PRODUCING WELSH LAMB HIGH IN OMEGA 3 FATTY ACIDS

A report for Cardiganshire farmers producer group 'Cardi lamb', Menter a Busnes, Wynnstay feeds and HCC by:

Ian Richardson
DFAS
University of Bristol

December 2006

Division of Farm Animal Science
University of Bristol
Langford
Bristol, BS40 5DU
0117 928 9291
ian.richardson@bristol.ac.uk

PRODUCING WELSH LAMB HIGH IN OMEGA 3 FATTY ACIDS

PRODUCING WELSH LAMB HIGH IN OMEGA 3 FATTY ACIDS

Summary

One hundred and twenty sheep were divided into groups of 20. Five groups were allocated to one of five paddocks in the same field. One group grazed grass alone, all the others had access to a creep feed which contained standard cereal concentrates, the same diet with some of the cereal substituted with either whole linseed, or one of two fish oil preparations. The sixth group were housed indoors from weaning and fed only the standard creep feed. Animals were all slaughtered\on the same day at a local abattoir. Meat from the loin was taken the next day and transported to the University of Bristol where the fatty acid composition, vitamin E content and colour and lipid stability were analysed. The remaining loin meat was cooked, cut into portions and assessed by a trained sensory panel.

Feeding concentrates as a creep feed improved the weight and carcass conformation of lambs over those finished at the same age on grazed grass alone. However, this feed reduced the amount of valuable omega-3 fatty acids in the meat and increased the less valuable omega-6. The omega-6 to omega-3 ratio was increased from 1.9 to 3.5, when the desirable value is less than 4. Feeding concentrates alone, with no grass, increased this ratio further to an undesirable 6.2. Substituting some of the cereal in the creep feed with whole linseed returned the fatty acid concentrations and ratios to those found in the grass grazed animals.

As the amount of concentrate in the diet increased so the concentration of vitamin E in the muscle decreased and lipid oxidation increased. Vitamin E increased and lipid oxidation decreased when linseed was fed, though none of the diets produced meat with as much vitamin E and hence stable fat, as the grass grazed animals.

Feeding fish oils was able to increase the important fatty acids, EPA and DHA, more so in one of the preparations than the other. Meat from these animals was less oxidatively stable than that from the other animals and would have benefited from supplementary vitamin E in the diet.

Although the sensory panel were able to distinguish between the samples from animals fed the different diets, the differences were small and it is debatable as to whether consumers would differentiate these differences from week to week. The biggest differences were for the reduced lamb flavour and increased abnormal flavour produced with cereal feeding and these might be notable. Substituting some of the cereal with whole linseed produced sensory scores very similar to that of grazed animals.

This project demonstrated that if lambs are fed high cereal concentrates as a creep feed in order to finish them sooner; it is at the expense of fatty acid composition and flavour. Finishing lambs post-weaning solely on concentrates is very deleterious. Substituting some of the cereal with whole linseed restores both the fatty acid composition and the sensory scores to those of grass grazed animals.

PRODUCING WELSH LAMB HIGH IN OMEGA 3 FATTY ACIDS

Report of the Division of Farm Animal Science, University of Bristol on the fatty acid composition, sensory (eating quality) assessment and meat stability during simulated retail display, of meat from Welsh lambs fed one of six diets.

Partners:

Farmer Producer Group
Wynnstay Feeds
HCC
Institute of Grassland and Environmental Research
University of Bristol

Background

A group of 9 farmers in North Ceredigion came together under the 'Agrisgôp'(Managing Farms with IT) programme. Following lengthy discussions on the future of lamb sales and having researched various avenues the group members came across 'Functional Foods'.

Scientifically, functional foods have been defined as "affecting beneficially one or more target functions in the body beyond adequate nutritional effects in a way that is relevant to either an improved state of health and well-being and/or reduction of risk of disease." Functional foods and drinks therefore have health benefits beyond their nutritional value.

The human diet is currently too rich in omega-6 (n-6) fatty acids and low in omega-3 (n-3) fatty acids, particularly long chain n-3 fatty acids. The only natural dietary sources of these fatty acids are fish, and ruminant products (meat, milk and cheese) from cattle, sheep and goats.

There are a number of publications which point out the value of feeding grass over concentrates to improve the n-3 fatty acid content of lamb meat. Grass and forages increase the concentration of α-linolenic acid (18:3*n*-3) in meat and this fatty acid is then converted by enzyme systems into the desirable long-chain n-3 PUFA (LCPUFA) such as eicosapentaenoic acid (EPA, 20:5*n*-3) and docosahexaenoic acid (DHA, 22:6*n*-3) (Fisher et al., 2000). Alternative systems, feeding linseed or linseed oil which are also rich in α-linolenic acid (18:3*n*-3), have been reported to improve the n-3 fatty acid content of sheep meat by the University of Bristol in conjunction with Harper Adams Agricultural College (Wachira et al., 2002; Cooper et al., 2004; Demirel, et al., 2004;; Nute et al., 2006). In contrast, concentrate diets based on grains and protein supplements are high in linoleic acid (18:2*n*-6), the precursor of the n-6 series of PUFA.

Lamb

It is the practise of some farmers to supplement new season lambs with concentrates, often as a creep feed, in order to get them to market early before the price declines. This concentrate is usually based on cereals and would be high in n-6 fatty acids, diluting the beneficial effect of grass grazing on promoting n-3 PUFA content in the meat. The purpose of this trial was to assess alternative concentrate feeds fed in a creep-feed system which would maintain or enhance the n-3 fatty acid composition of the meat of animals fed concentrates at grass during the finishing period.

