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in

Molina Alcaide E. (ed.), Ben Salem H. (ed.), Biala K. (ed.), Morand-Fehr P. (ed.). Sustainable grazing, nutritional utilization and quality of sheep and goat products

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 67

2005
pages 133-141

Article available on line / Article disponible en ligne à l'adresse :

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To cite this article / Pour citer cet article

Wood J.D., Fisher A.V., Nute G.R., Whittington F.M., Richardson R.I. **Effects of diets on fatty acids and meat quality.** In : Molina Alcaide E. (ed.), Ben Salem H. (ed.), Biala K. (ed.), Morand-Fehr P. (ed.). *Sustainable grazing, nutritional utilization and quality of sheep and goat products* . Zaragoza : CIHEAM, 2005. p. 133-141 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 67)

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Effects of diets on fatty acids and meat quality

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SUMMARY – The balance between polyunsaturated (P) and saturated (S) fatty acids in sheepmeat is unfavourable according to nutritionists. However, sheepmeat has significant concentrations of *n*-3 polyunsaturated fatty acids whose health benefits are now recognised. Furthermore these can be increased by feeding dietary ingredients which contain high levels naturally, such as grass and linseed (high in 18:3 *n*-3, the precursor of the *n*-3 series) or fish oil (high in the long chain *n*-3 fatty acids). The P:S ratio can be rectified by feeding dietary lipid sources that are "protected" from rumen biohydrogenation. Fatty acids have important roles in meat quality, for example in regulating fat firmness, shelf life and flavour. Oxidation of unsaturated fatty acids occurs naturally to benefit meat quality although excessive production of lipid oxidation products may impact adversely. Tissue antioxidant status is a major factor regulating oxidation, with vitamin E playing a central role. Grass feeding boosts vitamin E levels to the benefit of meat quality and possibly also the wellbeing of the animal.

Key words: Meat quality, sheep meat, fatty acids, shelf life.

RESUME – "*Effets des régimes sur les acides gras et la qualité de la viande". Selon les nutritionnistes, le bilan entre les acides gras saturés (AGS) et polyinsaturés (AGPI) de la viande de mouton n'est pas adéquat. Cependant les teneurs en AGPI* n-*3 de la viande de mouton, dont les effets positifs pour la santé ont déjà été prouvés, ne sont pas négligeables. Par ailleurs, la quantité de ces composés peut être augmentée par l'incorporation dans la ration d'aliments naturellement riches en AGPI, tels que l'herbe ou les graines de lin (riches en 18:3* n-*3, le précurseur de la série des acides* n-*3) ou l'huile de poisson (riche en acides gras* n-*3 à chaîne longue). Le rapport AGPI/AGS peut également être modifié par l'apport dans la ration de lipides protégés des phénomènes de biohydrogénation qui ont lieu dans le rumen. L'impact des acides gras sur la qualité de la viande est considérable, notamment sur la fermeté de la matière grasse, la durée de conservation, et la flaveur. L'oxydation des AG insaturés se déroule naturellement et a un impact positif sur la qualité de la viande, bien qu'une oxydation excessive des lipides puisse avoir un effet négatif. Le statut antioxydant du tissu est un important facteur de régulation de l'oxydation, au sein duquel la vitamine E occupe une place essentielle. L'utilisation de l'herbe dans l'alimentation animale augmente les teneurs en vitamine E au profit de la qualité de la viande et probablement aussi du bien-être animal.*

