Nutritional value and sensory characteristics of meat eating quality of Australian prime lambs supplemented with pelleted canola and flaxseed oils: Fatty acid profiles of muscle and adipose tissues

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Abstract

The effects of canola or flaxseed oil dietary supplementation on *Longissimus thoracis et lumborum* (LTL) muscle and visceral adipose tissue fatty acid (FA) profiles and meat sensory traits in Australian prime lambs from different breeds were investigated. Sixty lambs were fed one of the following pellet treatments: no oil (Control), 2.5% canola, 5% canola, 2.5% flaxseed and 5% flaxseed, balanced by breed (purebred Merino, and first-cross lambs from Corriedale rams mated to Merino ewes and White Suffolk rams mated to Corriedale ewes). Lambs were individually supplemented daily with 1 kg of oil-enriched wheat-based pellets throughout the 7-week feeding trial, after a 3-week adjustment period and an unlimited access to water and lucerne hay. At the end of the feeding trial, all animals were slaughtered. From each carcass, an LTL muscle sampled at the 12/13th rib interface and a visceral adipose tissue sampled from the vicinity of the liver were taken and subjected to fatty acid analysis. A separate LTL muscle sample was utilised for sensory evaluation of meat eating quality. The inclusion of 5% flaxseed oil significantly decreased n-6/n-3 ratio in both tissues. The muscle from lambs fed 5% oil supplements had higher omega-3 long-chain polyunsaturated FA (n-3 LC-PUFA) contents and reached the claimable health-benefitting value without deleterious sensory effects. The n-3 LC-PUFA component in visceral adipose tissue was negligible. Tissue FA profiles and sensory quality were influenced by lamb breed. There were significant interactions between oil supplementation levels and lamb breed on some visceral adipose FA and meat juiciness. These findings indicate that a combination of dietary manipulation and lamb genetics can be used as an effective management tool to deliver a nutritionally improved n-3 LC-PUFA lamb to consumers.

Keywords: Omega-3 fatty acids; prime lamb; oil supplementation; muscle; adipose tissue; meat sensory eating quality

1. Introduction

Heart disease is a global health threat and the leading cause of death worldwide [1]. It is widely accepted that omega-3 long-chain ($\geq C_{20}$) polyunsaturated fatty acids (n-3 LC-PUFA) including eicosapentaenoic acid (EPA, 20:5n-3), docosapentaenoic acid (DPA, 22:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) play a critical role in the prevention of cardiovascular and inflammatory diseases in humans [2] and also the improvement of visual and brain development in infants and children [3]. The n-3 LC-PUFA cannot be synthesised by humans and other vertebrates due to the absence of Δ^{15} desaturase enzyme, and therefore the need for n-3 LC-PUFA to be included in the diet [4]. The recommended dietary n-3 LC-PUFA intakes for the prevention of chronic diseases in adult males and females in Australia and New Zealand are 610 and 430 mg/day, respectively [5]. Nichols *et al.* [6] indicated that Australian adults need about 500 mg of n-3 LC-PUFA daily, but the average intake of n-3 LC-PUFA in Australia was reported to be 246 mg/day [7]. Thus, there is clearly a current shortfall in dietary intake of these health-benefitting n-3 LC-PUFA, and a recognized need for an increase in the consumption of n-3 LC-PUFA in Australian diets.

Meat from ruminants has been implycated in the increased risk of cardiovascular diseases and metabolic syndrome, due to its high content of saturated fatty acids [8]. However, ruminant meat is an important source of n-3 LC-PUFA contributing approximately 40% of the average daily intake of these FA for adults in Australia [9]. Cooper *et al.* [10] reported that supplementing lambs with fish oil and/or marine algae, which are rich in n-3 LC-PUFA, substantially increased the levels of EPA and DHA in *Longissimus* muscle and adipose tissues. However, the use of marine oils in animal diets may increase fishy flavour and rancidity [11] and also may not be sustainable or cost-effective. Recently, vegetable oils, especially oil from canola and flaxseed, have been used as supplements in lamb diets to enhance the n-3 LC-PUFA content in meat [12, 13]. The principal n-3 PUFA in canola oil and flaxseed oil is exclusively α-linoleic acid (ALA, 18:3n-3) [14, 15]. This FA can act as a potential precursor for the synthesis of the more beneficial n-3 LC-PUFA [16]. In addition to diet, genetics may contribute a long-term and cumulative impact on lamb FA composition [17, 18]. Therefore, FA profiles of lamb products can theoretically be manipulated through crossbreeding. However, on-farm research on the potential modification of FA profiles in both muscle and visceral adipose tissues from lambs fed canola oil or flaxseed oil and the appropriate supplementation levels of these oils in diets remains limited, hence the need for the current study.

Along with nutritional attributes, sensory characteristics are a key factor strongly influencing the demand and willingness to pay decisions of lamb consumers [19]. Numerous studies in meat sheep have concluded that sensory traits were mainly influenced by animal age [20] and feeding regimes [21-23]. However, most of these studies were conducted to compare sensory variation in lambs fed different types of forages. Studies investigating the effects of concentrate-based systems on sensory characteristics are currently limited. Other studies have shown that lamb breed has an impact on meat eating quality [24, 25], but this impact is highly variable. For instance, Monaco *et al.* [26] reported that sire breed significantly affected sensory traits, while Safari *et al.* [27] concluded that no difference occurred in the eating quality of loin meat from purebred Merinos and their crossbred lambs.

Therefore, the major objective of this study was to investigate the FA profiles of LTL muscle and visceral adipose tissues, and variation in sensory traits of meat from Australian prime lambs supplemented with canola oil or flaxseed oil enriched pellets. The following hypotheses were tested: Pellets enriched with canola or flaxseed oils: (i) enhance n-3 LC-PUFA profiles to meet

the values considered more optimal for human diets; (ii) do not adversely influence sensory properties of lamb, and
(iii) lamb breed influences tissue FA profiles and meat eating quality.

2. Materials and methods

2.1. Location, animal ethics permit and experimental animals

This research was conducted at the Cressy Research and Demonstration Station, Cressy, Tasmania, Australia, between June and August 2014. The experimental design and procedures were approved (Permit No. A13839) by the University of Tasmania Animal Ethics Committee. The study was also in accordance with the 1993 Tasmania Animal Welfare Act and the 2013 Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

Sixty weaned prime lambs at seven months of age, with an initial mean liveweight of 33.4 kg and body condition score of 2.7 were utilised in this study. The lambs comprised 20 purebred Merinos (MxM), 20 first-crosses from Corriedale sires mated to Merino dams (CxM), and 20 progeny of White Suffolk sires mated to Corriedale dams (WxC). They were dewormed and identified with ear tags prior to the commencement of the feeding trial.

