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Health beneficial long chain omega-3 fatty acid levels in Australian lamb managed under extensive finishing systems☆

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ABSTRACT

The variation in levels of the health claimable long chain omega-3 fatty acids, eicosapentaenoic acid (EPA, 20:5n-3) plus docosahexaenoic acid (DHA, 22:6n-3) across production regions of Australia was studied in 5726 lambs over 3 years completed in 87 slaughter groups. The median level of EPA plus DHA differed dramatically between locations and sometimes between slaughters from the same location. The ratio of EPA plus DHA from lambs with high values (97.5% quantile) to lambs with low values (2.5% quantile) also differed dramatically between locations, and between slaughters from the same location. Consistency between years, at a location, was less for the high to low value ratio of EPA plus DHA than for the median value of EPA plus DHA. To consistently obtain high levels of omega-3 fatty acids in Australian lamb, there must be a focus on lamb finishing diets which are likely to need a supply of α-linolenic acid (18:3n-3), the precursor for EPA and DHA.

1. Introduction

The value of meat to the purchaser is mostly dependent on eating quality, keeping quality and nutritional value. All these can be influenced by nutrition and the genetic background (Warner, Greenwood, Pethick, & Ferguson, 2010) and the former two also by chilling and processing methods (Hopkins, 2010). Fatty acids in meat, along with minerals including trace elements and vitamins, are vital components that contribute to the nutrient value of meat in terms of physiological and biochemical functions. These components can be influenced by genetics and nutrition. Among fatty acid major groups, polyunsaturated fatty acids such as omega-3 (n-3) and omega-6 (n-6) in foods have been highlighted due to their anti- and pro-effects on inflammatory and autoimmune diseases, respectively (McAfee et al., 2010; Palmquist, 2009; Simopoulos, 2002).

According to Australian standards, to claim meat as a source of omega-3, it needs to have 30 mg of long chain omega-3 fatty acids per 100 g of meat in the form of eicosapentaenoic acid (EPA) or docosahexaenoic acid (DHA). By contrast, the European standard for a source of omega-3 is 40 mg per 100 g (Commission Regulation (EU), 2010). Lamb production in Australia and some other countries is primarily based on year round extensive finishing systems. Under these finishing systems, animals are often finished on widely differing diets. These diets include both irrigated and dryland pasture, green and senesced pasture as well as feed supplements including hay, grain legumes, cereal grains, oil seed by-products or crop residues (e.g. Dixon & Stockdale, 1999; Hopkins, Beattie, & Pirlot, 1995; Hopkins, Holst, & Hall, 1995). It is known that diet has a major effect on polyunsaturated fats in meat (Daley, Abbott, Doyle, Nader, & Larson, 2010; Simopoulos, 1999). Pannier et al. (2010) reported that extensive lamb production sometimes produces meat with high levels of long chain omega-3 fatty acids, but not always. This is not surprising because of the wide range of finishing diets used in extensive grazing systems.

Ponnampalam et al. (2014) showed that, under production systems that finish lambs at similar live weights, the largest systematic sources of variation in EPA plus DHA concentrations were 1) variation between location and slaughter time within location and 2) differences between slaughter times in the amount of between animal variation. Other

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sources of systematic variation such as genetics (sire, dam and breed effects), rearing type (singles versus multiples) and gender were much smaller. We would suggest that, from a practical point of view, these latter sources of variation of EPA plus DHA can be ignored when finishing lambs in extensive grazing systems.

The present paper documents 1) variation between location and slaughter times within location and 2) differences between slaughter times in the amount of between animal variation for EPA plus DHA. It covers 87 slaughter times from 3 matings (across 3 years) of 8 commercial-like lamb production locations in the wheat-sheep and high rainfall grazing zones (ABARE, 2003) of Australia. At each slaughter time the lambs were slaughtered at a similar target carcass weight (about 21–22 kg). The present study discusses the characteristics of those locations that were able to maintain higher levels of EPA plus DHA over a 3 year production period (2007–2010).

2. Materials and methods

2.1. Experimental design and sample collection and measurement

This large research study was approved by 5 respective Animal Experimentation Committees across 4 states of Australia. van der Werf, Kinghorn, and Banks (2010) describe fully the design of the experiment from which the lambs were sourced for the current work, including the procedure used to select the sires for AI mating with the flocks' base ewes. Sires were selected from a range of breeds used in the Australian sheep industry (Merino, maternal and terminal meat breeds). The base ewes, depending on the research site usually consisted of approximately 80% Merino ewes and 20% Border Leicester × Merino ewes. Lambs were generally maintained under extensive pasture conditions at 8 lamb production sites, but were fed grain, hay or feedlot pellets when the supply was limited (Table 1). In Table 1 early post-weaning is the feed availability to lambs during the first half of the period since lambs were separated from dams before slaughter and late post-weaning is the feed availability to lambs during the second half of the period before slaughter, respectively. Lambs were slaughtered in three consecutive years, with between 28 and 30 kills in each year. The slaughter procedure has been reported elsewhere (Pannier, Pethick, Geesink, Ball, Jacob, & Gardner, 2014). In brief, during the years 2008–2010, *longissimus lumborum* (LL) muscle samples from approximately 5726 lambs were collected at 24 h post-mortem. There were several slaughter occasions (kills) at each location in each year (Fig. 1).