Mots-clés : *Qualité de la viande, mouton, acides gras, durée de conservation.*

Introduction

Interest in the fatty acid composition of meat stems, mainly from the effects of fatty acids on the health of consumers, is increased. Saturated fatty acids are "bad" because they are implicated in various diseases such as cardiovascular disease and cancer and unsaturated fatty acids are "good" because their consumption is associated with a lower risk of these conditions. Official bodies such as the UK Department of Health (1994) have recommended that the ratio of polyunsaturated (P) to saturated (S) fatty acids (P:S) in the diet should be about 0.4. The major fatty acids which contribute to this ratio are shown in Fig. 1. Lamb and beef are higher than pork (and poultry) in the saturated fatty acids palmitic (16:0) and stearic (18:0) and lower in the major polyunsaturated fatty acid (PUFA), linoleic acid (18:2). This means that the P:S ratio is less than 0.4 in the two ruminant species (Fig. 2). More recently, nutritionists have focussed on the type of PUFA in the diet and the balance between the *n*-6 PUFA formed from 18:2 and the *n*-3 PUFA formed from α-linolenic acid (18:3). The recommended ratio of *n*-6:*n*-3 is below 4.0 and, as can be seen, the ruminant meats have more favourable ratios than pork in this case. In a survey of meat purchased in supermarkets (Fig. 1), the percentage of 18:3 in lamb was double that in beef. We have consistently seen this in our studies.

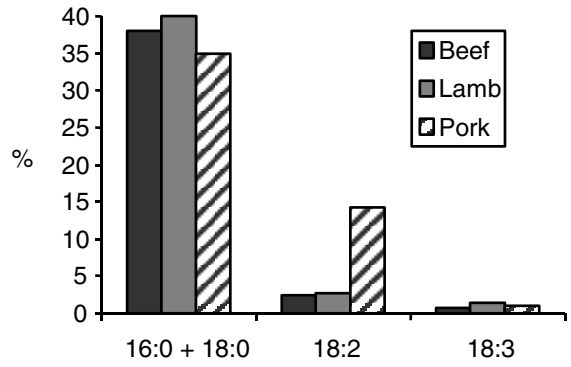

Fig. 1. Fatty acid composition (%) of *longissimus dorsi* muscle in beef, lamb and pork (Enser *et al*., 1996).

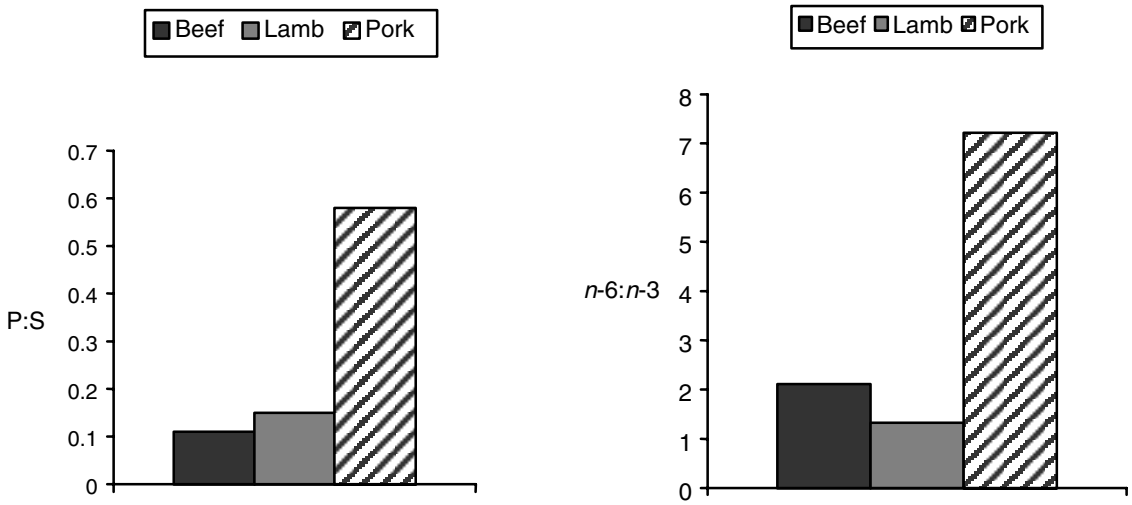

Fig. 2. Fatty acid ratios in muscle – P:S and *n*-6:*n*-3 (Enser *et al*., 1996).

