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Effect of animal and nutritional factors and nutrition on lamb meat quality

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SUMMARY – Consumption of lamb meat in the EU has remained constant for several years, although there has been a decrease in countries with high consumption and a increase in countries that consume low amounts of lamb meat. Lamb meat is a natural product, with a characteristic flavour, which because of its high price, is regarded as a luxury product. The parameters that define lamb meat quality, colour, juiciness, tenderness and flavour, are discussed. Colour is the main factor that consumers use to discriminate when buying lamb. These parameters are influenced by biological and technological factors, the most important of which are live weight and diet composition, which affect the amount and composition of fat in different adipose tissues.

Key words: Lamb, meat quality, animal factors, nutritional factors.

RESUME – *"Effets des facteurs animaux et nutritionnels sur la qualité de la viande d'agneaux". La consommation de viande d'agneau dans l'Union Européenne n'a pas variée au cours de ces dernières années. Cependant, il y a eu une diminution dans les pays à haute consommation d'agneau et une augmentation dans les pays à basse consommation. La viande d'agneau est un produit naturel, avec une flaveur caractéristique. En raison de son prix élevé, elle est considérée comme un produit de luxe. Dans cet article, les paramètres caractéristiques de la qualité de la viande d'agneau, comme la couleur, la tendreté, la jutosité et la flaveur ont été discutés. La couleur est le principal facteur de choix pour l'achat de viande ovine par les consommateurs. Tous ces paramètres sont influencés par des facteurs biologiques et technologiques dont les plus importants sont le poids vif et la composition de la ration qui peuvent influencer la quantité et la composition des lipides des différents tissus adipeux.*

Mots-clés : *Agneau, qualité de la viande, facteurs animaux, facteurs nutritionnels.*

Introduction

The concept of meat quality is very difficult to define because of the subjective nature of the attributes which are commercially important, such as colour, texture, juiciness and flavour. Definition is further complicated by the intrinsic heterogeneity of meat, even from one species. For the consumer, quality includes a series of characteristics which make the cooked meat edible, attractive, appetising and nutritious. It is, therefore, more appropriate to speak of the "quality that the consumer perceives". In general, lamb is perceived by the consumer as a natural product, with a characteristic taste, free of substances that affect human health, but also as an expensive and, therefore, to some extent a luxury product. The requirements for lamb meat are very specific for particular markets. Some aspects of quality are, however, also related to, or modified by, the chain of production and marketing.

As a result of the existence of numerous breeds of sheep and a diversity of production systems, there is a wide variety of carcasses to satisfy different consumer requirements both, in local and international markets. In Northern and Central Europe heavy carcasses of 16-23 kg are preferred, and in the Mediterranean Basin, very light carcasses of 4-8 kg from milk lambs, and of 8-12 kg from young lambs finished on concentrates.

Lamb fat, as in that of other ruminants, has a very low content of polyunsaturated fatty acids (PUFA), and a very much greater content of saturated fatty acids, because of the hydrogenation of unsaturated fatty acids in the diet by the rumen micro-organisms, and of the existence of a variety of fatty acids specific to ruminants, such as trans-unsaturated fatty acids, and odd chain and branched chain fatty acids.

Dietary fat generally has less effect on the fat composition of ruminants than of monogastric animals. Wide variations are, however, reported in the fatty acid composition of each carcass fat depot. Although nutrition of lambs has an important effect on the quantity and, to a lesser extent, on the quality of the carcass fat, other factors, such as sex, breed, age at slaughter and system of production, which are closely related to the feeding system, also influence fat deposition. This paper, therefore, discusses the effects not only of nutrition but also of these factors on the organoleptic qualities that determine the acceptability of lamb meat to the consumer.

Consumption of lamb meat

In the 12 countries comprising the European Union prior to the entry of Austria, Finland and Sweden in 1994, the total consumption of all meats and of sheep and goat meat showed very little change between 1987 and 1997. Total annual consumption increased from 85.0 to 85.5 kg per capita, and consumption of sheep meat from 3.7 to 3.9 kg per capita. In the countries of North Africa and the Middle East bordering the Mediterranean, sheep is generally the most preferred meat, although consumption is much lower than that of poultry, which is largely produced industrially from imported grain.