These LL samples (~20 g) were dissected without any visible external fat (subcutaneous), freeze dried and ground using a FOSS Knifetech™ 1095 sample mill (FOSS Pacific, Unit 2, 112–118 Talavera Road, North Ryde, NSW 2113). The same grinding equipment was used across all laboratories. A homogeneous 0.5 g ground sample was used for fatty acid extraction, methylation and quantification by gas chromatography as described by Ponnampalam et al. (2014), a rapid modified procedure developed from the method reported by O'Fallon, Busboom, Nelson, and Gaskins (2007). One hundred μL of nonadecanoic acid methyl ester (C19:0, Sigma Aldrich Pty Ltd, Castle Hill, NSW 2154, Australia) was added to muscle samples as an internal standard dissolved in chloroform (10 mg C19:0/mL $CHCl_3$). The contents were hydrolysed using 0.7 mL of 10 N KOH in water and 5.3 mL of methanol to form free fatty acids. After mixing well with a vortex, the contents were incubated at 55 °C for 1.5 h, with vigorous mixing at 20 min intervals and then cooled to room temperature using tap water. Upon cooling, the contents were mixed with 0.6 mL of 24 N sulphuric acid in water and the mixing, incubation and cooling process occurred as above. After cooling the tubes to room temperature, the fatty acid methyl ester (FAME) was separated with 1 mL of hexane solvent by mixing for 5 min and centrifuging at 2000 rpm for 10 min. Two hundred μL of hexane containing FAME was collected into a Gas Chromotograph (GC) vial and fatty acid fractions were quantified by capillary GC (HP INNOWAX 60 m × 0.25 mm, 0.5 μm, Agilent J & W Scientific, Santa Clara, CA, USA).

Samples collected from the 8 sites were systematically allocated in order of sample to three laboratories for sample processing and fatty acid determination. For 2008 born progeny, muscle samples were distributed to three laboratories (Department of Primary Industries, Victoria; Food & Agriculture, Western Australia; and Commonwealth Scientific International Research Organisation, Western Australia) for fatty acid determination. For 2009 and 2010, samples were analysed at the latter two laboratories. Each laboratory followed the same procedures, columns and temperature setup. Calibration was achieved by testing the same pool sample 10 times each year. A variation of less than 5% between laboratories was maintained in the current study. All fatty acid peaks were identified using a reference standard (Supelco C4–C24 mix, Sigma Aldrich Pty Ltd, NSW 2154, Australia), which was run in each batch. Fatty acid levels in the muscles are reported in mg/100 g meat. Before reporting, fatty acid traces from each year were tabulated, tested for outliers, and analysed for predicted means of EPA (20:5n-3) and DHA (22:6n-3). The total amount of EPA and DHA (EPA plus DHA) was calculated as the sum from the total fatty acid profiles of GC quantification.

2.2. Statistical analysis

Our approach was to firstly develop a statistical model for EPA plus DHA that took into account the variances and covariances that are induced by the effects of sires, dams and the between lamb variation. It was important to allow the between lamb variation to differ with each slaughter time within each location (Ponnampalam et al., 2014). Using this statistical model, the median value of EPA plus DHA at each location and slaughter time was calculated; this represents the value of EPA plus DHA for a typical lamb. The model was further used to calculate, for each site and location, the ratio of a large EPA plus DHA lamb (with only 2.5% of lambs having a greater value) compared to a small EPA plus DHA lamb (with only 2.5% of lambs having a lower value). For instance, if lambs with greater EPA plus DHA concentrations had twice the level of EPA plus DHA than lambs with lower EPA plus DHA concentrations then the ratio will be 2. Finally the ratio for each location and slaughter time was plotted against the median for each location and slaughter time, which allows identification of site and slaughter time combinations for which a *typical* lamb has EPA plus DHA > 23 mg/100 g (which is equivalent to >30 mg per 135 g serving) and site and slaughter time combinations for which *most* lambs have EPA plus DHA > 23 mg/100 g. Details of these analyses are given in the next two paragraphs.

The natural logarithm of EPA plus DHA was analysed as a restricted maximum likelihood (REML) model with a fixed effect for each location by slaughter time combination, random effects for sire identity and dam identity and a separate residual variance for each location by slaughter time combination. A logarithmic transformation was chosen so that the between sire variance was similar at kills with both low and high values of EPA plus DHA. Chi square change in deviance tests were used to examine the necessity of including various effects in the model. Only one of 5726 lambs with necessary measurements was excluded as a statistical outlier.