The trials

Following a meeting between the farmers, Arwyn Jones, HCC and Dr Nigel Scollan, IGER, the following trails were suggested:

Control – 12 lambs finished on grass only

Control – Neutral – 12 lambs finished on grass + commercial lamb finisher

Negative Control – 12 lambs finished indoors on commercial lamb finisher (lambs artificially reared with no grass input during lifetime)

Experimental

Group 1 (12 lambs) Grass standard creep with some wheat and rapeseed extract substituted by linseed

Group 2 (12 lambs) Grass standard creep with some wheat substituted by Pure fish oils at 5%

Group 3 (12 lambs) Grass standard creep with some wheat substituted by a EPA/DHA-rich omega-3 product at 2.5%

Experimental animals, diets and slaughter

The diets were formulated (in conjunction with IGER) and made by Wynnstay.

Diet composition

			Linseed Blue %	'PUFFA' oil Purple %	Omega-3 product Red %	Lambmaster Orange/Black %
1	Wheat 1	[X]	26.9	29.4	26.9	31.9
2	Barley	[X]	15.1	15.1	15.1	15.1
50	Wheatfeed	[X]	15.0	15.0	15.0	15.0
170	Rapeseed Ext	[X]	9.75	14.75	14.75	14.75
181	Whole Linseeds	[ ]	10.0	-	-	-
190	Palm Kernel Exp	[X]	11.0	11.0	11.0	11.0
403	Sugar Beet Pulp	[X]	2.5	2.5	2.5	2.5
450	Limestone Flour	[X]	2.0	2.0	2.0	2.0
452	Salt	[X]	0.6	0.6	0.6	0.6
456	Ammonium Chloride	[X]	0.7	0.7	0.7	0.7
811	Wynnstay Sheep	[X]	0.25	0.25	0.25	0.25
858	Femosca	[X]	0.2	0.2	0.2	0.2
971	Molasses	[X]	6.0	6.0	6.0	6.0
980	Omega 3 Supp	[ ]	-	-	5.0	-
981	Puffa Oil	[ ]	-	2.5	-	-
Total			100.0	100.0	100.0	100.0

The trial was held on one farm over a period of 5-6 weeks. Sheep were gathered from the farmer participants to produce a flock of 120 sheep which were divided into 6 groups of 20 each. One group was finished indoors on a total concentrate diet with no green forage. The remaining groups of 20 were finished in one field which had been divided into 5 paddocks. One group finished on grazed grass alone, the others had access to one of the experimental diets as a creep feed. When the lambs were ready for market they were transported to the Dunbia abattoir at Llanybydder. Members of the farmers group were present on the slaughter day and 2 members on the day of sampling along with a member of HCC and the University of Bristol.

Carcasses were weighed and graded at the abattoir. Grades (fatness and conformation) can be turned into numerical values for statistical analysis. All carcasses were U or R which score 4 and 3 respectively. For fatness carcasses were 3L, 3H, 4L or 4H, which convert to 11, 13, 15 or 17 respectively.

Meat Quality measurements

The loins from one side of the carcasses of 12 of the 20 lambs from each group were boned out, vacuum packed and transported back to the University of Bristol in insulated boxes under ice. Upon arrival at Bristol sub-samples were taken, vacuum packed and frozen for analysis of fatty acid composition and vitamin E content. The rest of the loin was conditioned for 10 days, a section cut off, vacuum packed and frozen for subsequent sensory (taste) panel analysis. Steaks were cut from the remaining muscle, packed in modified atmosphere packs (O_2:CO_2, 80:20) and subject to simulated retail display (16h light, 8h dark, 3°C, 700lux). Colour on the surface of the steaks was measured though the pack lid daily, with a Minolta Chromameter until the colour in all steaks had deteriorated beyond acceptable. Further packs were taken on day 7 of display and analysed for lipid oxidation as thiobarbituric-acid reacting substances (TBARS) by the method of Tarladgis, Watts & Younathan (1960), modified by the use of a Buchi 321 distillation unit. Vitamin E in the lean was measured by the method of Arnold, Scheller, Arp, Williams & Schaefer (1993). Muscle fatty acid composition was measured in the. *longissimus* muscle taken from the sixth to eighth rib as detailed in Cooper et al. (2004).

The day before sensory assessment, samples were thawed initially at room temperature and then kept at 4ºC overnight. On the morning of sensory assessment, the loin was cut into 2.0 cm thick steaks and placed under a domestic grill and cooked, turning every 3 minutes, to an internal muscle temperature of 75ºC as measured by a thermocouple probe inserted into the approximate geometric centre of each steak. A panel of ten trained assessors, previously selected according to BS 7667 (BSI, 1993) and who received additional training in the assessment of specific lamb flavours constituted the taste panel. The 8-point category scales go from e.g. extremely tough, very tough, moderately tough, slightly tough, slightly tender, moderately tender, very tender, and extremely tender. However, the panel are used as an instrument to find differences. They may not use all the scale and it is not a consumer survey of acceptability. They were given one sample from each treatment at each sitting, so there were 12 sittings to get through all the 12 replicates, i.e. 12 lambs per treatment by 6 treatments. They tend to use the middle of the scale thus leaving themselves higher and lower values available for scoring should they come across an extreme sample within the sitting. We balance all treatments within a sitting and they are allocated in defined order which changes between sittings and between panellists. Hence, if the first sample they test is very tough and it is allocated a given score, subsequent samples will be scored in relation to that sample. However, as the panellists are specially selected and trained then they tend to give a similar score for a given tenderness every time they come across it.

All results were subject to one-way analysis of variance using diet as the variable factor and a Tukey HSD test for difference between means.

Field divided into paddocks

Group at grass with concentrate creep-feeder

Results.