The small increase in average consumption of sheep and goat meat in the EU 12 masks contrasting trends in individual countries. In Greece and the United Kingdom, the countries with the highest and third highest per capita consumption in 1987, consumption declined by 2 and 10 per cent to 13.8 and 6.0 kg/head, respectively. In all other countries consumption increased. The increases ranged from 7% to 18% in Spain, France and Ireland, where consumption was 6.5, 5.1 and 8.0 kg/head respectively in 1997, to small absolute, but large percentage, increases in countries with consumption per capita of less than 3.0 kg in 1987, ranging from 23% in Portugal to 150% in the Netherlands. The increase was negligible in Italy. In these countries, lamb meat is an alternative, almost luxury, meat.

This trend in consumption results in an increased emphasis on carcass quality to maintain the market share of lamb. There are several indicators of the importance of quality. In Northern and Central Europe, especially in the large French market, low fat cover is very important and specifications are very closely defined for both carcass weight and fat class within the EU official classification scheme. For British exporters the official scheme was not sufficiently precise, and a division of fat class 3 into low (L) and high (H) was introduced, to enable the ideal export carcasses to be differentiated. Exports from New Zealand now contain a proportion of specially selected chilled joints at high prices, indicating the increasing importance of quality in the European market.

The introduction of Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) regulations, for lamb carcasses from specific systems of production in specific geographical areas, is gaining importance as another method of promoting more consistent production of carcasses with specified characteristics. There is a number of these schemes in Portugal, Spain, France and now in Scotland. The introduction of individual identification of animals, which has already begun in France and is under discussion in the remainder of the EU, will widen and simplify the process of associating carcass characteristics with production systems, breeds, and pre- and post-slaughter handling.

All these trends point to the importance of research to identify the factors that really determine the carcass characteristics associated with consumer preferences for particular types of sheep meat. Criteria, such as carcass weight and fatness, although associated in a general way with some aspects of quality, are often poor indicators of quality in specific groups of animals. As the acceptability of different intensities of flavour in lamb meat varies widely both between and within countries, there is a need for definitions of quality related to measurable characteristics of flavour. Rousset-Akrim *et al*. (1997) and Young *et al*. (1997) indicate that the intensity of different flavours in lamb meat produced in different systems is associated with retronasally assessed smell of volatile compounds in the heated fat. Work is needed to explore more fully the extent to which these compounds are affected by growth patterns of lambs, the use of different feeds and handling pre- and post-slaughter.

Organoleptic quality of lamb meat

Effects of pre- and post-slaughter factors on the organoleptic quality of lamb meat

Meat quality is influenced by pre-slaughter factors that determine the composition of the muscle, by various biochemical reactions after slaughter and by technological factors, which determine the intensity of these reactions (Fig. 1).

