, <i>n</i> -3	1.91a	1.34a	0.45b	0.63b	1.25	1.32	1.00	1.01
22:5, <i>n</i> -3	1.60a	0.94b	0.85b	1.10ab	1.62	1.57	1.83	2.04
Saturated (S)	44.4	43.80	45.90	46.00	40.29	40.43	36.86	37.06
Monounsaturated (M)	34.90b	32.00b	40.80a	39.60a	35.69	35.65	31.69	31.39
Polyunsaturated (P)	17.90a	14.10ab	10.60b	12.50b	16.18b	16.12b	23.63a	23.70a
(M+P)/S	1.20	1.04	1.13	1.14	1.30	1.29	1.50	1.49
Total peroxidisable ^d	10.65a	8.30a	4.12b	5.23b	7.70	7.91	9.14	9.52

^a Of the same lipid fraction, means within the same row with a different letter are statistically different ($P < 0.05$).

^b DMA dimethyl acetals formed from fatty aldehydes during methylation.

^c CLA conjugated linoleic acid.

^d Fatty acids with three or more unsaturated bonds.

maintain lipid stability in pasture-fed beef. The high contents of peroxidisable lipids, coupled with ageing changes in other muscle components, appeared to be the main factors responsible. α -Tocopherol concentrations of 4–6 $\mu\text{g/g}$ muscle appeared to be sufficient to minimise lipid oxidation of meat from aged grain-fed but not aged pasture-fed cattle.

Lanari, Schaefer, Liu, and Cassens (1996) postulated that metmyoglobin could be produced not only by the autoxidation of oxymyoglobin but also by a direct reaction between the lipid radicals and the oxymyoglobin. In the presence of radical quenching anti-oxidants like α -tocopherol, the reaction between the lipid radicals and oxymyoglobin may be inhibited via a competitive reaction between the antioxidant and oxymyoglobin for lipid radicals (Lanari et al., 1996). The antioxidant concentration in fresh meat was sufficient to inhibit lipid oxidation during the 7-day period. Therefore, the discolouration observed at this stage was probably due to autoxidation of the myoglobin. Although vitamin E supplementation increased the lipid stability of aged

meat from grain-fed steers, the colour stability was not affected. This result suggests that the link between pigment and lipid stability may not be as strong as previously thought and that factors other than α -tocopherol may play an important role in determining colour stability.

4. Conclusions

The alterations in the fatty acid composition and antioxidant concentration in the meat due to pasture or grain finishing significantly altered the colour and lipid stability of fresh and aged beef. Although beef from cattle raised in good quality pasture had α -tocopherol contents similar to those from grain-fed meat supplemented with 2500 IU of vitamin E, they also had a higher proportion of peroxidisable lipids. These two factors combined resulted in a reduction in the colour stability of pasture-fed fresh beef, however, no difference in colour stability was detected in aged beef.

Pasture feeding with and without supplementation increased lipid oxidation of aged beef. Vitamin E supplementation did not improve the colour and lipid stability in pasture-fed beef. In contrast with previous publications, no benefits in colour stability were detected by supplementing grain-fed cattle when meat was viewed for 7 days.

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