The median EPA plus DHA concentration for each location by slaughter time combination was obtained from the predicted mean value on the logarithmic scale and back-transforming. Asymptotic normal confidence intervals were calculated on the logarithmic scale and then back transformed to the original scale. The residual variation for each location by slaughter time combination is summarised as the ratio of EPA plus DHA from lambs with high values (97.5% quantile of EPA plus DHA) to lambs with low values (2.5% quantile of EPA plus DHA). The ratio is calculated as $\exp(2 \times 1.96 \times \sigma)$, where exp denotes the exponential function and σ is the estimated residual standard deviation obtained for a location by slaughter time combination using the REML analysis. Confidence

Table 1
The nutritional history of 2007/08, 2008/09 and 2009/10 born cohort lamb progenies from 8 production sites in Australia.

Sites (flock)	Slaughter number	Early post-weaning		Late post-weaning	
		Pasture	Concentrate	Pasture	Concentrate
Kirby					
2007/2008	Kills 1, 2 and 3	Green pasture (native grass/perennial grass)	Not provided	Native grass/perennial grass (dry)	Feedlot pellets 2–3 months
2008/2009	Kills 1, 2 and 3	Native grass/perennial grass/white clover	Not provided	Native grass/perennial grass (dry)	Feedlot pellets
	Kill 4	Native grass/perennial grass (dry)	Feedlot pellets plus barley	Native grass/perennial grass (dry)	Feedlot pellets plus barley
2009/2010	Kills 1, 2, 3 and 4	Improved perennial pasture	Lupin	Grazing oats	Feedlot pellets
Trangie[a]					
2007/2008	No kills	N/A	N/A	N/A	N/A
2008/2009	Kills 1, 2 and 3	Native pasture (windmill, spear, barley grass)	Oat grain/pellets/lucerne hay	Windmill, barley grass etc. (green and dry)	Feedlot pellets
2009/2010	Kills 1 and 2	Perennial ryegrass, fescue, phalaris	Barley (40 g/h/d)	Perennial ryegrass, fescue, phalaris	Oat grain at low levels
	Kill 3	Perennial ryegrass, fescue, phalaris	Barley (40 g/h/d)	Lucerne	Oat grain up to 600 g/day
Cowra					
2007/2008	Kills 1, 2, 3, 4 and 5	Lucerne pasture	Not provided	Desiccating Lucerne	Feedlot pellets for 2 months
2008/2009	Kills 1, 2 and 3	Lucerne and perennial pastures	Not provided	Desiccating lucerne and native pasture	Not provided
2009/2010	Kills 1 and 2	Stalky perennial pastures, 60% green	Oat and lupin grains (200 g/h/d)	Stubbles due to drought conditions	Oat and lupin grains (1050 g/h/d)
	Kill 3	Stalky perennial pastures, 60% green	Oat and lupin grains (200 g/h/d)	Forage oats (1000–1200 kg DM/Hec)	Oat and lupin grains (375 g/h/d)
Rutherglen					
2007/2008	Kills 1, 2, 3 and 4	Lucerne and annual ryegrass pasture	Not provided	Lucerne and annual ryegrass pasture	Not Provided
	Kill 5	Lucerne and annual ryegrass pasture	Not provided	Lucerne and annual ryegrass (dry)	Feedlot pellets last one month
2008/2009	Kills 1, 2, 3 and 4	Annual ryegrass/lucerne/phalaris pasture	Cereal/canola hay	Annual ryegrass/lucerne/clover	Cereal/canola hay
2009/2010	Kills 1, 2, 3 and 4	Annual ryegrass, lucerne, phalaris pasture	Triticale and silage	Lucerne pasture	Grains only mid Jan. to end of Feb. 2010
Hamilton					
2007/2008	Kills 1, 2, and 3	Triticale and hay	Feedlot pellets	Triticale and hay	Feedlot pellets
	Kill 4	Perennial pasture-ryegrass	Feedlot pellets	Lucerne and ryegrass	Feedlot pellets in small amount
2008/2009	Kills 1, 2 and 3	Perennial pasture-ryegrass	Barley 3 kg/wk/head	Rape and millet forage crop	Barley 4 kg/wk/head
	Kill 4	Perennial pasture-ryegrass	Barley 3 kg/wk/head	Green pasture ryegrass, tall fescue	Barley 4 kg/wk/head
2009/2010	Kills 1, 2, 3 and 4	Lucerne and chicory	Not provided	Rape and millet forage crop	Not provided
Struan					
2007/2008	Kills 1, 2, 3 and 4	Irrigated ryegrass pasture	Not provided	Irrigated ryegrass pasture	Not provided
	Kill 5	Irrigated ryegrass pasture	Not provided	Senesced ryegrass pasture	Barley & beans (2–4 months)
2008/2009	Kills 1 and 2	Irrigated ryegrass pasture	Not provided	Irrigated ryegrass pasture	Not provided
	Kill 3	Irrigated ryegrass pasture	Not provided	Senesced ryegrass pasture	Lentil/barley/silage
2009/2010	Kills 1 and 2	Irrigated ryegrass pasture	Not provided	Irrigated ryegrass pasture	Nil (kill 1) to 36 days feedlot (kill 2)
	Kills 3 and 4	Irrigated ryegrass pasture	Not provided	No pasture provided	3–4 months feedlot pellets
Turretfield					
2007/2008	Kill 1	Green ryegrass pasture	Not provided	Dry ryegrass pasture and barley stubble	Not provided
	Kills 2, 3 and 4	Green ryegrass pasture	Not provided	Dry ryegrass pasture and barley stubble	Barley and lupins 3–5 months
2008/2009	Kills 1 and 2	Windrowed ryegrass and wild oats	Barley/pea (0.25 kg/hd/d)	Dry ryegrass pasture and barley stubble	Barley/pea mix (0.5–0.75 g/hd/d)
	Kill 3	Windrowed ryegrass and wild oats	Barley/pea (0.40 kg/hd/d)	Feedlot pellets	Barley/pea mix and hay — *ad libitum*
2009/2010		Mix of ryegrass, clover, barley grass	Oat/pea or barley/pea mix	Pea stubbles and crop residues	Barley/pea mix (Jan 10) feedlot (April)
Katanning					
2007/2008	Kills 1, 2, 3 and 4	Annual grass and sub-clover	Not provided	Green to senesced pasture	Lupin, oat grains for 1–3 months
2008/2009	Kills 1, 2, 3 and 4	Annual grass and sub-clover	Lupin, oat grains (1–3 months)	Green to senesced pasture	Lupin, oat grains for 1–3 months
	Kill 5	Annual grass and sub-clover	Not provided	Annual grass and sub-clover	Not provided
2009/2010	Kills 1, 2 and 3	Annual grass and sub-clover	Lupin and oat grains (60:40)	senesced annual grass and sub-clover	Lupin and oat grains (60:40)

