Meat Science 92 (2012) 1–7

Contents lists available at SciVerse ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Lipid and colour stability of *M. longissimus* muscle from lambs fed camelina or linseed as oil or seeds

A.P. Moloney [a,*], C. Kennedy [b], F. Noci [a,c], F.J. Monahan [c], J.P. Kerry [b]

[a] Teagasc, Animal and Grassland Research and Innovation Centre, Grange, Dunsany, Co. Meath, Ireland
[b] Food Packaging Group, School of Food and Nutritional Sciences, University College, Cork, Ireland
[c] School of Agriculture, Food Science and Veterinary Medicine, College of Life Sciences, University College Dublin, Ireland

ARTICLE INFO

Article history:
Received 29 July 2011
Received in revised form 15 March 2012
Accepted 16 March 2012

Keywords:
Lipid oxidation
Lamb
Colour stability
Plant oil

ABSTRACT

Colour and lipid stability of *M. longissimus dorsi* (LD) from sheep fed diets containing different lipid sources (Megalac (MG), camelina oil (CO), linseed oil (LO), NaOH-treated camelina seed (CS), NaOH-treated linseed (LS) or CO treated with ethanolamine (CA)) were examined. After 100 days on-feed, samples of LD were collected, fatty acid profile determined and colour and lipid oxidation (2-thiobarbituric acid reactive substances; TBARS) measured during retail display in high oxygen packaging. The LS ration was most effective in increasing the 18:3n−3 and conjugated linoleic acid (CLA) concentration in muscle. Within camelina, CA resulted in the highest 18:3n−3 and lowest CLA concentration in muscle. There was no difference in colour stability. Oil (seed) supplementation increased TBARS compared to MG in the early part of display while linseed-based rations tended to cause higher TBARS than camelina-based rations. Higher muscle 18:3n−3 concentration was associated with higher oxidation during early retail display but this was not reflected in a loss of colour stability.

1. Introduction

Dietary recommendations to consume less saturated fat (WHO, 2003) have encouraged research into the modification of animal diets to increase the content of beneficial polyunsaturated fatty acids (PUFA), in particular, PUFA of the omega-3 series (18:3n−3, linolenic acid; 20:5n−3, eicosapentaenoic acid (EPA); 22:6n−3 docosahexaenoic acid (DHA)), and conjugated linoleic acid (CLA), in meat products (e.g. Scollan et al., 2006).

Dietary supplementation with oils rich in linolenic acid, linoleic acid (18:2n−6), EPA and DHA is one strategy used to achieve elevated levels of beneficial fatty acids in ruminant tissue (Noci, French, Monahan, & Moloney, 2007; Scollan, Enser, Gulati, Richardson, & Wood, 2003). However, increasing the degree of unsaturation of muscle lipids increases their susceptibility to oxidation (Nute et al., 2007; Vatansever et al., 2000), which in turn may induce myoglobin oxidation (Monahan, Skibsted, & Andersen, 2005) and so have deleterious effects on the appearance and shelf-life of meat. The challenge therefore is to enhance the nutritional composition of beef, in particular to increase the concentrations n−3 PUFA, while maintaining lipid stability and the stability of the bright red colour of fresh meat desired by consumers.

Accumulation of α-tocopherol in muscle tissue delays lipid and pigment oxidation (Kerry, Buckley, & Morrissey, 2000). Dietary supplementation with vitamin E improves the antioxidant to pro-oxidant balance in muscle as well as enhancing the protection of PUFA against peroxidation (Farrell, 1988). Rations designed to increase the concentrations of PUFA in tissue are therefore frequently supplemented with vitamin E beyond the level required for animal growth and well-being.

Camelina sativa is a summer annual oilseed of the genus *Cruciferae* which grows well in temperate climates and has lower costs of production than other oilseed plants such as rapeseed (Crowley & Frohlich, 1998). In addition camelina oil contains approximately 16.5% linoleic acid and 39% linolenic acid (Crowley & Frohlich, 1998) making it an attractive alternative source of n−3 PUFA to linseed. Feeding intact oil seeds rather than oils has practical advantages in terms of handling of feed ingredients and ration manufacture. However without some disruption of the seed coat, intact seeds may escape ruminal digestion completely and NaOH has been examined in this regard (Aldrich, Merchen, Drackley, Fahey, & Berger, 1997; Aldrich, Merchen, Drackley, Gonzalez, et al., 1997). Noci, Monahan, and Moloney (2011) demonstrated that providing lambs with a source of linolenic acid such as oils or NaOH-treated seeds of linseed or camelina was effective in increasing the concentrations of n−3 PUFA and CLA in muscle. The objective of the research reported in this paper was to determine if these modifications of the fatty acid composition affected the shelf-life characteristics during refrigerated display of the lamb.