Interest in meat fatty acids is also explained by their effect on the firmness of fat tissue and meat. Fatty acids have different melting points caused by differences in the number of double bonds and chain length (Fig. 3). Therefore, high concentrations of saturated fatty acids cause fat to be hard at room temperature and affect "mouth feel". This is particularly important in lamb which has high concentrations of saturated fatty acids.

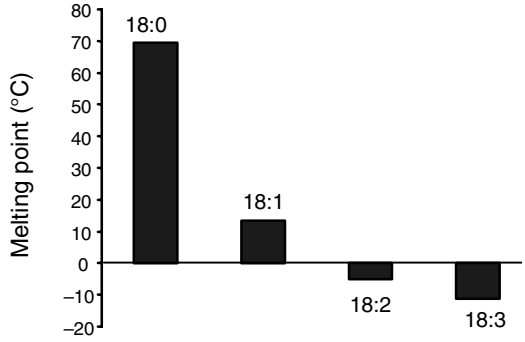

Fig. 3. Melting point of pure C18 fatty acids (°C).

Effects of dietary fatty acids on tissue composition and meat quality

Fat firmness

In lambs, as with pork and beef, the concentration of 18:0 is a good predictor of the melting point of subcutaneous fat and the hardness of the fat when eaten (Fig. 4). The data in Fig. 4 are taken from a study of 1000 lambs selected in 4 abattoirs and sampled throughout the year. The average melting point of subcutaneous fat was 39.5°C and the correlation between 18:0 and melting point was 0.89. It was calculated that only 35% of these fat samples would melt in the mouth when eaten, the rest having the "sticky" mouth feel of sheepmeat. The lowest melting points and concentrations of 18:0 during the year were in May-August, when the lambs have grazed.

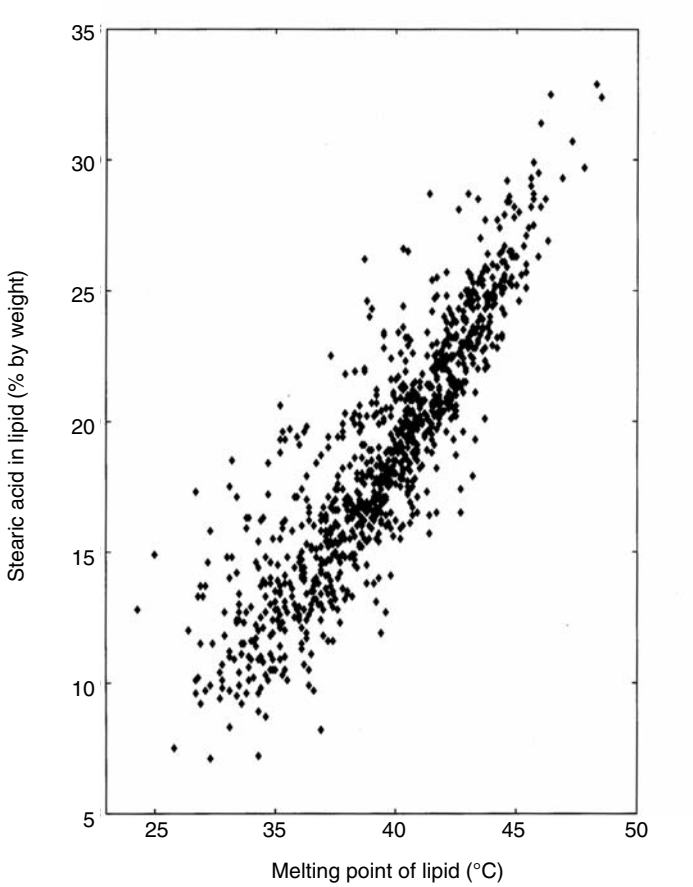

Fig. 4. Relationship between melting point of lipid and concentration of 18:0 (stearic acid) in lamb subcutaneous fat (Enser and Wood, 1993).