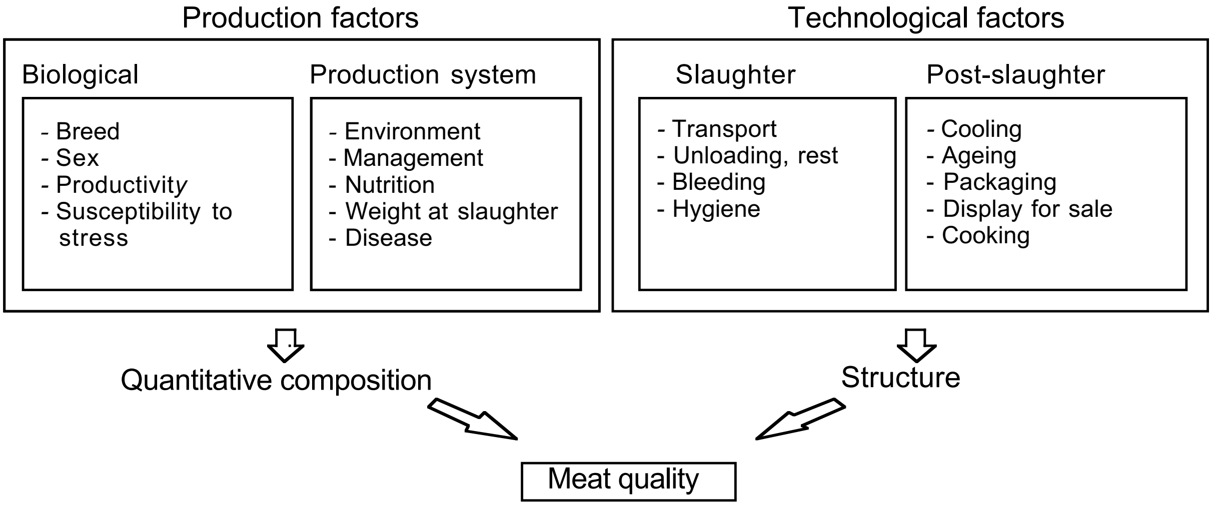

Fig. 1. Factors that influence the quality of meat.

After slaughter, there is a series of physio-chemical and biochemical changes in the skeletal muscles, which include the establishment of *rigor mortis* and a phase of aging. The length of aging used varies between species. These changes, to a great extent, determine the organoleptic quality of lamb meat and its suitability for packaging. The organoleptic quality of meat is determined by sensory characteristics related to colour, texture, smell, flavour and juiciness.

Aging results in a progressive softening of the muscle, a slight increase in water retention capacity and the development of a characteristic smell. Maturing lamb meat for 2-5 days increases the acceptability of the flavour, tenderness and general palatability. In Mediterranean countries, however, meat from light carcasses may be consumed 1 or 2 days after slaughter without a period of maturation.

The rapid cooling of muscle can cause the phenomenon called "cold shortening", which results in a considerable increase in the toughness of the meat, which is not reduced by maturing. Other processes, such as packing in a modified atmosphere, the use of lactic bacteria and/or bacteriocins and irradiation can be used, in addition to refrigeration, can improve the shelf life of the meat. Consumer acceptability and the subjective quality of lamb meat is also affected by the method of butchering, preparation for sale, marketing, the gastronomic tradition of the region and cooking methods.

pH

The main factor determining the quality of meat is its pH, which is related to biochemical processes during the transformation of muscle to meat. Consequently changes in the pH during the *post-mortem* period influence the organoleptic characteristics of the meat.

Stress before slaughter in lambs can produce a high level of pH. This affects meat colour more than other pre-slaughter factors. Also, as a result of the strong binding of water to proteins, the normal release of juices during mastication is reduced and the meat is very dry.

Type of muscle. The speed of degradation of glycogen differs between "red" and "white" muscles. Red muscles are characterised by the presence of many red fibres, which contract slowly, have an oxidative metabolism and a low concentration of glycogen, which is actively degraded to glucose. White muscles contract rapidly and have a high concentration of glycogen, normally with a glucolytic metabolism and an active degradation to lactic acid (Lawrie, 1988), which results a more rapid reduction in pH. As the proportions of red and white fibres differ within the muscles and between muscles in different parts of the body, it is important to measure the pH at several places in each muscle. The position of the muscle in the body also affects the final pH of the muscle.

Breed. No significant differences have been found in the final pH of the *Longissimus dorsi* muscle of English (Dransfield *et al*., 1979) and Spanish breeds (Sañudo *et al*., 1986). Horcada (1996), however, found higher final pH values in the Spanish Rasa Aragonesa than in the Lacha in lambs both slaughtered at 24 kg live weight (LW).

Sex. There is a slight tendency for males, because they are more excitable, to have slightly higher pH values than females. No differences in final pH were found by either Dransfield *et al*. (1990), between males, male castrates and female Suffolk lambs, or by Horcada *et al*. (1998) between male and female Lacha and Rasa Aragonesa weighing 12 and 24 kg LW.

Live weight. Although the concentration of glycogen generally increases with age, meat from older animals does not always have a lower pH (Smith *et al*., 1979; Solomon *et al*., 1980; Hawkins *et al*., 1985). For example, Sañudo *et al*. (1996) found an increase in final pH in muscle from 13 kg carcasses of Rasa Aragonesa lambs compared with 8 kg carcasses. Horcada (1996) had similar results in Lacha and Rasa Aragonesa, with higher pH values in carcasses from lambs slaughtered at 24 kg than at 12 kg, although the carcasses from 36 kg lambs had a lower pH.