2.2. Experimental design and dietary management

The experimental design was completely randomised, with 5 treatments and 12 lambs per treatment, balanced by breed. Lambs were supplemented daily with 1 kg of wheat-based concentrate pellets, with or without oil inclusion. The treatments included 1) no oil inclusion (Control); 2) 2.5% canola oil; 3) 5% canola oil; 4) 2.5% flaxseed oil and 5) 5% flaxseed oil. All diets were isocaloric and isonitrogenous. The study lasted for 10 weeks including a three-week adaptation period. Lambs were housed in individual pens with *ad libitum* access to lucerne hay and clean water. Residual feeds were removed prior to fresh feed being offered to all experimental lambs at 0900 hours.

2.3. Slaughter and sampling

At the end of the feeding trial, all lambs walked to an adjacent commercial abattoir (100 m) for slaughter according to Meat Standards Australia regulations and specifications after an overnight fast with water available in lairage. Visceral adipose tissue samples were taken immediately after evisceration from the liver. After 24 h chilling, two LTL muscle samples at the $12/13^{th}$ rib interface were removed from each carcass as commercial loin chops (approximately 200 g) – one chop designated for FA analysis, the other for sensory evaluation test. All samples were vacuum-sealed, code-labelled and stored at -20^0C until ready for analyses.

2.4. Feed chemical analysis

Representative pellet and lucerne hay samples were collected on days 0, 25 and 49 of the experimental period and kept at -20^0C for subsequent analyses. At the end of the experiment, the samples were defrosted, pooled and ground through a 1-mm screen. Samples were dried in triplicates in a fan-forced oven to a constant weight at 65^0C to determine dry matter (DM) content. Total Nitrogen (N) was quantified using an elemental analyser (PE2400 Series II; Perkin-Elmer Corp, USA), and multiplied by 6.25 to estimate crude protein (CP) content. Ether extract (EE) was determined using an ANKOM fat/oil extractor ($ANKOM^{XT15}$; ANKOM Technology, USA). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) contents were measured using an ANKOM fibre analyser ($ANKOM^{220}$; ANKOM Technology, USA). Ash content was quantified by combusting the samples in a furnace at 650^0C for 8 hours. Organic matter (OM) was computed as OM = 100 – Ash. Non-fibrous carbohydrates (NFC) was calculated as NFC = 100 − (CP + NDF + EE + Ash) [28]. A near infrared reflectance spectroscopy method [29] was used to estimate metabolisable energy (ME).

2.5. Lipid analysis

Total lipid extraction and FA profile analysis were undertaken at the Commonwealth Scientific and Industrial Research Organization (CSIRO) Food Nutrition & Bio-based Products, Oceans & Atmosphere, Hobart, Tasmania, Australia. Details of the procedures were previously published by Malau-Aduli *et al.* [30]. In brief, total lipids in 1 g of feed and muscle and 0.2 g of visceral adipose tissue samples were solvent extracted using a modified Bligh and Dyer [31] protocol. CH_2Cl_2: MeOH:Milli-Q H_2O (1:2:0.8 v/v) was used in a single-phase process to extract total lipids from the samples overnight. This was followed by phase separation with CH_2Cl_2:saline Milli-Q H_2O (1:1 v/v), and rotary evaporation at 40^0C to obtain total lipids.

Fatty acid methyl esters (FAME) from an aliquot of each total lipid were extracted with C_6H_{14}:CH_2Cl_2 (4:1 v/v, 3 times). Internal injection standard (19:0) was added in 1500 µL vial containing the extracted FAME. A 7890B gas chromatograph (GC) (Agilent Technologies, Palo Alto, CA, USA) equipped with an Equity™-1 fused silica capillary column (15 m x 0.1 mm internal diameter and 0.1-µm film thickness) (Supelco, Bellefonte, PA, USA), a flame ionisation detector, a split/splitless injector, and an Agilent Technologies 7683 B series autosampler were used to analyse the samples. Fatty acid peaks were quantified by ChemStation software (Agilent Technologies, Palo Alto, CA, USA). GC-mass spectrometry (GC/MS) analysis was undertaken to confirm FA identities using a Thermo Scientific 1310 GC coupled with a TSQ triple quadrupole. Samples were injected using a Tripleplus RSH auto sampler with a non-polar HP-5 Ultra 2 bonded-phase column (50 m x 0.32 mm i.d. x 0.17 µm film thickness). The HP-5 column was of similar polarity to the column used for GC analyses. The initial oven temperature of 45°C was held for 1 min, followed by temperature programming at 30°C per min to 140°C, then at 3°C per min to 310°C where it was held for 12 min. Helium was used as the carrier gas. Mass spectrometer operating conditions were: electron impact energy 70 eV; emission current 250 µA, transfer line 310°C; source temperature 240°C; scan rate 0.8 scan/sec and mass range 40-650 Da. Mass spectra were acquired and processed with Thermo Scientific XcaliburTM software (Waltham, MA, USA).

Fatty acid profiles were computed as percentages (g/100g of total FA or %) and content (mg/100g of wet tissue). Fatty acid percentages were qualitatively calculated from the FA area output as: FA% = (area of individual FA)*(100)/(total FA area). Fatty acid contents were computed as FA (mg/100g) = (Total lipid percentage)* 0.916 *([FA%]/100)*1000 [9], where 0.916 was utilized as the lipid conversion factor [32] as cited by Clayton [9].

2.6. Meat sensory evaluation test

Meat sensory evaluation test following the protocol described by Thompson *et al.* [33] was performed on 60 loin chops by a panel of 20 consumers. The samples were tested in two sessions involving 10 members per session. Consumers were between the ages of 30 and 60 years, who all ate red meat at least twice a week. To become familiar with the sensory test protocol, each panellist was served with three blank samples (which were purchased from a supermarket) at the beginning of each session, followed by 30 experimental samples. Panellists were required to evaluate tenderness, juiciness, flavour and overall liking of the samples on a nine-point hedonic scale [34, 35] (9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely).

The loin chop samples designated for sensory evaluation were thawed at 4^0C over 24 h before analysis. The loins were cooked on a barbeque (Spinifex 4 Burner Grill Unit) using conductive dry-heat on a fry grilling hot plate, with heat control knobs set at *"High"* position. No cooking oil and other

additives were used during cooking of the loin chops. Internal meat temperature was monitored using portable instant-read AcuRite meat thermometer (AcuRite, Lake Geneva, WI, USA). The loin chops were removed from the cooking surface when the internal core temperature reached 70^0C (medium doneness). After being rested for 3 minutes, the bone, subcutaneous fat and visible connective tissues were removed. The cooked meat was cut into 10 cubes of similar sizes (approximately 1 cm^3). Each cube was placed on a code-labelled disposable plastic plate and randomly served to panellists. The panellists were offered water and unsalted crackers between two samples to neutralize taste buds and minimize cross-sample contamination. In each session, the panellist tasted 30 cubes from 30 different lambs, giving a total of 600 replications in both sessions. Thus, each loin chop sample was evaluated by 10 panellists. The data provided an adequate statistical robustness and vigour for analysis, consistent with Thompson *et al.* [36] who reported that 10 raw consumer scores per meat sample were significantly sufficient to detect differences in sensory traits between samples.