In lambs, especially ram lambs, soft fat develops in animals fed grain-based (concentrate) diets. This is due not only to a lower concentration of 18:0 but also to an increased deposition of medium to long-chain (C10-C17) branched chain fatty acids formed from methylmalonate, a metabolite of propionate (Busboom *et al.*, 1981). These authors found that the total concentration of branched chain fatty acids was a good predictor of lamb fat firmness but the correlation with 18:0 was equally strong. As the concentration of branched chain fatty acids increased, that of 18:0 fell, perhaps by direct inhibition.

Fatty acid composition of muscle

The presence of the rumen makes fatty acid composition in beef and sheep more difficult to manipulate by changing diet than in pigs. Nevertheless, there are some clear effects of diet on tissue fatty acid composition.

The results in Fig. 5 are from a study by Wachira (1999) in which concentrate diets containing different fat sources were fed to Suffolk × Lleyn ram lambs between 26 and 40 kg live weight. Fat content of each diet was 6% of dry matter (DM). Feeding whole linseed, a good source of 18:3, doubled the concentration of this fatty acid in muscle. There was no increase in eicosapentaenoic acid (20:5 *n*-3) after feeding linseed which contrasts with the results of Scollan *et al*. (2001) in beef cattle. In more recent work, we have obtained bigger effects on tissue fatty acid composition by feeding sources of linseed and fish oil that are protected from rumen biohydrogenation by reacting the dietary protein with formaldehyde. This produces a matrix in which dietary lipid is trapped and unavailable to rumen microorganisms. The lipid is then released when exposed to the higher pH conditions of the small intestine. In this way, dietary PUFA are absorbed unchanged and deposited in body tissues. In a recent study (Cooper *et al*., 2004), 18:3 was increased to 3.8% of neutral lipid fatty acids by feeding a protected linseed supplement.

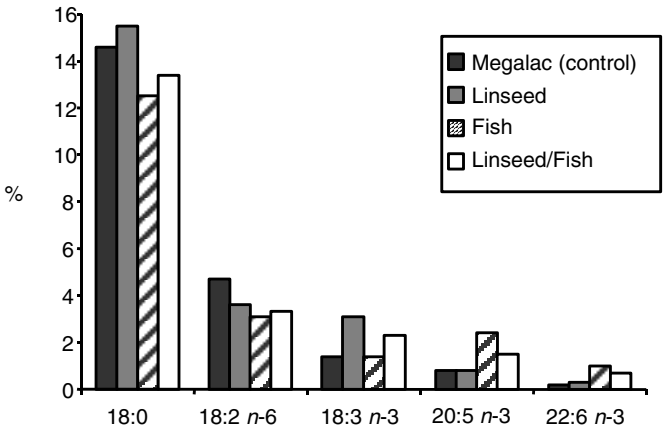

Fig. 5. Effects of dietary lipid sources on *longissimus dorsi* fatty acids (%) in Suffolk lambs (Wachira, 1999).

Effects of fatty acids on shelf life

Shelf life in lamb, in common with other meats, is determined mainly by the persistence of the bright red colour of oxymyoglobin in the meat surface. This colour change from red to brown, denoting the appearance of metmyoglobin, can be accelerated by several factors, including free radicals produced from oxidation of unsaturated fatty acids. Leg muscles from the lambs in Fig. 5 were displayed for 6 days under retail conditions after which fatty acid oxidation, was assessed by measuring thiobarbituric acid-reactive substances (TBARS). The results (Fig. 6) show that oxidation was greatest in the animals fed fish oil. This value exceeded 2.0, which is the point at which oxidation products begin to produce a rancid flavour in the meat. Values were lower than 2.0 in all other diets.