Nutrition. A low plane of feeding can result in chronic nutritional stress, characterised by low reserves of muscle glycogen and increased final pH values in the meat (Bray *et al*., 1989). The plane of feeding and the type of feed are closely related to the effect of the period of pre-slaughter fasting and stress before slaughter.

Stress. Sheep appear to be little affected by stress and do not show abnormal decreases in pH. Brazal and Boccard (1977) found no significant differences in average pH values in *Longissimus dorsi* muscles of stressed, tranquillised and control lambs although the decrease in pH was greater in stressed than in control lambs. Devine *et al*. (1993) observed a significant increase in final muscle pH in lambs, which was directly related to the level of stress to which they were exposed.

Colour

Meat colour, one of the most important criteria in initial selection by the consumer, is related to the concentration of pigments, mainly myoglobin, the chemical state of the myoglobin on the surface of the meat, the structure and physical state of muscle proteins and the proportion of intermuscular fat.

Values of pH above the isoelectric point of proteins of 5.5 result in an open structured muscle and a greater diffusion of light between the myofibrils of the muscle, which make the cut face of the meat darker (Seideman and Crouse, 1986).

Breed. Colour can vary with breed and aptitude of breed for meat or milk production. The greater precocity of milk breeds implies an earlier deposition of fat than in meat breeds (Wood *et al*., 1980; Butler-Hogg *et al*., 1986) and a greater concentration of myoglobin as a result of the greater demand for oxygen (Renerre, 1986). Sañudo *et al*. (1993) found no differences in the content of pigment and the L*, a* and b* coordinates of the *Longissimus dorsi* of light carcasses (10-12 kg) of Rasa Aragonesa, Lacaune and German Merino lambs. Similarly Horcada (1996) found no significant differences in the content of pigments in meat from Lacha and Rasa Aragonesa lambs weighing from 12 to 36 kg before slaughter; the Rasa Aragonesa, however, had lower value for lightness (L*). A comparison by Sierra *et al.* (1988) of carcasses from 24 kg live weight lamb from British and Spanish breeds found that the content of myoglobin was higher in the British than in the Spanish lambs.

Sex. Dransfield *et al*. (1990) found no significant differences in colour parameters between males, castrate males and females. Similarly, Horcada *et al.* (1998), found no differences in colour parameters between Rasa Aragonesa and Lacha males and females, fed in the same way and slaughtered at the same age.

Live weight. The intensity of meat colour increases with age, because the concentration of myoglobin in the meat increases (Jacobs *et al*., 1972; Morbidini *et al*., 1994). The increase is rapid in the first stages of development of the animal but stabilises later. Sañudo *et al*. (1993) found greater quantities of pigments and lower value for lightness (L*) in meat from lambs of 28-30 kg live weight than in that from 23-25 kg lambs of the Rasa Aragonesa, Lacaune and German Merino breeds. Horcada (1996) found higher value for lightness (L*) in meat from Rasa Aragonesa and Lacha lambs weighing 12 and 24 kg than in those of 36 kg.

Nutrition. Meat from suckling lambs is paler than that from weaned lambs because of the low concentration of iron in ewe milk (Lawrie, 1988). The increased pigmentation in meat from weaned lambs is due to a higher iron content in diets rich in forages and concentrates. Kirby (1996) showed that feeding a supplement of 500 IU of vitamin E increased the shelf life of lamb meat by four days. This was not improved by feeding a higher level of vitamin E (1000 IU) or vitamin E enriched with selenium.

Exercise. Muscles used in walking are darker because of the greater requirement for oxygen for the release of energy in the muscle. Thus the *Extensor carpi radialis* locomotor muscle is darker and has a higher concentration of myoglobin than the *Longissimus dorsi* support muscle (Cross *et al*., 1986).