It is now known that:
Green = grass grazed (GG), Orange = GG + std concentrate creep, Black = Concentrate only indoors, Blue = GG + linseed, Purple = GG + Fish oil containing creep feed and Red = GG + a concentrate with an omega-3 product rich in EPA/DHA

Carcass weight and grades.

Weights and grades are available for the 12 out of the 20 lambs in each group which were assessed at the University of Bristol. The grass grazed group (green) were the lightest (average cold weight 19.9kg) showing that creep feeding did promote more rapid growth. The red group were not significantly heavier than the green group or lighter than the orange black or blue group (average 22.5kg). The purple group produced the heaviest lambs (average 23.3 kg). This data should be interpreted with caution as it is not certain that all the groups of lambs started at the same average weight or that the selection of 12 from 20 was random. The green group, grass grazed alone, were the least well finished, with 2 grade U and 10 grade R, and was similar to the red group (4,8), all other groups had more U grades than R, blue and purple having most (9,8). For fatness, the green and orange groups had the lowest scores but were not statistically significantly different from the red, blue or black groups. Purple were fatter than the red, green and orange groups.

Fatty acid analysis

The results for the fatty acid analysis of loin muscle are shown in Tables 1-3. None of the diets affected the total fat (which was approximately 3.7%), saturated fat or monounsaturated fat content of the meat. The polyunsaturated fat (PUFA) content of the meat varied with diet. The PUFA content of the green (grass-grazed group) was significantly less than the blue (linseed-fed), with all the other groups being intermediate.

The aim of the trials was to maintain or increase the n-3 (omega-3) fatty acids in the animals fed supplemental concentrates, particularly long chain polyunsaturated fatty acids (LCPUFA) compared to those grazing grass alone. As the animals went from grass-grazed to an all concentrate diet (green versus black) the amount of n-3 LCPUFA decreased significantly, but this was restored when the concentrate contained linseed (blue group). Simultaneously, the n-6 LCPUFA increased with concentrate feeding.

Lamb fat is high in saturates which is reflected in the polyunsaturate to saturate (P:S) ratio of <0.2, as opposed to a desirable value of >0.4, in all samples. It is difficult to change this ratio in ruminants. Only the linseed diet (blue) increased the ratio significantly above that of the grass-grazed group.

The other nutritionally important ratio is that between n-6 and n-3 fatty acids which can be expressed either as the ratio of 18:2*n*-6 to 18:3*n*-3 or total n-6 to total n-3, the latter including the LCPUFA. As the diet went from grass-grazed through standard creep concentrate to solely concentrate feeding so the 18:2*n*-6 to 18:3*n*-3 increased from a beneficial ratio of <2 to >6, the desired ratio being <4. Substituting linseed in the creep feed restored the ratio to <2. Feeding rations with fish oils (purple and orange) maintained the ratio at <4 but higher than the grass-fed group. These feeds must have contained a high proportion of n-6 containing cereal. When all PUFA were considered a similar pattern was seen for the standard or linseed diets, but the fish oil diets gave a better ratio because of the increased LCPUFA incorporated from these diets (see below).

Tables 2 and 3 present the data for the individual fatty acids. In table 2 the results are expressed as weight of an individual fatty acid in 100g of lean muscle tissue. In Table 3 the results are expressed as a proportion (%) of the total fatty acid content. Expressing the results in this way can even out the effect of different total fat content which would affect the total weight of individual fatty acids.

The different diets had no effect on the amounts of the individual saturated fatty acids or the main monounsaturated fatty acid, oleic acid (Table 2). The polyunsaturated fatty acids varied with diet composition, hence those rich in n-3 fatty acids (grass and grass plus linseed were highest in 18:3n-3 and the high concentrate diet was highest in 18:2n-6). The 18:2 increased from green to orange to black, grass to grass + std concentrates to all concentrates and decreased when some of concentrates were replaced by linseed (blue). Conversely 18:3 decreased with increased concentrates feeding, green to black and improves back to above grass level (non-statistically significant blue over green) EPA goes down with cereal feeding and is improved back to grass with linseed (blue). Feeding fish oil rich diets (purple and red) improved the EPA and DHA, significantly above grass (green) for DHA. The pure fish oil addition at 2.5% was more effective at raising the DHA concentration in meat than the omega-3 product fed at 5%. (it was declared as 50% oil so should have been contributing similar amounts of omega-3 long chain fatty acids as the pure fish oil fed at half the rate, but does not appear to have been as efficiently incorporated. DHA concentration was approximately doubled over that of the grass-only animals for omega-3 product, but nearly trebled for the fish oil.

In Table 3, it can be seen that when individual fatty acids are expressed as a proportion of the total fat content and thus lessening the effect of differences in total fat content between groups, that there are more statistically significant differences. Noticeably, the all concentrate diet produced a lower proportion of CLA than the grazed group, the proportion of 18:3n-3 in the meat of the linseed fed animals is now significantly greater than in meat from the grazed animals.

Sensory analysis

All the samples were scored slightly to moderately tender and there were no differences. This is good. The difference between the smallest (5.12) and largest value (5.36) does not show a statistically significant difference. There were no differences in juiciness. Red and blue samples scored highest for lamb flavour and black (highest concentrates) lowest. This was significantly less. The other samples, green, purple and orange, were intermediate and not significantly different from red and blue or black. Abnormal means a flavour note that they might not usually associated with lamb and was found at a significantly higher level in black and orange than green, red or blue, purple was intermediate.

The overall liking is a question we ask, but it is an opinion of only 10 people and might not represent the whole population. There were no significant differences, though nearly so and it can be seen that black gave a numerical value less than the rest and this may be a combination of the higher abnormal flavour and lower lamb flavour. Orange also had a higher abnormal flavour, but this seems to have been counteracted by the stronger lamb flavour than black.