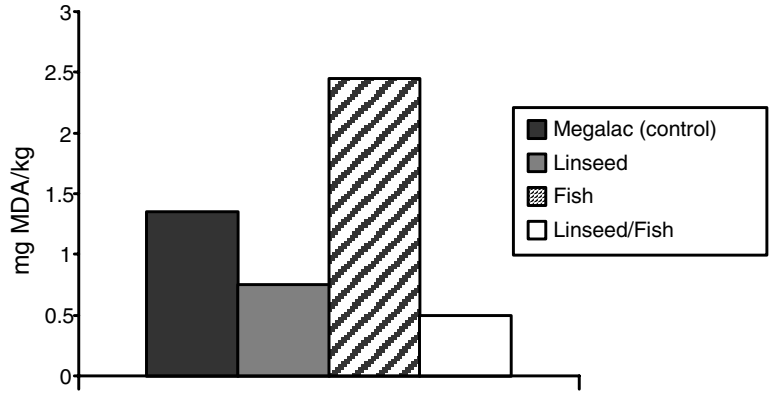

Fig. 6. Effects of dietary lipid sources on lipid oxidation (TBARS, mg MDA/kg) in leg muscles of Suffolk lambs conditioned for 6 days then displayed for 6 days (Kurt, 1999).

Colour is commonly measured using a colour meter which records CIELAB coordinates. From these, the parameter saturation can be calculated which is a measure of colour intensity. This value falls as the muscle pigments oxidise. In the samples described in Figs 5 and 6, saturation declined fastest in the fish oil group during retail display following 10 days conditioning. However, the change in saturation was less marked than we have seen in similar studies with beef.

Effects of fatty acids on flavour

Flavour in meat derives from volatile compounds produced during cooking. Some of these are products of Maillard reactions between sugars and amino acids and some are derived from fatty acid oxidation. Also, the fatty acid oxidation products interact with products from Maillard reactions to produce a further range of odour and flavour compounds. Elmore *et al*. (2000) cooked muscle samples from the lambs fed the megalac, linseed, fish oil and fish oil/linseed diets and found that lipid oxidation products were at much higher concentrations in the more unsaturated samples, especially fish oil. These results were similar to those in beef cattle fed similar diets (Elmore *et al*., 1999).

The trained taste panel at Bristol evaluated grilled loin chops from these same lambs and the results for the main flavour terms (Fig. 7) showed no important differences between the diets. These results suggest that the extra volatile compounds observed by Elmore *et al*. (2000) on cooking the more unsaturated lamb samples were not detected by the panellists. Alternatively, the concentrations observed were below the detection threshold. In subsequent work with rumen-protected linseed and fish oil diets, we have increased *n*-3 PUFA to higher levels than shown in Fig. 5. This has impacted on taste panel scores, in particular for "fishy" in the case of fish oil.

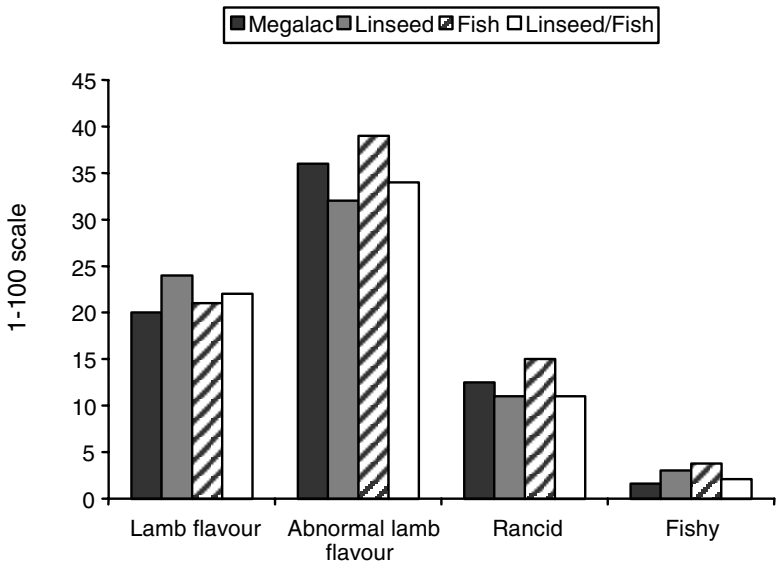

Fig. 7. Effects of dietary lipid sources on eating quality of grilled loin chops (1-100 scales, data from 3 breeds, pooled).