Texture

Meat texture is perceived as a combination of tactile sensations resulting from the interaction of the senses with physical and chemical properties, such as toughness, moisture and elasticity. Toughness can be defined as the ease with which meat can be cut and masticated, and is principally related to the muscle proteins. It is, however, also affected by intramusclar fat, the structure of the connective tissue, the size of the muscle bundles, rigidity and water retention capacity. In lamb meat there is little variation in toughness if the management of cooling after slaughter is correct. In other species, especially cattle, toughness is one of the most important criteria that determine meat quality for the consumer (Ouali, 1991).

Breed. Differences between breeds are associated with muscle characteristics. Breeds with muscles with a greater content of white fibres or with muscles that are more susceptible to proteolytic degradation during the Aging of the meat produce more tender meat (May, 1976).

Sierra *et al*. (1988) found that the meat of Spanish "ternasco" type lambs was slightly more tender than meat from lambs of British breeds slaughtered at the same weight. Horcada (1996) did not detect differences in tenderness between carcasses of the same weight from the Rasa Aragonesa and Lacha breeds, using shear force measurements, however Gorraiz *et al*. (1999) found textural differences when using a taste panel.

Sex. At the same age, meat from male is less tender than that from female lambs. After puberty the increase in testosterone in males increases the amount of collagen in the muscle and reduces the tenderness of the meat (Pommier *et al*., 1989).

Live weight. Meat tenderness decreases with age (Kirton, 1976; Ouali, 1991) as a result of an increase in the number of thermo-resistant linkages between the collagen fibres. No differences in meat tenderness, assessed by shear force, were found in carcasses of Rasa Aragonesa and Lacha lambs of 12, 24 and 36 kg live weight before slaughter (Horcada, 1996), possibly because the range of slaughter weights was not sufficient for the collagen to be restructured, and because increases in muscle fat content may have counteracted any decrease in tenderness. However, Gorraiz *et al*. (1999) found differences in texture, assessed by a taste panel, between Lacha and Rasa Aragonesa lambs slaughtered at 12 and 24 kg live weight. The meat from 24 kg lambs was harder, mealier, more cohesive and more difficult to swallow than meat from the milk-fed lambs.

Nutrition. High planes of nutrition increase the tenderness of lamb meat through an increase in intermuscular fat and a relative decrease in muscle collagen (Kemp *et al.*, 1981).

Juiciness

The juiciness of meat is perceived in two ways, first the sensation of moisture in the first moments of mastication produced by the rapid release of juices, followed by the slow release of serum and the stimulating effect of fat on the secretion of saliva.

Water holding capacity (WHC) is the ability of meat to retain its constituent water when an extraneous force or treatment is applied to it. This property affects the retention of vitamins, minerals and salts, as well as the volume of water retained. Muscles that lose water easily are drier and lose more weight during refrigeration, storage, transport and marketing.

Type of muscle. WHC is affected by the position of the muscle in the carcass with muscles in the rear third of the body having a lower WHC (Bouton *et al*., 1972). These differences can be explained by differences in muscle activity, percentage of red fibres, pH and the ratio of water to protein.

Breed. It does not appear that breed has a large effect on WHC. Hawkins *et al*. (1985) found no significant differences between meat from different English breeds. Similarly Sañudo *et al*. (1993) found no significant differences in the amount of water released from the *Longissimus dorsi* of Rasa Aragonesa, Lacaune and German Merino lamb carcasses weighing 13-15 kg. In contrast, Horcada (1996) observed a greater release of water from meat of Rasa Aragonesa than Lacha lambs, especially in lambs slaughtered at 24 kg live weight.

Sex. Horcada *et al*. (1998) found no effect of sex on WHC.

Live weight. In general increases in weight reduce WHC (Kemp *et al*., 1981; Solomon *et al.,* 1980). Horcada (1996), however, observed that meat from Rasa Aragonesa and Lacha lambs slaughtered at 24 kg live weight released water more readily than that from lambs slaughtered at 12 and 36 kg.

Stress. Animals slaughtered with low reserves of glucogen in their muscles as a result of stress have final pH values higher than the isoelectric point of proteins, resulting in the presence of free radicals, which capture water and increase the WHC of the meat (Forrest *et al*., 1979).

Transport appears to have little effect on sheep. Warris *et al.* (1990) found that WHC, measured as losses from semi-extended muscle, was not affected by periods of transport before slaughter of between 1 and 6 hours.