The results for flavour profile are scored on a 0-100 line scale, e.g. 0 for fatty/greasy would be no detection of fatty or greasy and 100 would be a very large fatty or greasiness. All the values are very much to the lower end of the scale and only sweet, bitter, liver and kidney produced statistically significant differences. Sweet and bitter are not necessarily opposites, e.g. orange has a similar score for sweet and bitter whilst green has the lowest score for bitter and an intermediate score for sweet. Samples from the red group were ‘sweeter’ than all the rest, which were not different from one another. Orange had the highest bitter score, green, red, blue and purple the lowest and black was intermediate to these.

Black and orange had a significantly higher livery note than green or red, purple and blue being intermediate. Black, purple and orange had significantly higher kidney notes, almost twice that of green, red and blue.

In previous studies with beef we have found that livery is not necessarily a bad note and that it went along with beef flavour, i.e. was a component of it and often associated with grass feeding. In this case it seems to be more associated with concentrate feeding and to have a positive relationship with abnormal flavour, the more the livery note, the higher the abnormal score, however there was only a very slight deterioration in lamb flavour as livery increased (see Figure 1). Livery was associated with kidney (Figure 2) and liver and kidney might be combined as ‘offaly’ or ‘bloody’ (my speculation). For orange, purple and black, for a given ‘livery’ score, the panel found a higher than average ‘kidney’ score compared to the red, blue or green groups, these groups having the highest 18:2 to 18:3 ratios..

Overall this was good tasting lamb, with subtle differences between the treatments. Values were quite low on the scale and we cannot say with any certainty whether an average consumer would notice these differences from week to week. From the individual data it was noted that for some attributes, e.g. Kidney and Livery there was a wide spread of data, less so for red or green.

Vitamin E concentration and fat and colour stability

Lush growing grass contains high concentrations of vitamin E which is absorbed into the body and deposited into muscle. Cereal concentrates are relatively low in vitamin E and animals put on to a high cereal concentrate diet will lose vitamin E over the weeks. In Figure 3 it can be seen that as you go from grass grazed (green), through grass + concentrates(orange) to all concentrates (black) so the vitamin E intake and deposition in the muscle falls, subsequently allowing more fat oxidation during retail display (as measured by the TBARS value). Feeding linseed (blue) gave an improved vitamin E concentration compared to creep feed or concentrates (orange and black).Linseed has natural antioxidant content, and fat oxidation was less though greater than grass alone. Values less than 2 are acceptable. Purple is one of the fish treatments and produced higher concentrations of EPA and DHA in the muscle. These fatty acids have 5 and 6 double bonds respectively and are much more susceptible to oxidation. Hence, although the vitamin E was present in the muscle of these animals at a similar concentration to those on the blue or orange diet, the oxidation was still greater due to its fatty acid composition. Values of TBARS less than 2 are acceptable. Black, purple and red would have benefited from additional vitamin E in the diet. We had not anticipated the animals reducing their grass intake so much due to a large creep feed intake.

Colour changes from day to day of chops packed in modified atmosphere packs and displayed under lights are shown in Figure 4. There were few differences, red (grass + standard creep concentrate) appears to be most colour stable! All groups had acceptable colour well over the 7 days required by retailers.

Table 1. Amounts of major fatty acid groups (mg/100g muscle) and nutritional indices of lean loin (*longissimus*) muscle

Diet	Green Grass Grazed	Orange Grass + concs	Black All concs	Blue Linseed	Purple Fish Oil 1	Red Fish Oil 2	sig	sed
Sum all FA	3519.6	3688.5	3486.4	3548.6	3859.1	3796.8	288.4	ns
Sum SFA	1460.1	1400.0	1332.4	1363.4	1444.9	1524.9	126.3	ns
Sum MUFA	1436.9	1578.8	1540.3	1453.6	1664.7	1610.2	127.3	ns
Sum PUFA	238.8^{a}	262.7^{ab}	252.8a^{b}	280.5^{b}	267.6^{ab}	245.8^{ab}	13.08	*
all LC PUFA	88.9^{ab}	89.0^{ab}	80.6^{a}	85.8^{ab}	105.2^{c}	91.1^{b}	2.52	***
n-3 LCPUFA	52.2^{b}	49.1^{b}	37.1^{a}	52.0^{b}	71.3^{c}	57.8^{b}	2.63	***
n-6 LCPUFA	36.7^{ab}	40.0^{ab}	43.4^{b}	33.8^{a}	33.9^{a}	33.3^{a}	1.81	**
P:S ratio	0.10^{a}	0.13^{ab}	0.14^{ab}	0.16^{b}	0.12^{ab}	0.11^{a}	0.010	**
18:2*n*-6/18:3*n*-3	1.93^{a}	3.48^{a}	6.19^{b}	1.86^{a}	3.49^{a}	2.87^{a}	0.55	***
n-6:*n*-3 ratio	1.29^{a}	1.97^{a}	3.51^{b}	1.33^{a}	1.47^{a}	1.50^{a}	0.32	***

Sum all FA is the amount of all fatty acids derived gravimetrically, not all fatty acids are reported, but this value is used to calculate % composition
FA –fatty acids, SFA – saturated fatty acids, MUFA – monounsaturated fatty acids, PUFA – polyunsaturated fatty acids,
LCPUFA – long chain polyunsaturated fatty acids
CLA – conjugated linoleic acid
P:S ratio - (18:2+18:3)/(12+14+16+18), *n*6:*n*3 ratio - (18:2+20:3+20:4/18:3+20:5+22:5+22:6)
Sum SFA = 12:0+14:0+16:0+18:0
Sum MUFA = 16:1+9c18:1+11c18:1+20:1
Sum PUFA = 18:2*n*-6+18:3*n*-3+20:3*n*-6+20:4*n*-6+20:5*n*-3+22:4*n*-6+22:5*n*-3+22:6*n*-3
Sum longchain *n*-6 PUFA = 20:3*n*-6+20:4*n*-6+22:4*n*-6
Sum longchain *n*-3 PUFA = 20:5*n*-3+22:5*n*-3+22:6*n*-3
Sum all longchain PUFA = 20:3*n*-6+20:4*n*-6+20:5*n*-3+22:4*n*-6+22:5*n*-3+22:6*n*-3