Studies with beef and lamb have shown that *n*-3 PUFA concentrations in phospholipids and neutral lipids are increased when grass, fresh or conserved, is the main constituent of the diet (Enser *et al*., 1998). In a study by Fisher *et al*. (2000), Suffolk cross lambs were reared on lowland grass or on a standard concentrate diet. The total lipid of *semimembranosus* contained higher concentrations of 18:3, 20:5 and 22:6 *n*-3 PUFA in the grass-fed group and higher concentrations of 18:2 and 20:4 *n*-6 in the concentrate group (Fig. 8). In grilled loin chops, taste panellists gave higher scores for lamb flavour and overall liking to the grass group and higher scores for abnormal lamb flavour, metallic, bitter and rancid to the concentrate group (Fig. 9).

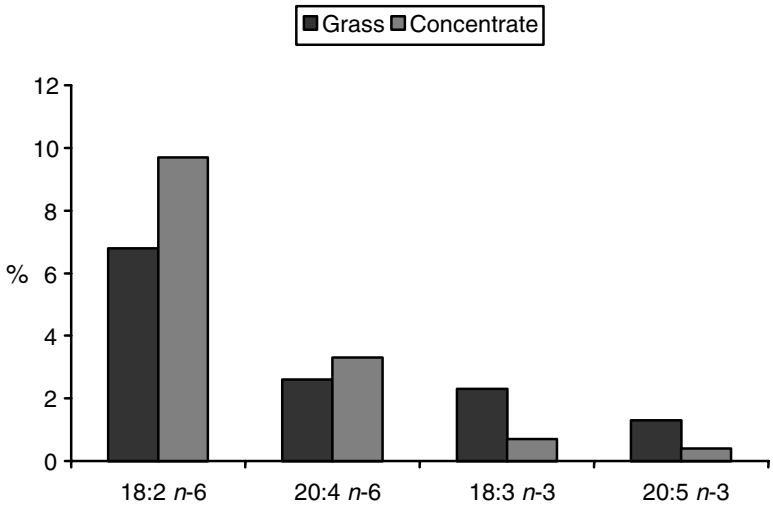

Fig. 8. *n*-6 and *n*-3 PUFA (%) in *semimembranosus* muscle of Suffolk cross lambs (Fisher *et al*., 2000).

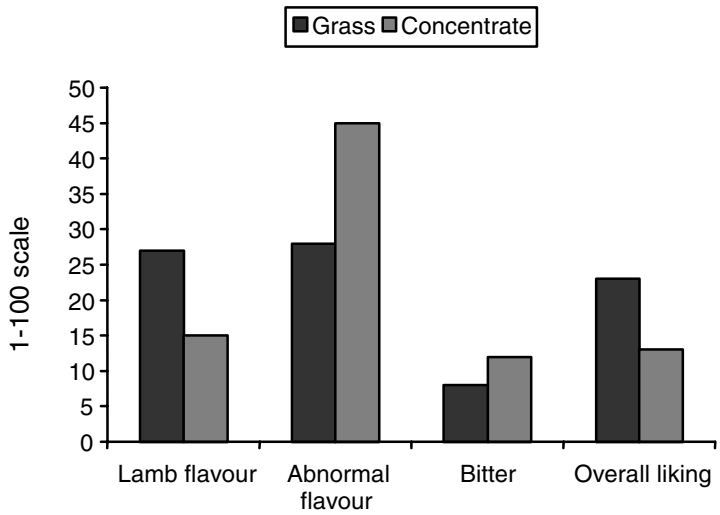

Fig. 9. Flavour scores given by trained taste panel (Fisher *et al*., 2000).