2.7. Statistical analysis

All data were analysed using Statistical Analysis System software version 9.2 (SAS Institute, Cary, NC, USA). Summary statistics including means and standard errors were computed and scrutinised for any erroneous data entry. For FA profile analysis, the data were fitted into a general linear model (PROC GLM) with oil supplementation, lamb breed, and their interaction as fixed effects, and total lipid percentages, individual and major group FA percentages and contents as dependent variables. For sensory attributes, a mixed model (PROC MIXED) was used to analyse tenderness, juiciness, flavour and overall liking of meat samples as dependent terms. The fixed effects in the model were oil supplementation, lamb breed and their interaction. The random effects in the model included individual panellists, order of tasting and sessions. Significant differences and mean separations at the $P < 0.05$ threshold were performed using Tukey's probability pairwise comparison tests.

3. Results

3.1. Feed ingredients, chemical compositions and fatty acid profiles

The ingredients and chemical compositions of the experimental pellets and lucerne hay are given in Table 1. Wheat was the major carrier ingredient (465 - 551 g/kg) in the pellets. The CP, EE and ME contents, and other chemical compositions were relatively similar among the 5 pellets. Lucerne hay had more CP, NDF, ADF and less EE than the pellets.

The total lipid percentage, FA composition and 18:3n-3 content of feedstuff are presented in Table 2. The extracted lipid percentages in pellets were relatively similar ranging from 4.2% to 4.8%. The prominent FA in pellets were 18:2n-6 and 18:1n-9, while 16:0 and 18:3n-3 accounted for the highest FA percentage in lucerne hay. Control pellets had higher PUFA composition (48.4%) and n-6/n-3 ratio (11) compared to oil supplemented pellets. Oil supplemented pellets had higher 18:3n-3 content than control pellets. Lucerne hay contained high 18:3n-3 content (176.2 mg/100g), and had low n-6/n-3 ratio (0.8). EPA, DHA and DPA were not detected in the pellets and lucerne hay.

3.2. Muscle fatty acid profile

A marked decrease ($P < 0.05$; Table 3) in the n-6/n-3 ratio was observed in lambs fed flaxseed oil pellets compared to lambs offered control pellets, while the n-6/n-3 ratio of lambs in canola oil treatments did not significantly differ from other treatments ($P > 0.05$). Lambs fed flaxseed oil and 5% canola oil pellets had significantly lower 17:0 composition ($p < 0.05$) than those offered the control pellets. The inclusion of 5% oil in pellets markedly increased ($P < 0.05$; Table 3) EPA and DPA contents, whereas these contents were unaffected by supplementing with 2.5% oil. Oil supplementation significantly increased ($P < 0.05$) DHA content in experimental lamb

LTL muscle. As a consequence, the content of EPA+DHA and total n-3 LC-PUFA content of lambs fed 5% oil enriched pellets was significantly higher ($P < 0.01$) than that of lambs in the control treatment. Oil inclusion did not alter total lipid percentage (intermuscular fat (IMF) percentage), and the PUFA/SFA ratio ($P > 0.05$).

The IMF percentages, FA profile in the LTL muscle were significantly influenced by lamb breed ($P<0.05$) (Table 3). Crossbred lambs had higher ($P < 0.05$) IMF percentage than purebred Merinos. First-cross CxM lambs recorded the highest 14:0 (2.2%), 16:0 (23.6%) and total SFA (45.1%) percentages. However, the percentage of 18:2n-6 (4.8%) was lowest in CxM lambs. Purebred Merinos had significantly higher ($P < 0.05$) of EPA (0.9%), DHA (0.3%) and DPA (0.8%) percentages than CxM lambs (0.4%, 0.1% and 0.5% respectively). Pure-bred Merinos and WxC lambs had markedly higher ($P < 0.05$) total PUFA, n-3 PUFA, n-6 PUFA percentages than CxM lambs, although these percentages did not signify-cantly differ between MxM and WxC lambs. First-cross CxM lambs had a lower PUFA/SFA ratio in LTL muscle than MxM and WxC lambs. However, the n-6/n-3 ratio was not affected by lamb breed. The EPA and DHA contents of purebred Merinos were significantly higher ($P < 0.05$) than those of crossbred lambs. As a consequence, purebred Merinos had markedly higher ($P < 0.001$) total content of EPA+DHA than crossbred lambs. The contents of DPA and total n-3 LC-PUFA were not influenced by lamb breed. There were no significant interactions between oil supplementation and lamb breed.

3.3. Visceral adipose tissue fatty acid profile

Supplementation with 5% flaxseed oil significantly increased ($P < 0.05$; Table 4) the percentages of 18:3n-3 (2.6%) and DPA (0.12%) in adipose tissue compared to the control treatments (1.2% and 0.05%, respectively). Furthermore, lambs fed 5% flaxseed pellets had significantly higher total PUFA (9.2%) and n-3 PUFA (2.7%) compositions than those offered control pellets (5.2% and 1.3%, respectively). Lambs from the 5% oil treatments had lower total SFA percentage than those from the control treatment. The inclusion of 5% flaxseed oil in lamb diet significantly increased PUFA/SFA ratio, and reduced the n-6/n-3 ratio in comparison with the control treatment. The 18:3n-3 content in visceral adipose tissue of lambs fed pellets containing 5% flaxseed oil (696.1 mg/100g wet tissue) was markedly higher than that of the control (338.6 mg/100g wet tissue). The inclusion of 5% flaxseed oil also recorded the highest DPA and total n-3 LC-PUFA contents. The total lipid percentage in visceral fat was not influenced by oil supplementation. The proportions of 14:0 and 17:0 in visceral adipose tissue were significantly influenced by lamb breed ($P < 0.05$) (Table 4). First-cross CxM lambs had significantly higher ($P < 0.05$) 14:0 propor-tion (3.1%) than MxM (2.5%) and WxC lambs (2.4%). The 17:0 percentage of WxC lambs (1.4%) was significantly lower than that of purebred Merinos (1.8%). Purebred Merinos recorded the highest 20:4n-6 percentage (0.07%) and content (32.1 mg/100g wet tissue). The percentage and content of 22:5n-6 from CxM lambs was highest. The PUFA/SFA and n-6/n-3 ratios and the n-3 PUFA contents were not affected by lamb breed.

Significant interactions between oil addition and lamb breed on percentages and contents were observed. First-cross CxM lambs recorded the highest 14:0 percentage when they were fed pellets containing 2.5% flaxseed oil, while the lowest 14:0 percentage was observed in WxC lambs fed the 5% flaxseed oil pellets. The adipose 16:0 percentage of CxM lambs fed 2.5% canola oil pellets was lowest ($P < 0.05$), while the highest 16:0 percentage was obtained in MxM lambs from 2.5% canola oil treatment. First-cross CxM lambs offered 5% flaxseed oil pellets had higher DPA percentage and content than WxC lambs fed the control pellets. First-cross CxM lambs fed canola oil pellets had significantly higher 22:5n-6

contents than MxM lambs offered pellet containing flaxseed oil.