* Corresponding author. Tel.: +353 46 9061100; fax: +353 46 9026154.
E-mail address: aidan.moloney@teagasc.ie (A.P. Moloney).

0309-1740/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.meatsci.2012.03.011

2. Materials and methods

2.1. Experimental design and animal management

The fat sources examined were Megalac® (MG), camelina oil (CO), linseed oil (LO), camelina seed treated with NaOH (CS), linseed treated with NaOH (LS) and camelina oil amides (CA). Further details are in Noci et al. (2011). Six experimental rations were prepared which differed in the source of fat used (Table 1). All rations were formulated to be isonitrogenous and isoenergetic and a mineral and vitamin mix was added to the rations with a target vitamin E concentration of 500 IU/kg concentrate. In the CA diet, camelina oil amides were included at a level calculated to provide the same amount of fatty acids as that of the CO diet. Individual fat sources and the other ingredients were mixed in batches of approximately 500 kg using an Abbey Gearbox drive Diet Feeder 100 (Abbey, Nenagh, Co. Tipperary, Ireland), and mixed at 1700 rpm for 15 min. Fatty acyl amides were melted at 70 °C immediately prior to inclusion in the diet mix to facilitate the mixing. Three batches of each ration were prepared during the course of the study. One sample was collected for each ration from each batch and stored at −20 °C pending analysis of vitamin E concentration while samples were collected periodically for fatty acid analysis (Noci et al., 2011).

Sixty-six crossbred wether lambs (average body weight 40.0 kg, s.d. 4.69) were blocked by initial bodyweight and within block, assigned at random to one of 6 rations. The animals were housed in individual pens and fed once daily in the morning and had free access to clean drinking water. The concentrate allowance was 25 g/kg body weight and was increased every four weeks based on animal weight. Animals also received 100 g of chopped hay/day. The animals were slaughtered after 100 days on the experimental rations. Further experimental details are in Noci et al. (2011).

Table 1
Ration formulation and fatty acid composition.

	Treatment[1]					
	MG	CO	LO	CS	LS	CA
Ingredients (g/kg)						
Barley	350	285	285	282	328	303
Beet pulp	350	430	430	370	339	363
Soybean	103	100	100	30	29	112
Molasses	100	100	100	100	100	100
Minerals and vitamins mix[2]	25	25	25	25	25	25
Megalac	72	–	–	–	–	–
Camelina oil	–	60	–	–	–	–
Linseed oil	–	–	60	–	–	–
Camelina seed/NaOH	–	–	–	193	–	–
Linseed/NaOH	–	–	–	–	179	–
Camelina oil amide	–	–	–	–	–	97
Vitamin E (mg/kg)	360	416	414	368	364	366
Fatty acids (g/100gFAME)						
C 16:0	39.73	8.04	7.89	9.48	12.12	7.64
	1.00)	(1.20)	0.47)	(2.02)	(3.23)	(0.19)
C 18:0	5.13	4.32	4.17	4.07	6.14	3.76
	(0.09)	(1.14)	0.26)	(0.53)	(1.70)	(0.46)
C 18:1	34.69	14.04	17.40	12.58	18.92	12.97
	(0.62)	(0.45)	(0.74)	(0.38)	(4.27)	(0.28)
C 18:2	14.91	20.11	21.68	21.09	16.92	20.32
	(2.14)	(0.40)	(0.33)	(1.10)	(2.42)	(0.50)
C 18:3	0 (0)	29.57	46.13	28.58	37.37	27.12
		(2.09)	(0.47)	(2.89)	10.66)	(0.82)
C 20:1	1.57	13.36	0.47	12.45	0.69	13.34
	(0.39)	(2.77)	(0.19)	(1.13)	(0.12)	(0.12)
SFA[a]	46.65	14.30	12.82	15.70	19.58	13.81
	(1.23)	(2.19)	(0.64)	(2.95)	(5.03)	(0.62)
MUFA[b]	37.33	31.31	18.29	28.97	20.42	30.00
	(0.27)	(3.57)	(0.86)	(1.61)	(4.67)	(0.19)
PUFA[c]	15.28	53.29	68.19	53.69	55.02	51.80
	(2.04)	(1.34)	(0.69)	(2.10)	(12.55)	(0.56)
n−6:n−3[d] ratio	–	0.71	0.48	0.76	0.47	0.75
		(0.06)	(0.01)	(0.11)	(0.07)	(0.04)

[1] MG = Megalac, CO = camelina oil, LO = linseed oil, CS = NaOH-treated camelina seeds, LS = NaOH-treated linseeds, CA = camelina oil amides.