[a] There was no 2007/08 cohort at the Trangie site.

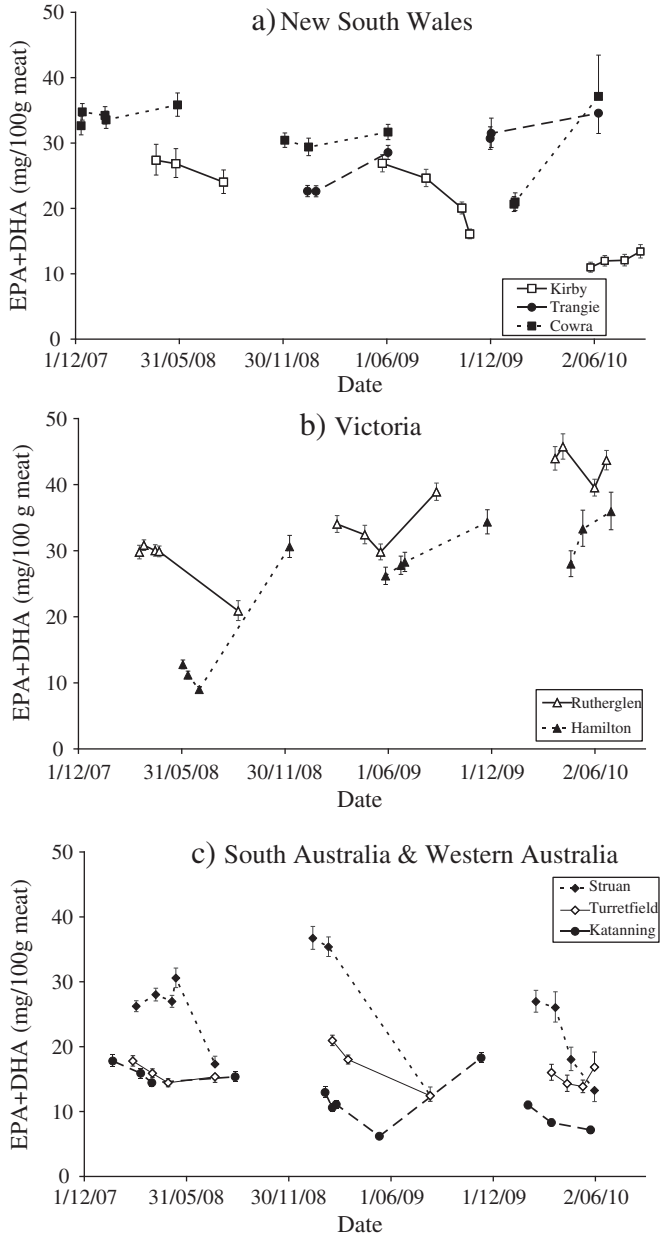

Fig. 1. a–c. The predicted median concentration of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in meat for each slaughter from 8 locations, over 3 consecutive years. Each symbol represents a slaughter date. The median EPA plus DHA for each location by slaughter time combination were obtained from the predicted mean value on the logarithmic scale and back-transformed. Error bars are 95% confidence intervals. For graphical clarity, in some cases only one side of the confidence interval is shown.

intervals for the ratio were calculated using the asymptotic normal approximation for each σ and back-transforming to the ratio scale. A line showing how the ratio and median relate when exactly 95% of lambs at a slaughter time have EPA plus DHA < 23 mg/100 g (which is equivalent to 30 mg per 135 g serving) is calculated as follows.

$$\text{Ratio} = \exp((2 \times 1.96 \times (\ln(23) - \ln(\text{median}))) / \Phi^{-1}(0.95))$$

where ln denotes the natural logarithm and Φ^{-1} denotes the inverse of the Gaussian distribution function.