Table 2. Fatty acid composition of loin muscle by weight (g/100g muscle) and as a proportion of total fat (mg/100g fat), Showing the effect of diet.
a). Fatty acids by weight mg/100g muscle

Fatty acid	Diet	Green	Orange	Black	Blue	Purple	Red	sed	sig
lauric	12:0	7.63	5.94	6.52	6.03	7.29	7.88	0.88	ns
myristic	14:0	100.14	89.53	90.19	88.61	101.32	102.48	10.42	ns
	15:0	12.81	11.40	11.07	10.78	12.37	13.10	1.19	ns
palmitic	16:0	735.87	761.70	742.80	730.73	816.61	806.07	68.58	ns
	16:1	59.18	67.60	65.94	56.79	69.96	66.13	6.06	ns
	17:0	36.91	35.43	36.65	34.83	38.98	36.91	3.14	ns
stearic	18:0	616.48	542.80	492.85	538.01	519.65	608.42	50.32	ns
trans-vaccenic	*trans*18:1	124.36 [a]	155.52 [ab]	141.22 [a]	153.91 [ab]	213.87 [b]	165.29 [ab]	14.93	**
oleic	9c18:1	1204.6	1251.6	1239.9	1146.8	1252.8	1303.1	104.8	ns
cis-vaccenic	11c18:1	46.32 [a]	101.59 [cd]	90.12 [bc]	93.50 [bc]	121.70 [d]	70.25 [ab]	6.61	***
linoleic	18:2n-6	97.80 [a]	130.44 [bc]	143.44 [c]	126.32 [bc]	125.12 [bc]	114.07 [ab]	6.32	***
	20:1	2.38 [a]	2.43 [a]	3.05 [a]	2.60 [a]	6.44 [b]	5.45 [b]	0.32	***
α-linolenic	18:3n-3	52.12 [bc]	43.19 [ab]	28.78 [a]	68.37 [c]	37.28 [ab]	40.68 [ab]	3.93	***
CLA	CLA9c11t	41.41	41.35	28.61	34.58	42.81	40.11	4.64	ns
	20:3n-6	3.82 [ab]	4.07 [b]	4.32 [b]	3.42 [a]	3.80 [ab]	3.80 [ab]	0.15	**
arachidonic	20:4n-6	31.52 [ab]	34.22 [ab]	36.64 [b]	29.12 [a]	28.74 [a]	28.30 [a]	1.56	***
EPA	20:5n-3	22.92 [bc]	20.33 [b]	14.62 [a]	22.74 [bc]	26.01 [c]	23.06 [bc]	1.23	***
	22:4n-6	1.34 [a]	1.68 [ab]	2.46 [b]	1.29 [a]	1.36 [a]	1.16 [a]	0.19	***
DPA	22:5n-3	22.76 [bc]	21.62 [ab]	17.66 [a]	22.60 [bc]	26.22 [c]	22.91 [bc]	1.10	***
DHA	22:6n-3	6.54 [a]	7.13 [a]	4.86 [a]	6.63 [a]	19.02 [c]	11.81 [b]	0.64	***

CLA – conjugated linoleic acid, EPA – eicosapentaenoic acid, DPA – docosapentaenoic acid, DHA – docosahexaenoic acid

b). Fatty acids (% of total fat)

Fatty acid	Diet	Green	Orange	Black	Blue	Purple	Red	sed	sig
lauric	12:0	0.22 ^{b}	0.16 ^{a}	0.18 ^{ab}	0.16 ^{a}	0.18 ^{ab}	0.21 ^{b}	0.015	*
myristic	14:0	2.84	2.40	2.51	2.34	2.57	2.68	0.13	ns
	15:0	0.37 ^{b}	0.31 ^{ab}	0.31 ^{ab}	0.29 ^{a}	0.31 ^{ab}	0.35 ^{ab}	0.016	*
palmitic	16:0	20.89	20.51	21.05	20.15	21.13	21.02	0.41	ns
	16:1	1.68 ^{ab}	1.83 ^{b}	1.86 ^{b}	1.54 ^{a}	1.82 ^{b}	1.71 ^{ab}	0.056	***
	17:0	1.05	0.97	1.04	0.96	1.01	0.97	0.027	ns
stearic	18:0	17.47 ^{c}	14.52 ^{ab}	14.04 ^{ab}	15.13 ^{ab}	13.35 ^{a}	15.94 ^{bc}	0.46	***
trans- vaccenic	*trans*18:1	3.56 ^{a}	4.23 ^{a}	4.00 ^{a}	4.21 ^{a}	5.61 ^{b}	4.47 ^{a}	0.26	***
oleic	9*cis*18:1	34.16 ^{ab}	33.86 ^{ab}	35.27 ^{b}	32.21 ^{a}	32.36 ^{a}	34.07 ^{ab}	0.53	***
cis-vaccenic	11*cis*18:1	1.33 ^{a}	2.86 ^{b}	2.63 ^{b}	2.76 ^{b}	3.22 ^{b}	1.84 ^{a}	0.15	***
linoleic	18:2*n*-6	2.79 ^{a}	3.71 ^{ab}	4.48 ^{b}	3.85 ^{ab}	3.35 ^{ab}	3.14 ^{a}	0.28	***
	20:1	0.07 ^{a}	0.07 ^{a}	0.09 ^{a}	0.08 ^{a}	0.17 ^{b}	0.15 ^{a}	0.008	***
α-linolenic	18:3*n*-3	1.48 ^{b}	1.15 ^{ab}	0.88 ^{a}	2.07 ^{c}	0.97 ^{a}	1.13 ^{ab}	0.095	***
CLA	CLA9c11t	1.18 ^{c}	1.09 ^{ab}	0.78 ^{a}	0.92 ^{ab}	1.09 ^{ab}	1.09 ^{ab}	0.083	*
	20:3*n*-6	0.11	0.12	0.14	0.11	0.10	0.10	0.010	ns
arachidonic	20:4*n*-6	0.91 ^{ab}	1.01 ^{ab}	1.18 ^{b}	0.92 ^{ab}	0.77 ^{a}	0.78 ^{ab}	0.098	*
EPA	20:5*n*-3	0.66 ^{ab}	0.58 ^{ab}	0.46 ^{a}	0.73 ^{b}	0.70 ^{ab}	0.66 ^{ab}	0.062	*
	22:4*n*-6	0.038 ^{a}	0.049 ^{ab}	0.080 ^{b}	0.040 ^{b}	0.037 ^{a}	0.031 ^{a}	0.008	***
DPA	22:5*n*-3	0.65	0.62	0.55	0.70	0.71	0.64	0.054	ns
DHA	22:6*n*-3	0.19 ^{a}	0.21 ^{ab}	0.15 ^{a}	0.22 ^{ab}	0.52 ^{c}	0.33 ^{b}	0.031	***