3.4. Meat sensory characteristics

Sensory scores of loin chops were affected by lamb breed apart from flavour (Table 5). Purebred Merinos had lower sensory scores ($P < 0.05$) for tenderness and juiciness than crossbred lambs. Furthermore, meat of WxC lambs was assessed with a more overall liking value in comparison with purebred Merinos. Eating quality was not affected by oil supplementation ($P > 0.05$). However, there was a significant interaction between dietary oil inclusion and lamb breed on juiciness with MxM lambs fed pellets containing 5% oil having the lowest scores.

4. Discussion

4.1. The fatty acid profiles of experimental feeds

The differences in FA profiles of experimental pellets resulted from variations in the FA composition of supplemented oils. The most abundant FA in canola and flaxseed oils were oleic (18:1n-9; 60% of total FA) and alpha-linoleic (18:3n-3; 55% of total FA) acids respectively, while 18:3n-3 accounted for approximately 10% of total FA in canola oil. In contrast, LC-PUFA are generally absent or account for very minor proportions in these oils [14, 15]. Thus, the inclusion of canola oil or flaxseed oil increased the percentage and content of 18:3n-3 and total n-3 percentage in the pellets. As a consequence, the n-6/n-3 ratio was lower in all the pellets. In other studies, canola and/or flaxseed oils have also been used to improve the total n-3 percentage and thus reduce the n-6/n-3 ratio in animal diets [13, 37].

4.2. Effect of oil supplementation on tissue FA profiles

The IMF percentage of LTL muscle in the present study was higher than those reported by Jerónimo *et al.* [37] and Jandasek *et al.* [38], mainly because they used younger lambs (3-4 months old) with lighter slaughter weights (30-35 kg). IMF in the LTL muscle and total lipid percentages in visceral adipose tissues were not affected by oil supplementation types. This agrees with the findings of Jerónimo *et al.* [37] who also did not observe differences in IMF percentages between lambs supplemented with different vegetable oils. They concluded that lipid types added in lamb diets did not influence intramuscular fatty acid content. Furthermore, Dávila-Ramírez *et al.* [39] did not find any change in total lipid percentage between lambs fed diets containing 6% soybean oil and non-oil supplemented diets. Wood *et al.* [40] stated that the pattern of fat deposition is a major factor influencing FA profile in ruminant tissues. However, the amount of fat deposited in the tissues depends on animal growth rate and maturity, which in turn, are mainly controlled by diet and animal age [41]. The absence of significant oil supplementation effects on total lipid percentage in this study was probably attributable to the relative similarities in chemical compositions between experimental diets and the animals used were of the same age.

It was evident from this study that all diets resulted in an n-6/n-3 ratio in the LTL muscle below 4, which is the maximum recommended value for human diets [42]. Moreover, the inclusion of flaxseed oil in the pellets caused a significant decrease in the n-6/n-3 ratio in both muscle and visceral adipose tissues. This is due to lower levels of 18:2n-6 and higher levels of 18:3n-3 in the flaxseed oil supplemented diets than in the other diets (Table 2). Dubois *et al.* [15] and Ding *et al.* [14] reported that the 18:3n-3 composition of flaxseed oil was fivefold higher than that of canola oil. As a consequence, the addition of flaxseed oil to ruminant diets would increase the total muscle n-3 PUFA and potentially the n-3 LC-PUFA content [43] and thereby contribute to a decrease in the n-6/n-3 ratio [12]. A number of feeding trials have described the effects of flaxseed oil inclusion on intramuscular FA composition [12, 37, 44, 45]. In all of these trials, a decreased n-6/n-3 ratio was consistently

observed in the LTL muscle of lambs fed flaxseed oil supplemented diets, whereas the n-3 LC-PUFA proportions remained unaffected (Table 6). Radunz *et al.* [13] also found no differences in n-3 LC-PUFA compositions when lamb finishing diets were supplemented with 3% blend of soybean oil and flaxseed oil (2:1, v/v) into lamb-finishing diets (Table 6). Our results were in agreement with the aforementioned studies.

There were significant increases in muscle n-3 LC-PUFA contents when lambs were supplemented with 5% oil. The oil supplementation effects on meat n-3 LC-PUFA content might have been due to the greater amount of FA intake [44]. *Several in vitro* studies confirmed that biohydrogenation of n-3 LC-PUFA in ruminants is limited even without rumen protection technologies, and its extent depends on the amount of these FA available to rumen microbes [46, 47]. Moreover, Cooper *et al.* [10] suggested that FA contents reflect dietary levels. In contrast, other studies conducted in sheep concluded that the profile of absorbed FA is independent of dietary FA due to the high level of ruminal lipid biohydrogenation [48, 49]. However, the increased intake and associated uptake of dietary FA could be indicative that part of the dietary-derived n-3 PUFA intake had escaped biohydrogenation in the rumen [48]. Additionally, Doreau and Ferlay [50] stated that if large amounts of FA are available in the rumen, it is possible for significant uptake of dietary FA to occur. An alternative explanation for our results is the further biosynthesis by desaturation and elongation of 18:3n-3 to n-3 LC-PUFA by rumen microbes, as microbial n-3 LC-PUFA may account for up to 30% of n-3 LC-PUFA flow in the small intestine [17]. These FA are directly absorbed in the intestine and then stored in the tissue.

According to the Australian nutrient reference standard [51], food can be labelled as a ‘source’ of n-3 if it contains at least 30 mg of EPA+DHA per standard serve and can be a ‘good source’ if it contains no less than 60 mg of EPA+DHA per standard serve. A standard serve of red meat for Australia and New Zealand is reported to be 135g [52, 53]. Thus, the total content of EPA and DHA in the LTL muscle tissue produced from lamb offered 5% canola oil (22.3 mg/100g wet tissue) and 5% flaxseed oil (22.8 mg/100g wet tissue) (Table 3) achieved 30.2 and 30.8 mg per standard serve respectively (Figure 1), and thereby readily reached the ‘source’ level of n-3, while this claimable level was not attained by muscle produced from lamb fed the control and 2.5% oil supplemented diets.

Biochemically, DPA is an intermediary between EPA and DHA in the n-3 synthesis pathway [54]. Many epidemiological studies have demonstrated that DPA consumption is positively correlated with lower platelet aggregation, lower incidence of coronary heart diseases [55, 56], improvement in lipid metabolism and inhibition of inflammation [57]. Furthermore, Lim *et al.* [58] stated that DPA improves mental health. However, the roles of DPA in human health have been largely ignored, perhaps due to its structural similarity and also it being a negligible component of commercial products such as fish oils compared to the other two n-3 LC-PUFA [59, 60]. DPA contributes approximately 30% of total n-3 LC-PUFA in our diets [7]. It can serve as a reservoir for EPA and DHA because it is either retro-converted to EPA or elongated to DHA [61, 62]. Thus, some reports have suggested that DPA should be included in LC-PUFA intake [2, 7]. Indeed, Australia and New Zealand have offered guidelines for DPA intake along with EPA and DHA [60]. Including DPA in n-3 LC-PUFA intake would boost the total n-3 LC-PUFA content produced in lamb meat to higher values [9] which is consistent with our results (Figure 1).