In a study involving British lambs fed grass and Spanish lambs fed milk and concentrates, similar differences in fatty acid composition were observed, i.e. the grass fed animals had higher muscle concentrations of *n*-3 PUFA and the concentrate-fed animals had higher concentrations of *n*-6 PUFA (Sañudo *et al*., 2000). When the meat was assessed by both British and Spanish taste panels, both found the British lamb (higher in *n*-3 PUFA) to have a higher odour and flavour intensity, but whereas the British panel preferred the flavour and overall eating quality of the grass-fed lamb, the Spanish panel scored flavour liking and overall liking higher in the Spanish lamb (Fig. 10). This preference for grain-finished products is also expressed by USA taste panellists and consumers who are more used to the taste of beef and lamb produced in feedlot conditions, and prefer it to grass-fed beef and lamb (Larick and Turner, 1990). In the British/Spanish data set, wide ranges of *n*-3 and *n*-6 PUFA concentrations were found and quite strong correlations were seen between these and the taste panel scores, the strongest relationships involving 18:2, 20:4 and 18:3 (Table 1). For example the concentration of 18:3 was positively correlated with odour and flavour intensity scores given by both taste panels. The correlations with flavour liking and overall liking were positive for the British panel and negative for the Spanish panel.

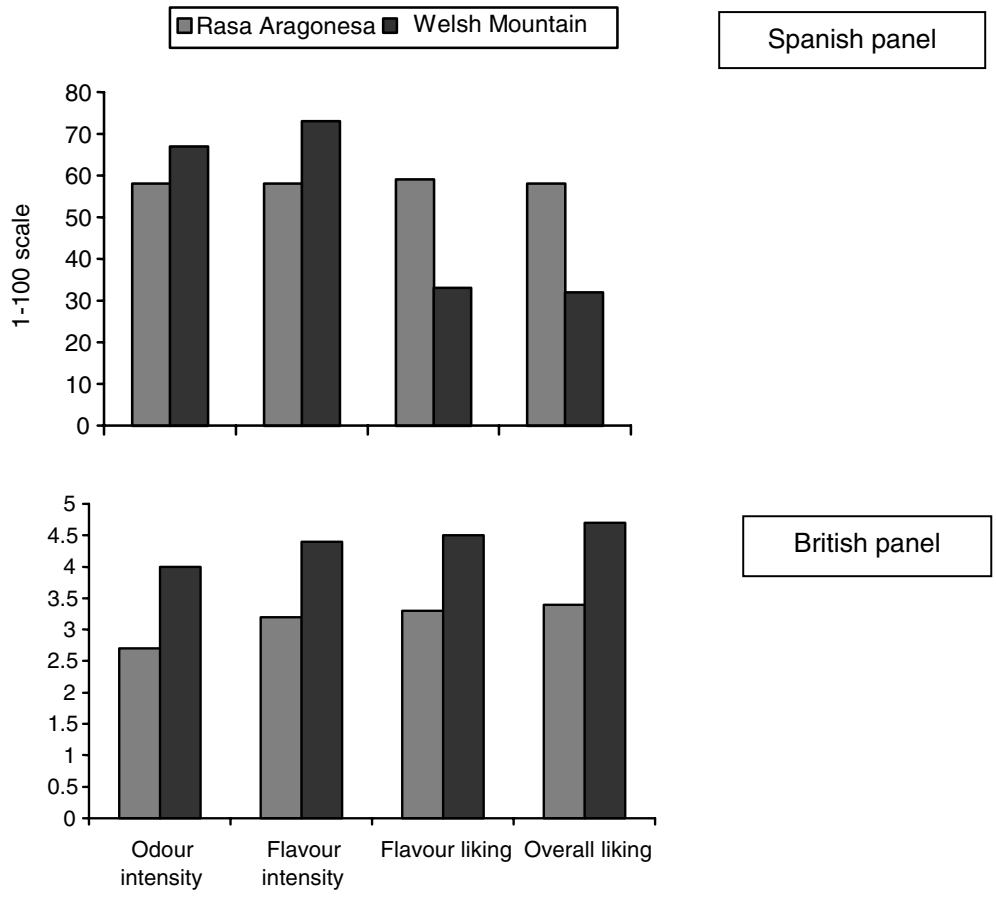

Fig. 10. Scores given by Spanish and British taste panels (Sañudo *et al*., 2000).