Flavour

Flavour is one of the most important factors in determining consumer acceptability of meat. The basic flavour of meat is related to water soluble compounds in the muscle, such as sugars, amino acids and nucleotides, which are common to different species. The characteristic flavour of meat of a particular species is determined, however, by the proportions of different fatty acids in the fat, and, in particular, by the unsaturated fatty acids, which are more susceptible to oxidation to volatile compounds of low molecular weight, such as aldehydes, ketones hydrocarbons and alcohols, which contribute to the aroma of meat. Phospholipids, which are rich in polyunsaturated fatty acids, also play a fundamental role in the flavour of meat. Breed, sex, system of management, nutrition, and post slaughter treatments of the carcass, can all affect carcass fat and hence the flavour of the meat (Rousset-Akrim *et al*., 1997; Young *et al*., 1997).

Small amounts of intramuscular fat, which are necessary to lubricate the muscle fibres, affect the flavour and juiciness of cooked meat.

The predisposition to oxidation of free fatty acids (linoleic, C18:2) and (arachidonic, C20:4) from the different meat lipid fractions, specially phospholipids in the cell membranes of the muscles and the adipocytes (Christie, 1981) contributes to the appearance of volatile compounds, responsible also for aroma of the meat (Rhee, 1992).

Methodology. Sensory analysis is a method for analysing and interpreting reactions to characteristics of foods and materials perceived by the senses of sight, smell, taste, touch and sound. The sensations experienced by consumers are not an intrinsic characteristic of the food, but result from an interaction between the food and the person. Analysis of the chemical and physical properties of a food provides information on the nature of the stimulus perceived by the consumer, but not on the sensation the consumer experiences.

Different tests exist for analysing the organoleptic characteristics of meat. First, there is a test in which untrained panellists express subjective reactions, indicating whether they like or dislike a food, or prefer one to another. Then there is a test that discriminates between two or more samples. Thirdly, there is a descriptive test which defines the sensory properties of a food and evaluates it as objectively as possible. The latter two tests require trained panellists. Although the descriptive test gives more information on the food than the other two, it is more difficult to carry out, the training of the panellists is more intense, and monitoring and interpretation of the results is more laborious (Cross *et al.*, 1978).

The different instrumental and sensory methods for measuring meat quality are useful and complementary for understanding the criteria of quality used by consumers, and each method has advantages and disadvantages. However, it must be stressed, that the correlations between sensory and instrumental methods are very variable, because of the large number of factors that influence quality.

Breed. It does not appear that breed has a large effect on flavour. Gorraiz *et al*. (1999), using a taste panel, did not find differences in the odour or flavour of meat from Lacha and Rasa Aragonesa lambs of the same weight.

Sex. Horcada *et al*. (1998) found females of Lacha and Rasa Aragonesa breeds had higher amount of intermuscular fat and firmer subcutaneous fat than males. There were no significant differences between sexes in both breeds in total saturated fatty acids, total unsaturated fatty acids and in the Iodine value in three fat depots. Females of Lacha breed had significantly higher percentages of pentadecanoic (C15:0), palmitic (C16:0) and palmitoleic (C16:1) fatty acids than the males. Females of the Rasa Aragonesa breed had a higher percentage of palmitoleic acid (C16:1) in the intramuscular depot and of palmitic acid (C16:0) in the subcutaneous depot than the males. These differences were, however, very small, probably as a result of the low slaughter weight, which was typical of Mediterranean systems. Low slaughter weights are likely to minimise or eliminate sex differences found in some experiments on large lambs from north European and US systems.

Live weight. Increases in weight are associated with an increase in flavour and odour, which may increase to a level that is undesirable (Hawkins *et al*., 1985; Ouali, 1990; Rousset-Akrim *et al*., 1997). Gorraiz *et al*. (1999) showed that live weight influences some aroma and flavour attributes of meat lamb from Lacha and Rasa Aragonesa breeds. Heavier lambs of both breeds had a woolly odour and flavour, and a more intense aftertaste in the cooked meat. Meat from 12 kg LW milk-fed lambs had a higher taste panel score for odour and flavour than meat from concentrate-fed lambs weighing 24 kg before slaughter.