CLA – conjugated linoleic acid, EPA – eicosapentaenoic acid, DPA – docosapentaenoic acid, DHA – docosahexaenoic acid

Table 4 Influence of diet type on the eating quality of grilled lamb loin

Attribute	Green Grazed grass	Orange Grass + std concs	Black Std Concs Indoors	Blue Grazed + Linseed	Purple Grazed + FO1	Red Grazed + FO2	vr	P	sig	lsd
8 point category scales used										
Texture	5.36	5.24	5.32	5.31	5.12	5.14	1.18	0.32	ns	!
Juiciness	4.22	4.28	4.12	4.27	4.42	4.27	0.80	0.55	ns	!
Lamb Flavour	4.36^{ab}	4.32^{ab}	4.06^{b}	4.64^{a}	4.33^{ab}	4.48^{ab}	2.49	0.03	*	0.34
Abnormal Flavour	2.91^{b}	3.44^{a}	3.44^{a}	3.03^{b}	3.20^{ab}	2.88^{b}	3.60	0.003	**	0.37
Hedonic										
Overall liking	4.60	4.46	4.20	4.68	4.47	4.66	2.19	0.054	ns	!
100mm line scale used										
Fatty/Greasy	12.42	11.93	13.17	14.47	14.38	13.98	0.64	0.67	ns	!
Sweet	12.82^{b}	12.22^{b}	10.21^{b}	13.09^{b}	11.37^{b}	16.50^{a}	3.18	0.008	**	3.33
Acidic	5.82	7.99	6.90	5.31	6.41	6.03	0.66	0.65	ns	!
Metallic	9.41	8.47	9.24	9.19	8.55	7.56	0.39	0.85	ns	!
Bitter	6.61^{b}	12.25^{a}	10.52^{ab}	7.58^{b}	6.81^{b}	7.98^{b}	2.49	0.03	*	3.98
Rancid	4.89	3.89	5.58	4.36	3.73	5.26	0.60	0.69	ns	!
Livery	11.44^{b}	17.47^{a}	16.49^{a}	15.05^{ab}	14.29^{ab}	10.44^{b}	2.54	0.02	*	4.83
Kidney	6.44^{b}	16.69^{a}	17.44^{a}	9.30^{b}	15.01^{a}	5.31^{b}	9.74	<0.0001	***	4.76
Ammonia	2.30	2.06	2.14	1.84	1.91	1.60	0.57	0.72	ns	!
Grassy	8.54	7.66	5.55	8.47	5.83	5.82	1.57	0.17	ns	!
Fishy	1.76	1.91	1.39	1.40	1.78	1.47	0.43	0.83	ns	!
Soapy	4.20	6.44	5.62	5.53	4.31	4.44	1.10	0.36	ns	!

Values are the means derived from analysis of variance with Type and assessor as factors, with 12 replications

* significant at 5 % ** significant at 1 % *** significant at 0.1 % ! least significant difference test post hoc not computed

Figure 1. The relationship between sensory scores for livery and those for lamb flavour or abnormal flavour