[2] The mineral and vitamin mix contained Ca (48%), Na (12%), ammonium chloride (12%), vitamin A (480,000 IU/kg), vitamin D_3 (96,000 IU/kg), vitamin E (20,000 IU/kg), cobalt carbonate (40 mg/kg), calcium iodate (80 mg/kg), iron sulphate (1000 mg/kg), manganese oxide (1,600 mg/kg), sodium selente (8 mg/kg), zinc oxide (2000 mg/kg).

[a] Saturated fatty acids (SFA) = sum of all even chain FA up to C22:0.

[b] Monounsaturated fatty acid (MUFA) = sum of C14:1, C16:1, C18:1, C20:1.

[c] Polyunsaturated fatty acid (PUFA) = sum of C18:2, C18:3, C20:2, C20:3, C20:4, C20:5, C22:4 and C22:6.

[d] n−6:n−3 ratio = Σ n−6/Σ n−3; Σ n−6 PUFA = sum of C18:2, C18:3n−6, C20:2, C20:3n−6, C20:4 and C22:2; Σ n−3 PUFA = sum of C18:3n−3, C20:3n−3, C20:5, C22:5 and C22:6.

2.2. Initial post-slaughter measurements

After slaughter, the weight of the carcass was recorded. Carcasses were then chilled for 24 h and the *M. longissimus dorsi* (LD), *M. semimembranosus* and *M. psoas major* muscles were removed by dissection. The pH of each muscle was measured by making a scalpel incision approximately 1 cm into its centre and inserting a pH electrode (EC-2010-11, Reflex Sensors, Ltd., Dublin, Ireland) connected to a portable pH meter (Model No. 210A, Thermo Electron Corp., Orion Products, Beverly MA 01915, USA) set to record at 5 °C. The pH electrode was calibrated using buffers of pH 7.00 and 4.00, stored in a solution of distilled, deionised water, KCl, Na_2HPO_4 and KH_2PO_4 (Thermo Electron Corp.) and rinsed between measurements. A steak, approximately 25 mm thick, from the centre of each muscle was overwrapped with oxygen permeable polyvinylchloride (PVC) film and placed in a dark chill room at 2 °C for 3 h to permit blooming and the colour coordinates (Hunter L, a, b) were measured using a benchtop Hunter Lab UltraScan XE spectrocolorimeter with Universal Software Version 2.2.2 (Hunter Associates Laboratory, Inc., 11491 Sunset Hills Rd., Reston, VA 20190-5280, USA) which was calibrated using its light trap and standard white calibration tile, prior to measurement. Three readings were made on non-overlapping areas of the muscle using the small optical port (Ø = 0.95 cm) and average values were reported as final readings. All measurements were made in the Hunter Lab colour space. Diffuse illumination (D_{65}, 10°) with an 8° viewing angle was used and the specular component was excluded. Muscle hue angle ('H') and saturation ('C') were calculated as $\tan^{-1}$ (b/a) and $\sqrt{(a^2+b^2)}$, respectively. Final conversion of hue angle from radians to degrees was achieved by multiplying $\tan^{-1}$ (b/a) by 180/π.

An additional two steaks, approximately 25 mm thick, were cut from the region of the 7th rib of the LD, vacuum-packed (Webomatic® vacuum-packaging systems SuperVax, ThyssenKrupp Schulte GmbH, Düsseldorf 40041, Germany) and stored at −30 °C pending analysis of fatty acid and vitamin E concentrations. The remaining LD was vacuum packaged and stored at −20 °C (3 months) pending measurement of colour stability and lipid oxidation under modified atmosphere packaging (MAP).

2.3. Modified atmosphere packaging (MAP), colour stability and lipid oxidation measurement

Frozen vacuum packed LD was transferred to the University College Cork. Within each treatment group, 7 samples were selected at random and allowed to thaw at 4 °C for 24 h. Samples were then removed from vacuum packaging and allowed to bloom for 1 h at 4 °C. The muscles were trimmed of external fat, cut into 5 steaks (25 mm, one for each sampling day) and each steak was placed on CPET/polyethylene trays (BXL Plastics Ltd., Thermoformed Containers Division, 79a Park Lane, Croydon CRO 1JG, UK) and sealed with a low