The levels of n-3 LC-PUFA were very low in the visceral adipose tissue of lambs receiving all experimental diets. Similar findings were observed by Bolte *et al.* [63] who investigated the effects of oilseed supplementation on lamb kidney and pelvic

fat. Meale *et al.* [64] also showed that the components of EPA, DHA and DPA in both subcutaneous and prerenal adipose tissues of lambs fed various lipid sources were negligible. This likely occurred as a result of a general predisposition of ruminants to preferentially deposit fatty acids in their tissues. Wood *et al.* [40] stated that a significant percentage (>90%) in adipose tissues is triacylglycerol which has shorter chain and more saturated FA, while the majority of lipid in muscle is phospholipid which contains a higher portion of long-chain FA and much higher levels of PUFA.

4.3. Lamb breed effects on tissue FA profiles

Breed is a major source of variation in tissue FA profile [18, 65]. The significant impacts of bovine breeds on tissue FA compositions have also been reported [66, 67]. The variations might have stemmed from differences in body fatness and cellularity of fat depots during growth [18]. De Smet *et al.* [68] and Sinclair [17] stated that the impact of genetic factors on FA composition is markedly lower than that of nutritional factors and they are difficult to interpret clearly. Therefore, although genetic effects deserve attention, future emphasis on feeds and feeding strategies is required for further understanding of the key nutritional aspects and factors influencing them in terms of diet and environment.

4.4. Effects on sensory quality

In previous studies, significant increases in muscle n-3 LC-PUFA content of lamb supplemented with vegetable oils rich in PUFA had no effect on meat sensory quality [39, 69] which is in agreement with our findings. Other studies conducted in goats and cattle also did not show any significant differences in sensory characteristics of meat when vegetable oils were included in the animal diets [70, 71]. In contrast, Francisco *et al.* [72] reported that meat obtained from lambs offered a diet supplemented with 8% flaxseed and soybean oil blend (2:1, v/v) had lower juiciness and overall liking scores, and higher scores for off-flavour in comparison with meat obtained from lambs fed 4% oil blend and non-supplemented diets. Moreover, Jaworska *et al.* [73] and Nute *et al.* [11] also studied lamb meat quality in response to supplementation with different oil sources. Their results showed that fish oil enriched diets had detrimental effects on sensory traits compared to other diets containing canola oil or flaxseed oil. They concluded that supplementing with oil enriched animal diets can alter oxidative degradation and the type of volatiles released during storage and processing, and that these outcomes were associated with a marked reduction of sensory properties in meat.

The effects of different lamb breeds on sensory meat eating quality traits are significant, although remain contradictory in the current literature. Pannier *et al.* [25] showed that sensory scores were higher in Merino lambs compared to first-cross Merino and first-cross terminal lambs. In contrast, Hopkins *et al.* [74] found that Merinos generally had lower sensory scores than first-cross terminal lambs, which is consistent with our findings. This could partly be attributed to the higher IMF percentage of crossbred lambs compared to purebred Merinos. Jandasek *et al.* [38] and Komprda *et al.* [75] reported that increased IMF levels resulted in higher scores for sensory properties. However, the mechanisms explaining the impacts on lamb meat sensory characteristics are complicated and still not fully understood [73]. The differences in meat eating quality are due to a variety of factors associated with livestock attributes such as muscle FA profile, IMF content, growth performance and maturity, which in turn, are influenced by genetics [76] and feeding regime [64].

5. Conclusions

The inclusion of 5% flaxseed oil in the pellets significantly depressed the n-6/n-3 ratio in both muscle and visceral adipose tissues. Lambs offered 5% oil supplement-ation had higher EPA+DHA and total n-3 LC-PUFA contents in the LTL muscle compared with lambs fed control pellets.

Furthermore, a standard serve (135 g) of meat produced from lambs supplemented with 5% oil in this study contained more than 30 mg of EPA+DHA and reached the claimable 'source' level of n-3 LC-PUFA. With the inclusion of DPA, the total n-3 LC-PUFA content of all experimental lambs would be a 'source' of n-3. The n-3 LC-PUFA contributed very negligible components in the visceral adipose FA profile. Oil supplementation did not cause any significant impact on total lipid percentages and sensory traits. Lamb breed influenced the IMF percentage of LTL muscle and FA profile in both tissues. It also significantly affected meat tenderness, juiciness and overall liking values. Significant interactions between oil supplementation and lamb breed on some visceral adipose FA and meat juiciness score were detected. These findings support the tested hypotheses. In conclusion, canola and flaxseed oils can be effectively used as dietary lipid sources in feedlot regimes in the Australian prime lamb industry. Purebred Merinos produce loin chops with higher EPA+DHA content but lesser tenderness and overall liking values compared to crossbred lambs. It is proposed that supplementing 5% canola oil or flaxseed oil into the diets of Australian prime lambs could considerably improve the health benefitting n-3 LC-PUFA content in their meat without detrimental impacts on sensory attributes of meat eating quality.

Competing Interest

The authors declare that they have no competing interests.

Authors' contributions

This work was carried out in collaboration between all authors. Author Don V. Nguyen ran the feeding trial, undertook the collection of experimental samples, performed laboratory analyses and wrote the first draft of the manuscript as part of his PhD project. Authors Aaron R. Flakemore, John R. Otto, Stephen W. Ives, Rowan W. Smith, Peter D. Nichols and Aduli E.O. Malau-Aduli contributed in the field, laboratory, reading and other aspects of making needed changes to the draft manuscript. Author Aduli E.O. Malau-Aduli as PhD Primary Supervisor, conceived the research idea, experimental design, wrote the funding grant, formulated the rations, linked up with commercial feed manufacturers, read and made final changes to the submitted manuscript as a research article. All authors read and approved the final manuscript.

Acknowledgements

The authors express sincere thanks to the Australian Centre for International Agricultural Research and the University of Tasmania for research scholarship funding. We are grateful to CopRice Feeds Cobden, Victoria, for producing the experimental pellets to specification. We acknowledge Tasmanian Quality Meats, Cressy, and Robinson Meats, Glenorchy, for assistance during slaughter and tissue sampling processes. Andrew Bailey, Peter Mansour, Hung Le and Quang Nguyen are thanked for their contributions and technical assistance in the field, laboratory analyses of feeds and fatty acid compositions and sensory evaluation of meat eating quality.