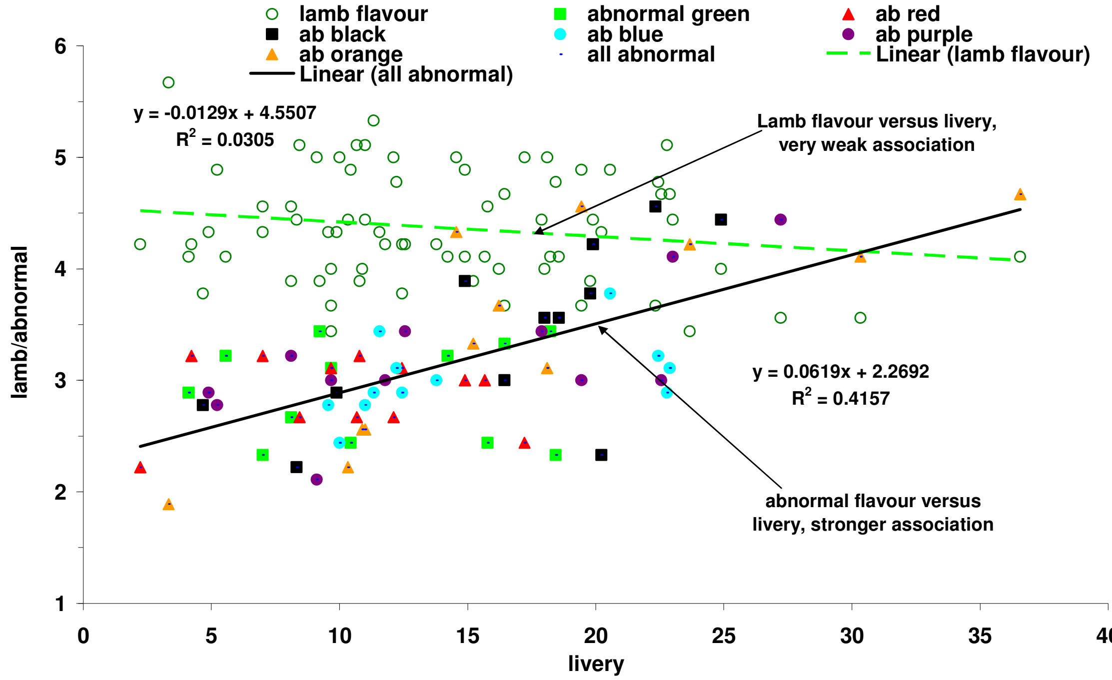


Figure 2. The relationship between livery and kidney scores for each group of lambs

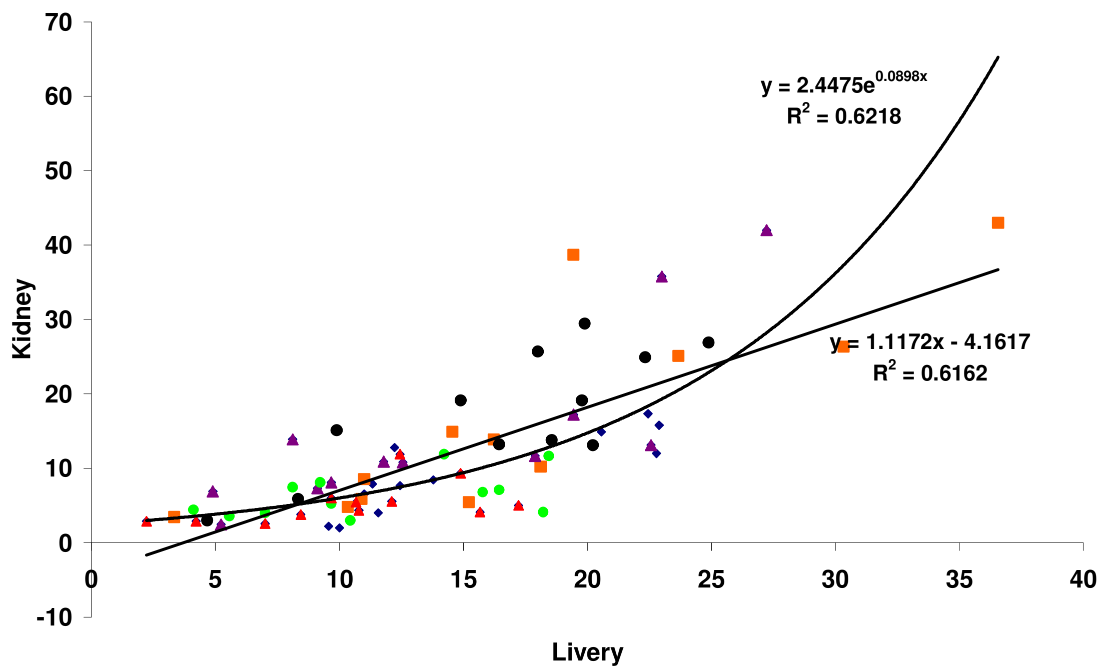


Figure 3. TBARS and vitamin mean values for the six diets.