3. Results

The target weight of 21–22 kg was not always achieved. Nevertheless, the average carcass weight of most slaughter times from the 8 locations was between 20 and 25 kg.

Terms for separate residual variation at each slaughter time within a site ($P = 2 \times 10^{-179}$) and sire identity ($P = 3 \times 10^{-41}$) were necessary to model the correlation structure of the data. The dam identity effect was only significant at the 0.07 level. However, a conservative approach for retaining dam identity effects was taken. There was no indication that the sire effect differed with location ($P = 0.27$ for test that sire correlation differs from 1) or the dam effect differed with year ($P = 0.52$), and thus terms for these effects were not included in the random components of the statistical model.

The median level of EPA plus DHA differed appreciably between locations, and sometimes between slaughter times from the same location (P less than 1×10^{-250}, Fig. 1). There was a moderate degree of consistency between the 3 years at most locations, although the median EPA plus DHA of Kirby was substantially lower in the third year than the first and second years (Fig. 1a), and the EPA plus DHA of Hamilton was substantially lower in the first year than the latter 2 years (Fig. 1b). The short 95% confidence intervals in Fig. 1 indicate that the medians are, effectively, known without error.

The ratio of EPA plus DHA from lambs with high values (97.5% quantile) to lambs with low values (2.5% quantile) also differed appreciably with slaughter times, both within and between locations (Fig. 2). These ratios summarise the variation between lambs within slaughter cohorts. The 95% confidence intervals indicate that most of these ratios are known with only moderate error. The degree of consistency between years, at a location, was much less for the high to low value ratio of EPA plus DHA (Fig. 2) than for the median value of EPA plus DHA (Fig. 2).

There was no clear relationship of the median EPA plus DHA to the high to low ratio of EPA plus DHA for the 87 slaughter times at 8 production locations (Fig. 3). Only 2 locations (Turretfield and Katanning) had all slaughter times with the typical (median) lamb having EPA plus DHA less than 23 mg/100 g meat. However, all of the 8 locations had at least some slaughter times where the typical (median) lamb had an EPA plus DHA less than 23 mg/100 g meat (i.e., 30 mg per 135 g serving). At 2 production locations (Rutherglen and Cowra) among the eight sites it was estimated that, at the majority of slaughter times, more than 95% of lambs had EPA plus DHA greater than 23 mg/100 g meat (Fig. 3). At these slaughter times the animals grazed lucerne (*Medicago sativa*) pasture late post-weaning in most years (Table 1). At these two locations, when a lucerne finishing option was not used during late post-weaning most lambs had an EPA plus DHA level less than 23 mg/100 g.

4. Discussion

The requirements for making claims or statements about foods having high levels, or being sources, of omega-3 fatty acids will differ in different parts of the world according to the food standards and the regulations they maintain. For example, in Australia and New Zealand a food can legally be claimed to be a source of omega-3 fatty acids if EPA plus DHA is greater than 30 mg per serving of that food (FSANZ, 2012), which provides 22% of the daily adequate intakes of omega-3 in the form of EPA plus DHA as recommended by the Food and Nutrition Board, USA 2002. The Australian Guide to Healthy Eating suggests 65–100 g of cooked meat as a serve (http://www.health.gov.au/internet/main/publishing.nsf/content/E384CFA588B74377CA256F190004059B/$File/fd-cons.pdf), which equates to 93–143 g of fresh meat. For illustrative purposes, the present study considers 135 g of meat to be a serve, a value used in some previous studies (Pannier et al., 2010). Thus lamb with EPA plus DHA > 23 mg/100 g meat will meet this Australian and New Zealand standard. While standards in other countries will vary, the principles of meeting those standards will apply universally. This study has focussed on the loin muscle (LL) because this muscle is the largest and most valuable in the carcase and also because a range of other traits were tested on the muscle (e.g. IMF, minerals, colour, shear force).