Nutrition. Rousset-Akrim *et al*. (1997) showed that there was little difference in the odours detected by a taste panel in lambs reared on concentrates or at pasture when they were slaughtered at less than 100 days of age. In older lambs slaughtered at 166-217 days, most odours were significantly lower in concentrate fed lambs.

Effects of nutrition on composition of adipose tissues in lambs

More than one hundred fatty acids have been found in lamb adipose tissue. Fat depots mainly consist of three fatty acids, palmitic acid (C16:0), stearic acid (C18:0) and oleic acid (C18:1n-9). Data on fatty acid composition of adipose tissues from 380 groups of lambs in 50 experiments showed that the C16:0 and the C18:1 fatty acids, the two main fatty acids by weight in most adipose tissues, had the lowest variation in both individual and total adipose tissues (Table 1).

Table 1. Mean fatty acid composition of lamb adipose tissues (% by weight)

Adipose tissue	Subcutaneous		Intermuscular		Intramuscular		Perirenal		Omental		Total adipose tissues	
Fatty acids	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
C14:0	4.5	3.5	5.1	12.6	3.5	9.0	3.5	7.6	4.5	17.6	4.1	55
C16:0	23.4	0.8	23.6	3.3	23.1	1.7	21.4	1.4	25.7	3.7	23.0	12
C18:0	14.5	2.9	16.5	10.8	17.1	5.1	27.0	2.6	25.8	7.2	18.0	45
C17:0	2.5	2.6	1.8	14.1	1.3	10.8	2.1	7.4	2.6	9.8	2.2	37
C16:1	3.2	3.2	2.1	20.0	2.8	7.5	2.2	7.9	2.8	18.2	2.9	51
C18:1	41.8	0.8	41.6	3.3	42.1	1.6	37.2	1.4	33.2	4.3	40.5	13
C18:2	4.0	5.1	3.6	23.9	5.9	7.4	5.0	6.9	5.3	16.9	4.4	80
C18:3	1.1	7.8	1.4	21.7	1.0	12.7	1.6	9.6	1.0	30.7	1.1	80

Methodology. Data for fatty acid composition of adipose tissues were influenced by the method of expression, but were generally expressed as percentages in weight. There were variations in the limits, depending on whether fatty acids shorter than C14:0 and longer than C18:0 were included. There were also great variations in the threshold of the system of reference. When reporting the contents of the main fatty acids there was no indication of whether odd and branched chain fatty acids had been included in the total. The contents of fatty acids were expressed as the weights of methyl ester derivatives, the percentages by weight of fatty acids or of other esters, such as propyl or butyl esters, or as percentages in moles of fatty acids or esters. (Boylan *et al.*, 1976; Smith *et al.*, 1979; Bas *et al.*, 1980; Miller *et al.*, 1980; Busboom *et al.*, 1981; Johnson *et al.*, 1988; Bas *et al.*, 1997).

Location of sample. The fat of the internal omental, mesenteric and renal-pelvic deposits is more saturated than the subcutaneous and intramuscular deposits that directly affect meat quality (Clemens *et al.*, 1974; Leat, 1976). These differences are due to the gradient in body temperature which results in the saturated fat with a higher melting point being deposited where the temperature is highest (Marchello *et al.*, 1967). An analysis of variance with a general linear model of all the data (lots x experiments) showed significant differences in fatty acid content between the adipose tissues. A gradient in even straight chain fatty acid content occurred from subcutaneous to mesenteric fat, with 43.2, 43.4, 49.6, 49.5, 52.3, 57.8% in subcutaneous, intramuscular, intermuscular, omental, perirenal, and mesenteric, respectively. PUFA content was highest in intramuscular and lowest in subcutaneous and intermuscular fat. Subcutaneous fat had the lowest C18:0 content and the highest contents of odd chain and branched chain fatty acids.

Intramuscular samples are generally taken from the *Longissimus dorsi* muscle and, occasionally, from the *Semimembranous* or *Triceps brachii* muscles. No significant difference in fatty acid content was found between intramuscular samples from these 3 locations. In subcutaneous fat, location had an important effect on fatty acid content.