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Table 1. Ingredients and nutrient composition of experimental feeds

Item	Control	2.5% canola	5% canola	2.5% flaxseed	5% flaxseed	Lucerne hay
Ingredients, g/kg						
Wheat	513	537	545	551	465	–
Paddy rice	260	230	210	220	280	–
Lupins	170	151	138	147	148	–
Canola oil (ml/kg)	-	25	50		-	–
Flaxseed oil (ml/kg)	-		-	25	50	–
Salt	10	10	10	10	10	–
Limestone	21	21	21	21	21	–
Sheep premix	1	1	1	1	1	–
Ammonium sulfate	12.6	12.6	12.6	12.6	12.6	–
Acid buff	6.2	6.2	6.2	6.2	6.2	–
Sodium bicarbonate	6.2	6.2	6.2	6.2	6.2	–
Chemical compositions, % dry matter						
Dry matter, (%)	89.8	90.2	87.9	90.5	89.4	89.6
Crude protein	14.7	14.5	14.4	14.5	14.5	17.4
NDF	23.8	23.5	23.9	23.7	23.3	46.5
ADF	9.2	9.3	8.9	9.5	9.0	30.9
NFC[1]	50.5	49.9	47.8	50.5	50.7	27.4
Ether extract	4.5	4.6	4.9	4.7	5.0	2.4
Ash	8.0	7.5	8.2	7.1	6.4	7.2
ME[2], MJ/kgDM	10.8	10.9	11.1	10.8	11.0	–

[1]NFC = non-fibrous carbohydrates [NFC = 100 − (CP + NDF + EE + ash)]
[2]ME = metabolisable energy.

Table 2. Total lipid percentage (g fat/100g tissue mass), fatty acid percentage (g/100g total FA) and alpha linolenic acid (18:3n-3) content (mg/100g feed) of experimental diets

	Control	2.5% canola	5% canola	2.5% flaxseed	5% flaxseed	Lucerne hay
Lipid percentage	4.2	4.3	4.7	4.5	4.8	2.2
FA composition[1]						
14:0	0.2	0.5	0.6	0.2	0.2	0.6
15:0	0.1	0.1	0.1	0.1	0.1	0.4
16:0	18.2	16.9	16.5	19.1	19.8	29.6
17:0	0.1	0.1	0.2	0.1	0.1	0.7
18:2n-6	43.4	28.4	26.7	25.6	24.7	19.1
18:3n-3	3.5	3.6	4.3	4.9	7.2	22.1
18:1n-9	23.9	37.5	38.9	32.3	34.1	2.5
18:0	3.4	4.1	4.1	4.4	5.1	4.7
20:4n-6	ND	ND	ND	ND	ND	ND
20:5n-3	ND	ND	ND	ND	ND	ND
20:3n-6	0.3	0.4	0.4	0.4	0.5	0.4
20:4n-3	0.4	0.5	0.2	0.5	0.6	0.5
20:2n-6	0.1	0.1	0.2	0.1	0.1	0.1
20:0	0.5	0.8	0.7	0.7	0.8	1.5
22:5n-6	ND	ND	ND	ND	ND	ND
22:6n-3	ND	ND	ND	ND	ND	ND
22:5n-3	ND	ND	ND	ND	ND	ND
∑SFA	24.1	23.0	25.0	26.7	28.7	47.3
∑MUFA	27.5	42.6	43.3	36.3	37.4	9.4
∑PUFA	48.4	34.4	31.7	37.0	33.8	43.3
PUFA/SFA	2.0	1.5	1.3	1.4	1.2	0.9
∑n-3 PUFA	3.9	4.1	4.8	5.5	7.9	23.6
∑n-6 PUFA	43.8	28.8	27.4	26.0	25.3	19.4
n-6/n-3	11.1	7.0	5.7	4.7	3.2	0.8
FA content						
18:3n-3	61.1	71.3	79.4	84.1	138.2	176.2

[1]∑SFA: total saturated fatty acid includes 14:0, 15:0, 16:0, 17:0, 18:0, 20:0, 21:0, 22:0, 23:0, 24:0; ∑MUFA: total monounsaturated fatty acid includes 14:1, 16:1n-9, 16:1n-7, 16:1n-5, 16:1n-13, 17:1n-8+a17:0, 17:1, 18:1n-9, 18:1n-7, 18:1, 19:1, 20:1n-11, 20:1n-9, 20:1n-7, 20:1n-5, 22:1n-9, 22:1n-11, 22:1n-9, 24:1n-9; ∑PUFA: total polyunsaturated fatty acid includes 18:3n-6, 18:2n-6, 18:3n-3, 20:4n-3, 20:4n-6, 20:5n-3, 20:3n-6, 20:2n-6, 22:5n-6, 22:6n-3, 22:5n-3, 22:4n-6, 24:6n-3, 24:5n-3; ∑n-3

PUFA: total omega 3 PUFA includes 18:3n-3, 20:5n-3, 20:4n-3, 22:6n-3, 22:5n-3; ∑n-6 PUFA: total omega 6 PUFA includes 18:3n-6, 18:2n-6, 20:4n-6, 20:3n-6, 20:2n-6, 22:5n-6, 22:4n-6; ND: not detected

Table 3. Effects of oil supplementation and lamb breed on intramuscular fat (IMF) percentage (g fat/100g tissue mass), fatty acid composition (g/100g total FA) and content (mg/100g wet tissue) on *Longissimus thoracis et lumborum* muscle