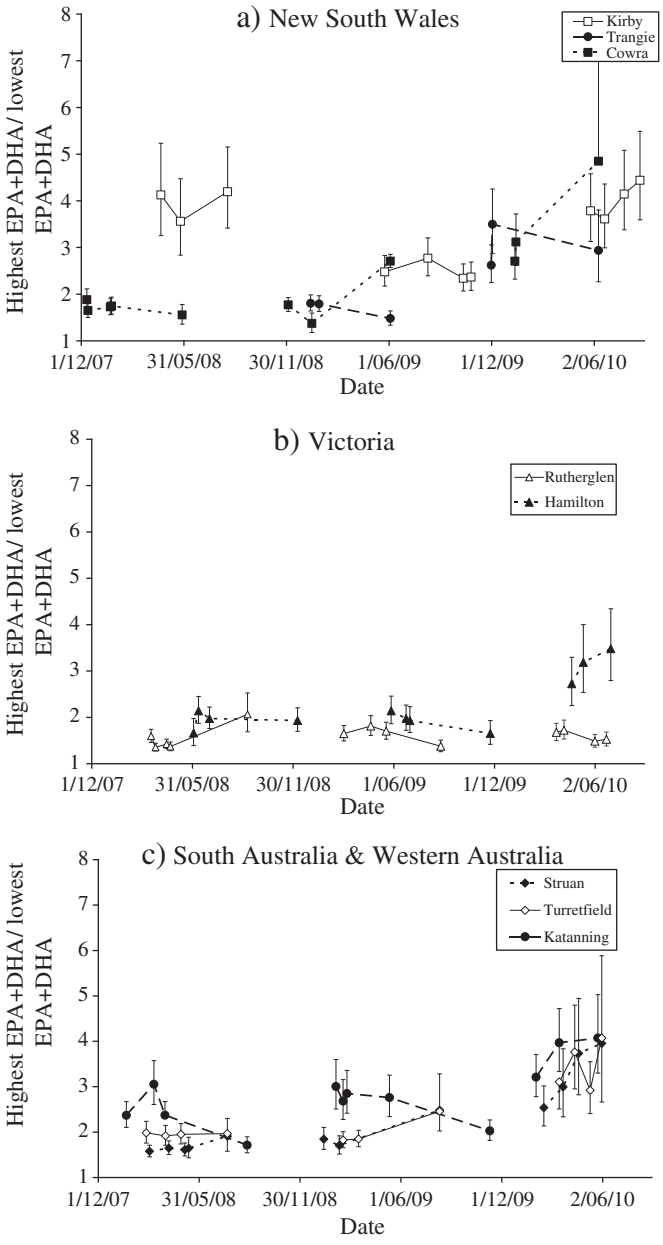

Fig. 2. a–c. Ratio of high value (97.5% quantile) of eicosapentaenoic acid (EPA) plus docosahexaenoic acid (DHA) to low EPA plus DPA value (2.5%) in meat for each slaughter from 8 locations over 3 consecutive years. Each symbol represents a slaughter date. Error bars are 95% confidence intervals. For graphical clarity, in some cases only one side of the confidence interval is shown.

In about one half of slaughter times the typical (median) lamb loin had EPA plus DHA levels greater than 23 mg/100 g meat, but in only about 25% of slaughter times did the large majority (95%) of lambs produce EPA plus DHA above this level. This indicates that meat from many slaughters of Australian lamb achieves health claimable levels of omega-3 fatty acids, but certainly not the majority. In order for Australian lamb cohorts to achieve health claimable levels of omega-3, lambs need to have both a high average level of omega-3 fatty acids and a lower variability between lambs in omega-3 fatty acids as indicated in the lower right hand section of in Fig. 3. Average levels and variability are not closely related, but together they determine the proportion of slaughtered lambs that will meet any omega-3 fatty acid standard that is based on the sum of EPA and DHA concentrations in meat.

In order to produce lamb with consistently high levels of EPA plus DHA, it is necessary to identify appropriate management strategies that ensure both high mean levels and low variability in EPA plus DHA. As the results vary greatly with slaughter time, and previous research has shown that levels of omega-3 fatty acids in meat are sensitive to an animal's diet (Ponnampalam, Sinclair, Egan, Blakeley, & Leury, 2001; Scerra et al., 2011; Scollan et al., 2006), the most important component of these management strategies will be finishing diet. This is important with regard to both the availability of diet of the typical animal along with the length of time in a slaughter cohort, as well as the variability in the diet actually consumed by individual animals in the cohort. The high variability in omega-3 levels between lambs managed in the same cohort might be due to selection of different dietary components when animals are offered mixed diets (Ponnampalam et al., 2014).

It is thus constructive to relate the results of this study, for different slaughter cohorts, to the nutritional history of those cohorts (Table 1). For example, the EPA plus DHA concentrations increased as the season progresses from winter (June–August) to spring (September–November) for lambs killed at Hamilton in years 2 and 3 (Fig. 1b), due to increases in the availability and quality of perennial ryegrass and tall fescue [year 2] pasture, and rape and millet forage crops including lucerne and chicory [year 3] (Table 1). It should also be noted that in each kill group from year 3, lambs at Hamilton were removed from rape and millet forage crops 2–3 weeks prior to slaughter and grazed on lucerne and chicory up to slaughter. In contrast, due to drought conditions in Southern Victoria (Hamilton), in year 1 there was low pasture availability during the autumn (March–May) season (for first 3 kills) necessitating the feeding of triticale, hay and feedlot grains pre-slaughter. This delivered very low levels of EPA plus DHA in the meat (Fig. 1b). The fourth kill from Hamilton site occurred in late spring (September–November) when animals had the opportunity to graze green pasture such as perennial grass or lucerne and thus the EPA plus DHA level was raised from 10 mg/100 g of meat to 30 mg/100 g meat. This event can also be seen in the last kill of years 2 and 3 for Hamilton lambs. These outcomes indicate that as seasonal conditions change from autumn (March to May) to winter (June to August) to Spring (September to November) the pasture availability and nutritive value increase, which in turn influences the EPA and DHA levels in meat.