Table 1. Correlations between fatty acid composition (%) and taste panel scores given by a Spanish (ESP) and British (GB) taste panel (Sañudo *et al*., 2000)

	Flavour intensity		Flavour liking	
	ESP	GB	ESP	GB
18:2 *n*-6	–0.5	–0.6	0.7	–0.5
18:3 *n*-3	0.4	0.7	–0.7	0.6

An explanation for these positive relationships between 18:3 and meat flavour is that the oxidation products of 18:3 and its derivatives are directly responsible for the differences in flavour observed between grass-fed cattle and sheep. Larick and Turner (1990) also found that the head space volatile compounds produced on cooking beef fed grass or grains were dominated by lipid oxidation products, especially aldehydes and Priolo *et al.* (2001) concluded in a review that *n*-3 PUFA oxidation products are mainly responsible for the particular flavour of grass-fed lamb. However, another explanation for the results is that *n*-6 and *n*-3 PUFA are markers for grain and grass diets, respectively and other components of meat are more directly responsible for the flavours produced. In sheep, several authors have shown that branched chain fatty acids of medium chain length are important constituents of lamb odours and flavours (Wong *et al*., 1975), and Young *et al.* (1997) showed that 4-methyloctanoic acid and 4-methylnonanoic acid were increased on a grass compared with a grain diet. Grass feeding also increased concentrations of diterpenoids, which derive from chlorophyll breakdown in the rumen. Similar results have been found in cattle (Melton, 1990). Young *et al*. (1997) also found that the concentration of 3-methylindole (skatole), which is responsible for boar taint in pigs, was increased in grass diets and was partly responsible for the grass-fed effect.

Several studies with cattle have shown that the bright red colour associated with oxymyoglobin is retained longer after grass feeding compared with grain feeding, i.e. shelf life is increased (Wood *et al*., 2004). This is linked to a reduced oxidation of muscle lipid (lower TBARS). We have speculated that this is due either to increased uptake of the main tissue antioxidant vitamin E from grass or accumulation of other antioxidants from grass which protect vitamin E or enhance its effects. Results in Table 2 are from a study in which lambs were fed a concentrate diet or a mixed grass-concentrate diet, the concentrate portions containing 60 or 500 mg/kg vitamin E. The results show that in the 60C diet the level of vitamin E in muscle was well below the target value of 3.0-3.5 mg/g found by other workers to be optimum (in fact 60 mg/kg is well above the normal level in concentrates which is 10-20 mg/kg). In this 60C group, lipid oxidation was greatest at day 6 of display. However, there was no clear effect of vitamin E on colour saturation and no evidence that grass feeding enhanced colour shelf life. These results show that shelf life in sheep and cattle is regulated in different ways and that metabolism of vitamin E is also different. More research is needed to understand these processes in sheep.

Table 2. Measurements made on *semimembranosus* muscles of lambs following feeding of a concentrate diet (C) or a mixed grass-concentrate diet (M). The concentrate contained 60 or 500 mg vitamin E/kg (Kasapidou, 2003)

	60C		500C	60M	500M
Muscle vitamin E†	1.01[a]	3.41[b]	2.88[b]	4.67[c]	
TBARS day 6	1.98[b]		0.07[a]	0.24[a]	0.09[a]
Colour sat day 6	18.43		18.87	19.04	18.79
18:2 *n*-6††	16.1[b]		16.1[b]	8.9[a]	10.2[a]
18:3 *n*-3††	2.0[a]	1.9[a]	2.8[b]	3.1[b]	

†mg/g.
††% of phospholipid fatty acids.
[a,b,c]Means with different superscripts are significantly different ($P < 0.05$).

Acknowledgements

The research reported here was funded by Department for Environment, Food and Rural Affairs (DEFRA), Meat and Livestock Commission (MLC), Roche Products Limited, ABN Limited, Pedigree Petfoods, Rare Breeds Survival Trust and Tesco Stores Limited.

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