	Treatment					Breed[1]			SEM[2]	P value[3]		
	Control	2.5% canola	5% canola	2.5% flaxseed	5% flaxseed	MxM	CxM	WxC		T	B	TxB
IMF percentage	2.9	3.1	3.4	3.2	3.3	2.6^{b}	3.4^{a}	3.5^{a}	0.18	NS	*	NS
FA composition[4]												
14:0	1.5	1.6	1.8	2.1	1.4	1.4^{b}	2.2^{a}	1.6^{b}	0.12	NS	*	NS
15:0	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.02	NS	NS	NS
16:0	21.7	22.3	21.5	23.7	21.8	21.6^{b}	23.6^{a}	21.6^{b}	0.36	NS	*	NS
17:0	1.2^{a}	1.1^{ab}	1.0^{b}	1.0^{b}	1.0^{b}	1.1	1.1	1.0	0.03	*	NS	NS
18:2n-6	6.7	5.7	6.5	5.1	5.9	6.5^{a}	4.8^{b}	6.4^{a}	0.26	NS	*	NS
18:3n-3	1.5	1.6	1.5	1.5	2.0	1. 7	1.4	1.7	0.10	NS	NS	NS
18:1n-9	33.2	35.8	33.0	34.9	32.3	34.0	34.6	33.0	0.53	NS	NS	NS
18:0	16.5	15.3	16.4	15.7	16.3	15.0	16.2	16.7	0.35	NS	NS	NS
20:4n-6	1.5	1.4	1.7	1.1	1.6	1.6	1.2	1.6	0.10	NS	NS	NS
20:5n-3 (EPA)	0.6	0.6	0.8	0.6	0.8	0.9^{a}	0.4^{b}	0.7^{ab}	0.06	NS	**	NS
20:3n-6	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.02	NS	NS	NS
20:4n-3	0.6	0.6	0.7	0.5	0. 7	0.7	0.5	0.7	0.05	NS	NS	NS
20:2n-6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	NS	NS	NS
20:0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.00	NS	NS	NS
22:5n-6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	NS	NS	NS
22:6n-3 (DHA)	0.1	0.2	0.2	0.2	0.2	0.3^{a}	0.1^{b}	0.2^{ab}	0.02	NS	*	NS
22:5n-3 (DPA)	0.6	0.6	0.7	0.6	0.7	0.8^{a}	0. 5^{b}	0.7^{ab}	0.05	NS	*	NS
∑SFA	43.0	42.0	42. 8	44.4	42.4	40.9^{c}	45.1^{a}	43.0^{b}	0.44	NS	***	NS
∑MUFA	43.4	45.3	43.4	44.7	43.6	44.5	44.6	43.2	0.44	NS	NS	NS
∑PUFA	13.6	12.7	13.8	10.9	14.0	14.6^{a}	10.3^{b}	13.8^{a}	0.60	NS	*	NS
PUFA/SFA	0.3	0.3	0.3	0.2	0.3	0.4^{a}	0.2^{b}	0.3^{a}	0.02	NS	*	NS
∑n-3 PUFA	3.4	3.7	3.9	3.3	4.5	4.4^{a}	2.9^{b}	4.0^{a}	0.21	NS	*	NS
∑n-6 PUFA	8.7	7. 7	8.6	6.5	8.0	8.6^{a}	6.4^{b}	8.5^{a}	0.38	NS	*	NS
n-6/n-3	2.6^{a}	2.3^{ab}	2.2^{ab}	2.0^{b}	1.8^{b}	2.1	2.2	2.2	0.09	*	NS	NS
FA content												
18:3n-3	24.9	39.2	36.7	40.8	49.3	33.2	48.0	37.4	3.75	NS	NS	NS
20:4n-6	24.9^{b}	32.1^{ab}	36.8^{a}	29.2^{ab}	33.9^{ab}	29.4	35.6	31.9	1.50	*	NS	NS
EPA	11.3^{b}	13.1^{ab}	17.0^{a}	14.2^{ab}	17.9^{a}	16.9^{a}	14.0^{b}	13.5^{b}	0.85	*	*	NS
22:5n-6	1.1	1.9	1.2	1.9	1.3	1.1	1.9	1.5	0.18	NS	NS	NS
DHA	2.8^{b}	4.5^{a}	5.3^{a}	4.2^{a}	4.9^{a}	5.2^{a}	3.9^{b}	4.1^{b}	0.30	*	*	NS
DPA	10.8^{b}	13.4^{ab}	16.3^{a}	13.8^{ab}	15.6^{a}	14.0	14.9	13.5	0.68	*	NS	NS
EPA+DHA	14.1^{b}	17.6^{ab}	22.3^{a}	18.4^{ab}	22.8^{a}	22.1^{a}	17.0^{b}	17.5^{b}	1.10	**	*	NS
EPA+DHA+DPA	24.9^{b}	30.9^{ab}	38.7^{a}	32.2^{ab}	38.4^{a}	36.1	32.8	31.0	1.72	**	NS	NS

[1]CxM: Corriedale x Merino; MxM: Merino x Merino; WxC: White Suffolk x Corriedale.

[2] SEM: Standard error of the mean.

[3]Row means bearing different superscripts within a fixed factor significantly differ (P<0.05); T: Treatment; B: Breed; NS: not significant (P > 0.05); * P < 0.05; ** P < 0.01; *** P < 0.001.

[4]Fatty acid groupings used are as indicated in Table 2; EPA: eicosapentaenoic acid; DPA: docosapentaenoic acid and DHA: docosahexaenoic acid.

Table 4. Variation in total lipid percentage (g fat/100g tissue mass), fatty acid compositions (g/100g total FA) and contents (mg/100g wet tissue) in visceral adipose tissue as influenced by oil supplementation and lamb breed

	Treatment					Breed[1]			SEM[2]	P value[3]		
	Control	2.5% canola	5% canola	2.5% flaxseed	5% flaxseed	MxM	CxM	WxC		T	B	TxB
Lipid percentage	76.5	78.4	81.5	77.0	79.5	77.8	79.6	78.2	2.64	NS	NS	NS
FA composition[4]												
14:0	2.7	2.6	2.8	2.7	2.4	2.5^{b}	3.1^{a}	2.4^{b}	0.12	NS	*	*
15:0	0.7	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.02	NS	NS	NS
16:0	23.9	22.7	22.3	23.2	23.7	23.3	23.4	22.8	0.26	NS	NS	*
17:0	1.9	1.5	1.7	1.7	1.5	1.8^{a}	1.7^{ab}	1.4^{b}	0.07	NS	*	NS
18:2n-6	3.0	4.1	3.6	3.1	3.4	3.4	3.6	3.2	0.17	NS	NS	NS
18:3n-3	1.2^{b}	1.6^{ab}	1.9^{ab}	1.9^{ab}	2.6^{a}	1.9	1.6	2.0	0.10	*	NS	NS
18:1n-9	23.7	24.3	23.5	23.0	23.0	22.9	24.1	23.5	0.33	NS	NS	NS
18:0	26.4	26.1	23.8	25.4	23.1	24.4	24.9	25.5	0.49	NS	NS	NS
20:4n-6	0.08	0.06	0.06	0.06	0.06	0.07^{a}	0.06^{ab}	0.05^{b}	0.01	NS	*	NS
20:5n-3 (EPA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	NS	NS	NS
20:3n-6	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.002	NS	NS	NS
20:4n-3	ND	ND	ND	ND	ND	ND	ND	ND				
20:2n-6	0.02	0.07	0.07	0.07	0.05	0.05	0.04	0.07	0.01	NS	NS	NS
20:0	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.01	NS	NS	NS
22:5n-6	0.08	0.07	0.10	0.10	0.07	0.04^{b}	0.13^{a}	0.08^{ab}	0.01	NS	**	NS
22:6n-3 (DHA)	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.003	NS	NS	NS
22:5n-3 (DPA)	0.05^{b}	0.09^{ab}	0.09^{ab}	0.10^{ab}	0.12^{a}	0.09	0.09	0.09	0.003	*	NS	*
∑SFA	57.5^{a}	55.3^{ab}	52.9^{b}	55.5^{ab}	52.8^{b}	54.6	55.4	54.4	0.68	*	NS	NS
∑MUFA	37.3	38.2	40.5	37.8	38.0	38.7	38.4	38.1	0.55	NS	NS	NS
∑PUFA	5.2^{b}	6.5^{ab}	6.6^{ab}	6.7^{ab}	9.2^{a}	6.7	6.2	7.5	0.21	*	NS	NS
PUFA/SFA	0.09^{b}	0.12^{ab}	0.13^{ab}	0.11^{ab}	0.17^{a}	0.12	0.11	0.14	0.01	*	NS	NS
∑n-3 PUFA	1.3^{b}	1.7^{ab}	2.0^{ab}	2.0^{ab}	2.7^{a}	2.0	1.6	2.1	0.06	*	NS	NS
∑n-6 PUFA	3.1	4.3	3.9	3.4	3.6	3.6	3.9	3.5	0.17	NS	NS	NS
n-6/n-3	2.4^{a}	2.5^{ab}	2.0^{ab}	1.7^{ab}	1.4^{b}	1.8	2.4	1.7	0.38	*	NS	NS
FA content												
18:3n-3	338.6^{b}	504.6^{ab}	601.7^{ab}	632.7^{ab}	696.1^{a}	570.9	493.0	591.7	55.42	*	NS	NS
20:4n-6	32.6	25.4	27.5	25.5	27.1	32.1^{a}	30.7^{ab}	19.8^{b}	2.08	NS	*	NS
EPA	5.7	5.1	5.8	5.9	5.8	5.0	5.8	6.2	0.23	NS	NS	NS
22:5n-6	26.0	28.9	35.5	34.6	25.0	12.5^{b}	48.7^{a}	28.6^{b}	2.94	NS	**	*
DHA	4.2	4.8	4.5	5.4	4.3	4.3	4.7	4.9	0.23	NS	NS	NS
DPA	16.4^{b}	24.6^{ab}	27.2^{ab}	33.9^{ab}	38.1^{a}	29.6	27.9	26.6	2.44	**	NS	*
EPA+DHA	9.9	9.9	10.4	11.3	10.1	9.3	10.4	11.0	0.33	NS	NS	NS
EPA+DHA+DPA	26.3^{b}	34.5^{ab}	37.6^{ab}	45.2^{ab}	48.2^{a}	38.9	38.3	37.6	2.71	**	NS	*