Although EPA plus DHA are not components of the diet of grazing animals, green pastures are rich sources of α-linolenic acid (18:3n-3, ALA) compared with dry pasture or pasture hay, which is absorbed during digestion and may be converted in the body tissues to long chain omega-3 fatty acids such as EPA and DHA (Simopoulos, 1999). The current study covering approximately 6000 lambs over three years show that the EPA plus DHA concentrations in meat vary with the pasture types that the animals have been grazing. Animals grazing lucerne pasture continuously produced greater levels of EPA plus DHA followed by perennial/annual pasture (ryegrass, fescue and phalaris). This was followed by native pasture (windmill grass, spear grass, barley grass) and then dry pasture/stubbles (wild oats, barley and oat stubbles).

For example at the Trangie site, when native pasture (windmill grass, spear grass, barley grass) in the first two kills of second year 2 was replaced by improved pasture (ryegrass, fescue and phalaris) in the first two kills of third year (Table 1), the EPA plus DHA levels were increased from 20 mg/100 g meat to 30 mg/100 g meat (Fig. 1a). As reported in the above paragraph for Hamilton, with seasonal changes from autumn (March–May) to winter (June–August) as the quality and nutritive value of pasture increases (data not available), in the last kill the EPA plus DHA levels were increased from 20 mg/100 g to 30 mg/100 g meat during year 2 and from 30 mg/100 g to 35 mg/100 g meat during year 3, respectively for Trangie (Fig. 1a). This clearly indicates the levels of EPA plus DHA varies with seasons and pasture types. Ponnampalam, Hopkins et al. (2010) showed that there was a good relationship between average levels of EPA plus DHA and ALA in slaughter cohorts of lambs, using results obtained from the first year of the present study for approximately 2000 lambs.

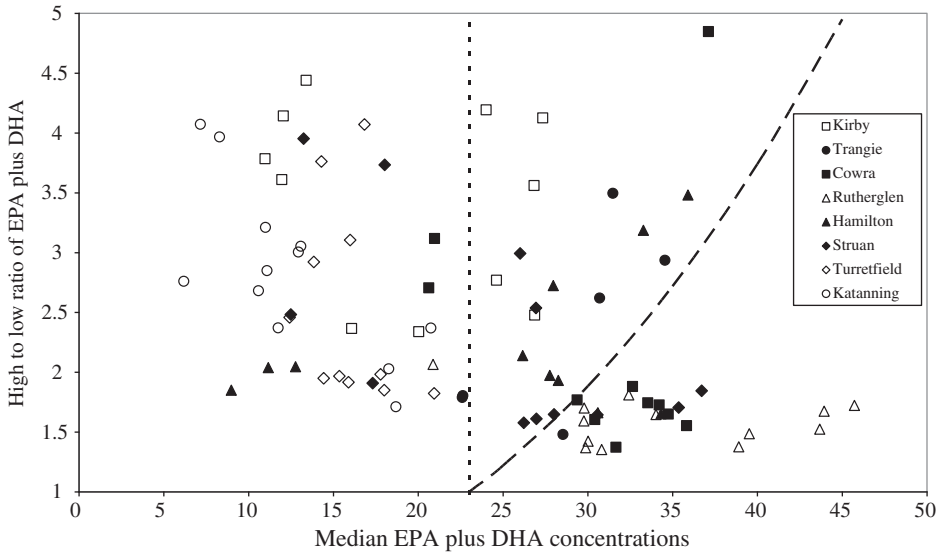

Fig. 3. Comparison of the ratio of high value (97.5% quantile) to low value (2.5% quantile) of EPA plus DHA to the median EPA plus DHA for each slaughter time from 8 locations over 3 consecutive years. Slaughter times to the right of the vertical short dash line are estimated to have EPA plus DHA > 23 mg/100 g for more than 50% of lambs. Slaughter times to the right and below of the long dash lines are estimated to have EPA plus DHA > 23 mg/100 g for more than 95% of lambs.