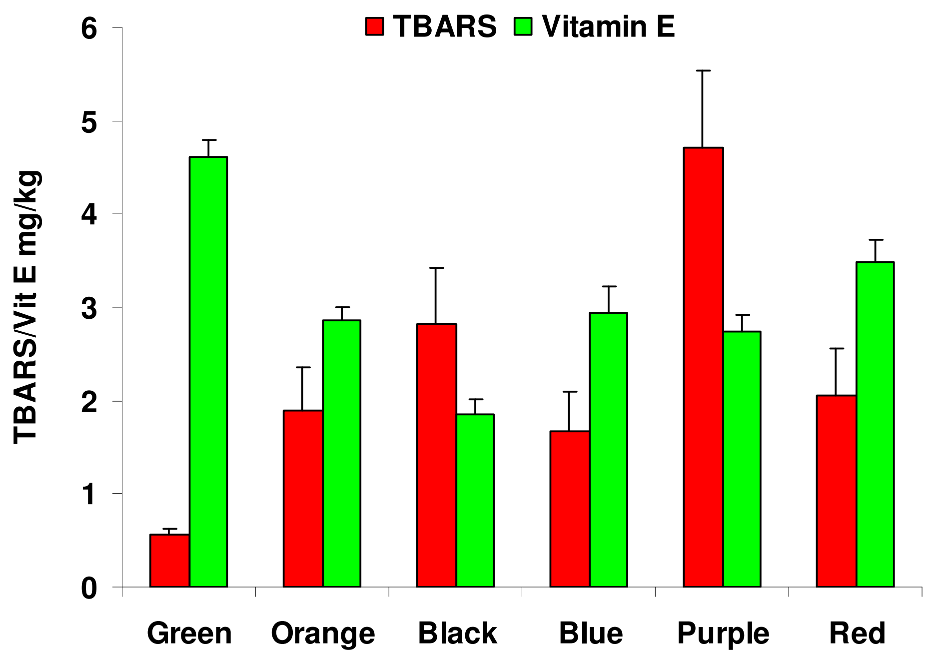
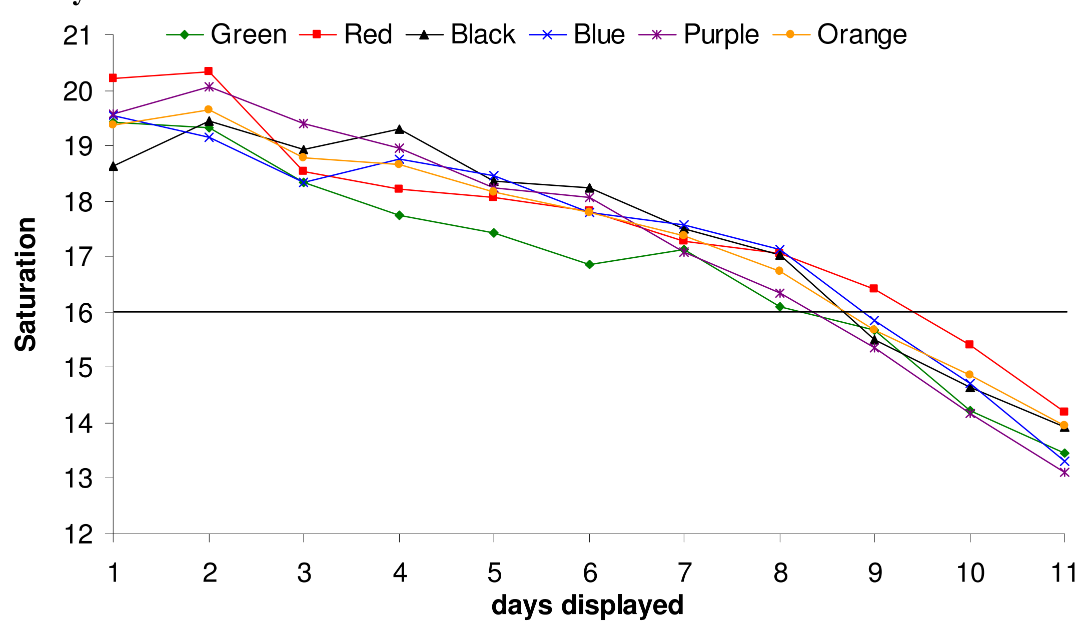


Figure 4. Change in colour saturation with time for lamb loin steaks, in MAP, from the 6 dietary treatments



References

Arnold, R.N., Scheller, K.K., Arp, S.C., Williams, S.N. & Schaefer, D.M. (1993). Dietary α-tocopheryl acetate enhances beef quality in Holstein and beef breed steers. *Journal of Food Science*, *58*, 28-33.

BSI (1993). Assessors for sensory analysis. Part 1. Guide to the selection, training and monitoring of selected assessors. *BSI 7667*. British Standards Institution, London, United Kingdom.

Campo, M.M.. Nute, G.R., Hughes, S.I., Enser, M., Wood, J.D. & Richardson, R.I. (2006). Flavour perception of oxidation in beef. *Meat Science, 72,* 303-311.

Cooper, S.L., Sinclair, L.A., Wilkinson R.G., Hallet, K.G., Enser, M, & Wood, J.D. (2004). Manipulation of the n-3 polyunsaturated fatty acid content of muscle and adipose tissue in lambs. *Journal of Animal Science, 82*, 1461-1470.

Demirel, G., Wachira, A.M., Sinclair, L.A., Wilkinson, R.G., Wood, J.D. & Enser, M. (2004). Effects of dietary n-3 polyunsaturated fatty acids, breeds and vitamin E on the fatty acids of lamb muscle, liver and adipose tissue. *British Journal of Nutrition, 91*, 551-565.

Fisher, A.V., Enser, M., Richardson, R.I., Wood, J.D., Nute, G.R., Kurt, E., Sinclair, L.A. & Wilkinson, R.G. (2000). Fatty acid composition and eating quality of lamb types derived from four diverse breeds x production systems. *Meat Science, 55*, 141-147.

Liu, Q., Scheller, K. K., Arp, S. C., Schaefer, D. M. & Williams, S. N. (1996). Titration of fresh meat colour stability and malondialdehyde development with steers fed vitamin E-supplemented diets. *Journal of Animal Science 74*, 117-126.

Nute, G.R., Richardson, R.I., Wood, J.D., Hughes, S.I., Wilkinson R.G. Cooper, S.L., Sinclair, L.A., (2006) Effect of Dietary Oil Source on the Flavour and Stability of Lamb Meat. Meat Science (Submitted)

Sanudo, C., Enser, M., Campo, M.M., Nute, G.R., Maria, G., Sierra, I. & Wood, J.D. (2000). Fatty acid composition and sensory characteristics of lamb carcasses from Britain and Spain. *Meat Science, 54,* 339-346.

Tarladgis, B.G., Watts, B.M. & Younathan, M.T. (1960). A distillation method for the quantitative determination of malonaldehyde in rancid foods. *Journal of the American Oil Chemists Society, 37*, 44-48.

Wachira, A.M., Sinclair, L.A., Wilkinson, R.G., Enser, M., Wood, J.D. & Fisher, A.V. (2002). Effects of dietary fat source and breed on the carcass composition, n-3 polyunsaturated fatty acid and conjugated linoleic acid content of sheep meat and adipose tissue. *British Journal of Nutrition, 88*, 697-709.