[1]CxM: Corriedale x Merino; MxM: Merino x Merino; WxC: White Suffolk x Corriedale.

[2] SEM: Standard error of the mean.

[3]Row means bearing different superscripts within a fixed factor significantly differ ($P<0.05$); T: Treatment; B: Breed; NS, not significant ($P > 0.05$); * $P < 0.05$; ** $P < 0.01$.

[4]Fatty acid groupings used are as indicated in Table 2; EPA: eicosapentaenoic acid; DPA: docosapentaenoic acid and DHA: docosahexaenoic acid.

Table 5. The effect of omega-3 supplementation and lamb breed on loin chop sensory characteristics

		Tenderness	Juiciness	Flavour	Overall liking
Treatment	Control	7.1	7.2	7.4	7.2
	2.5% canola	7.3	7.4	7.5	7.4
	5% canola	7.0	7.3	7.2	7.2
	2.5% flaxseed	7.2	7.1	7.3	7.2
	5% flaxseed	6.9	7.2	7.4	7.0
Breed[1]	MxM	6.9[b]	6.9[b]	7.2	7.0[b]
	CxM	7.2[a]	7.4[a]	7.4	7.2[ab]
	WxC	7.2[a]	7.3[a]	7.5	7.4[a]
SEM[2]		0.07	0.06	0.06	0.06
P value[3]	Treatment	NS	NS	NS	NS
	Breed	*	***	NS	*
	TxB	NS	*	NS	NS

[1]CxM: Corriedale x Merino; MxM: Merino x Merino; WxC: White Suffolk x Corriedale.
[2] SEM: Standard error of the mean.
[3]Row means bearing different superscripts within a fixed factor significantly differ (P<0.05); TxB: Treatment x Breed; NS, not significant (P > 0.05); * P < 0.05; *** P < 0.001.

Table 6. Effect of supplementing lambs with vegetable oils on the long-chain polyunsaturated fatty acid percentage of *Longissimus* muscle (g/100 g total fatty acids) and n-6/n-3 ratio[¥]

Oil source	Duration (week)	EPA	DPA	DHA	n-6/n-3	Reference
Control[1]	5	0.11	0.14	0.05	13.4	Urrutia *et al.* [45]
5% flaxseed	5	0.12	0.13	0.02	6.47	Urrutia *et al.* [45]
10% flaxseed	5	0.15	0.11	0.03	5.37	Urrutia *et al.* [45]
Control[2]	8	0.07	0.20	0.04	5.28	Noci *et al.* [12]
6% flaxseed	8	0.12	0.21	0.03	1.75	Noci *et al.* [12]
Basal diet[3]	6	0.38	0.70	0.24	6.18	Jerónimo *et al.* [44]
6% sunflower and flaxseed (1:2, v/v)	6	0.59	0.73	0.23	2.54	Jerónimo *et al.* [44]
Control[4]	6	0.07	0.06	0.31	NA	Radunz *et al.* [13]
3% soybean and flaxseed (2:1, v/v)	6	0.04	0.02	0.32	NA	Radunz *et al.* [13]
Control[5]	7	0.19	0.46	0.14	7.04	Jerónimo *et al.* [37]
6% flaxseed	7	0.50	0.54	0.20	1.60	Jerónimo *et al.* [37]

[¥]NA: data not available; EPA: eicosapentaenoic acid; DPA: docosapentaenoic acid; DHA: docosahexaenoic acid.
[1]The control diet was mainly composed of soybean meal and barley
[2]The control diet was based on Megalac (palm-oil based high in 16:0).
[3]The basal diet was composed of manioc and dehydrated lucerne
[4]The control diet contained mainly ground corn, alfalfa and soybean meal
[5]The control diet was sunflower based.

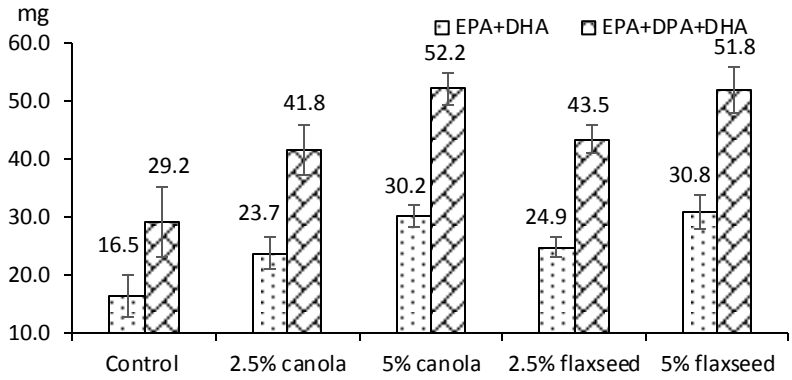

Figure 1: The absolute total contents of EPA+DHA and EPA+DHA+DPA in *Longissimus thoracis et lumborum* lamb muscle in a per standard serve (135 g) (EPA: eicosapentaenoic acid; DPA: docosapentaenoic acid and DHA: docosahexaenoic acid).