Most, but not all, slaughter cohorts at Rutherglen and Cowra were associated with the large majority of lambs having health claimable (for Australia) levels of EPA plus DHA. The common thread for these slaughter cohorts is that the lambs were finished with lucerne (alfalfa) pasture during the late post-weaning period (Table 1). At both Rutherglen and Cowra, when the slaughter cohorts were fed lucerne (alfalfa) in a mixed pasture stand, under natural rainfall conditions high EPA plus DHA levels were achieved. For Cowra lambs, much lower levels of EPA plus DHA were achieved in the first two slaughters of the third year when drought conditions caused lambs to be finished on low quality perennial pastures and stubbles, as opposed to lucerne. The positive results from Rutherglen and Cowra locations, at most slaughters, are also supported by recent findings that finishing lambs on perennial pasture having lucerne or quality lucerne hay elevates omega-3 fatty acid and vitamin E concentrations of meat at slaughter (Ponnampalam, Burnett, Norng, Warner, & Jacobs, 2012). Others (Bessa, Portugal, Mendes, & Santos-Silva, 2005) have also reported that replacing lucerne ground pellets by concentrate pellets containing cereal grains and protein meal significantly reduced the levels of EPA and DHA in meat from Merino Branco lambs. However, care must be taken when lucerne is used in winter dominant rainfall zones and in some high rainfall zones as a sole pasture for grazing. In high rainfall zones rumen bloat or red gut (McDonald et al., 2003) may be an issue, which may affect growth performance and carcass weight at finishing.

Similar to Cowra, when lambs at Rutherglen were finished on dry pasture with feedlot pellets rather than lucerne pasture (last slaughter of the first year, Table 1) the median EPA plus DHA level was reduced (only about 21 mg/100 g meat). In the second year, the last group (4th kill) from Rutherglen was killed in early spring after grazing good quality lucerne pasture. This compares with the other three cohorts from Rutherglen which were slaughtered in early to late autumn after grazing annual ryegrass/lucerne pasture. This resulted in a difference in the EPA plus DHA concentrations in meat with lamb grazing lucerne from spring (September–November) season delivering greater levels compared with lambs grazing annual ryegrass/lucerne pasture during autumn.

The results from the 3 years of observations clearly show lamb progeny from Katanning in Western Australia and Turretfield in South Australia consistently had low values of EPA plus DHA. These two sites both have a dry summer/wet winter Mediterranean type climate, which leads to senesced pastures during the late summer to autumn period. They also had high levels of grain finishing with barley stubbles or pea stubbles. Previous studies have reported that grain finishing or feedlot finishing in sheep (Bessa et al., 2005; Nuernberg et al., 2005) and cattle (Ponnampalam, Mann, & Sinclair, 2006; Scollan et al., 2006) reduced the omega-3 fatty acid content in meat compared with pasture finishing. The latter effects can be clearly seen in the 3rd year finishing from Struan lambs where, lambs were offered a feedlot ration for 3 and 4 months prior to the 3rd and 4th slaughter, respectively. This compares with the 1st slaughter that finished on irrigated green pasture and the 2nd slaughter that was finished on pasture with 36 days of grain supplementation (Table 1). As a consequence, the EPA plus DHA concentration dramatically reduced over the four slaughters (Fig. 1c). Also, the ratio of EPA plus DHA from lambs with high values of EPA plus DHA to lambs with low values of EPA plus DHA increased dramatically over the four slaughters (Fig. 2c). Differences in EPA plus DHA levels will occur between muscles associated with different activities, due to differences in the ratio of type I and type II muscle fibres. However, it would be expected that diet would affect the level of EPA plus DHA in all muscles within a carcass in a similar manner. The LL muscle has been chosen because it is the largest muscle in the carcase and one of the most valuable.

Polyunsaturated fatty acids, such as EPA and DHA, are mainly deposited in phospholipids of muscle membranes. The reason is that phospholipids are functional lipids that maintain many physiological and biochemical functions in the muscle tissues, for example muscle membrane fluidity, membrane structure, insulin action and signal transduction (Benatti, Peluso, Nicolai, & Calvani, 2004). In contrast, the saturated fatty acids are predominantly deposited in triglycerides of adipose tissues. Physiologically active muscles may have lower intramuscular fat (total muscle lipid) but have higher levels of phospholids with greater EPA and DHA concentrations than the less active muscles. The active muscles have a higher proportion of slow twitching red fibres (Type I) that tend to store more polyunsaturated fatty acid than white fibres (Type II) for their fast twitching activities. As a consequence, as reported in Storlien et al. (1995) and Ponnampalam, Warner et al. (2010), greater concentrations of EPA and DHA are found in active muscles such as leg muscle than in less active muscles such as LL, even though the intramusculer fat content of leg muscle is lower than the LL.

It may be a challenge to produce lamb with high levels of EPA plus DHA in most parts of South Australia (excluding the south-east region)

and Western Australia unless an appropriate finishing diet is designed for use during the extended dry months. Various possibilities include the use of algal supplements (Ponnampalam, Burnett, Ji, Dunshea, & Jacobs, 2012), oilseeds containing linolenic acid (flaxseed), irrigated pasture and drought resistant perennial fodder species.

5. Conclusions

This study indicates that to consistently obtain high levels of omega-3 fatty acids from lamb in Australia, there must be a focus on the finishing diet. It is not only important to maintain high average levels of omega-3 fatty acids, but also important to achieve low levels of variability between animals within a slaughter cohort. Finishing with lucerne has been identified as very promising for consistently obtaining high levels of omega-3 fatty acids. The efficacy of the latter strategy needs to be confirmed in a wide range of environments and management situations. Other finishing systems need to be identified, which may include novel pastures or specific supplementation of feedlot diets.

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