The melting point (MP) of all adipose tissues can be predicted from the contents of C18:0 and the C16:1 fatty acids.

MP = 0.489 C18:0 (%) –0.605 C16:1 + 30.5 (R^2 = 0.76)

The MP of subcutaneous fat can be estimated with accuracy from the contents of C18:0 and odd chain fatty acids.

MP = 25.67 + 0.702 C18:0 –0.190 Odd FA (R2 = 0.82)

Sex. Differences in fatty acid composition between sexes are generally small. Fat of male lambs is softer than that of females, as a result of a higher content of unsaturated fatty acids, which reduces the melting of point of fats (Crouse *et al.*, 1981; Wood, 1984; Horcada *et al.*, 1998). Entire male lambs had a lower content of C16:0 and C18:0 in subcutaneous, perirenal and intramuscular fats and a higher C16:1, C18:2, odd chain and branched chain fatty acid content than female or castrated lambs. The difference between sexes was smaller in perirenal and intramuscular fat than in subcutaneous. With some diets which are rich in starch as a result of high proportions of barley or wheat, the average content of saturated even straight chain fatty acids was 4 percentage units lower in entire males than in females. This lower level of saturated fatty acids in entire males was accompanied by a higher level of mono-unsaturated, even fatty acids in perirenal fat or by a higher level of both saturated, odd fatty acids and branched, chain fatty acids (Bas *et al.*, 1980).

Breed. Breed effects on fatty acid content were the same in subcutaneous and internal adipose tissues, but were larger in the former. There were, however, interactions between breed and diet that were often associated with differences in body fatness and thickness of the subcutaneous adipose tissue. Breed differences should, therefore, be estimated at the same degree of maturity and fatness (Webb and Casey, 1995). Finnsheep, both pure and in crossbreds, have a lower C18:0 content and a higher content of C18:1 fatty acid (L'Estrange and Hanrahan, 1980) and odd fatty acid content (Boylan *et al.*, 1976). These results agreed with French data, in which the index of fat softness was improved by crossing with rams of the Texel breed (Legrand and Jabet, 1994) and some rams of the Rouge de L'Ouest breed (Normand *et al.*, 1997). In unweaned lambs, small differences in the C12:0, C14:0 and C16:0 content of subcutaneous adipose tissue, which could be related to differences in milk intake, were reported by Zygoyannis *et al.* (1985), in unequal groups of male and female of Sarakatsaniko and Karagouniko lambs.

Live weight. The main effects of an increase in live weight on the fatty acid content of the adipose tissues of the lambs are due to two phenomena. First, an increase in live weight is correlated with an increase in time from weaning, which results in a progressive decrease in the C14:0, C16:0 and C16:1 content of adipose tissues and an increase in the C18:0 content (Kemp *et al.*, 1981; Webb and Casey 1995). Secondly, the content of odd chain fatty acids increases as a result of *de novo* synthesis, resulting from the increased activity of rumen micro-organisms. Suckling lambs have almost no odd chain fatty acids. Feeding milk alone reduces the content of polyunsaturated, 18 carbon atom fatty acids, which in adult ewes comprise more than 40% of the total fatty acids (Leat, 1976; Noble *et al.*, 1970). Light lambs had almost no odd and branch chain acids in their adipose tissue because the post-weaning period was very short. In older animals the content of unsaturated fatty acids, as indicated by the ratio of C16:1:C16:0, was often high on account of an increase in fatness. Horcada, (1996) observed that, as the slaughter weight of Rasa Aragonesa and Lacha lambs increased, saturated fatty acids decreased and monounsaturated fatty acids increased in subcutaneous and intramuscular fat, and polyunsaturated fatty acids increased in subcutaneous fat and decreased in intramuscular fat.

Nutrition. The influence of the level of metabolisable energy of the diets was tested on the fatty acid profile of the adipose tissues of the lambs, but its effects were not easy to distinguish from the effects of the difference of composition or the ratio of roughage to concentrate. Composition of the diet had a significant effect on the contents of most fatty acids, but the magnitude of this effect varied with the type of adipose tissue and with sex. Variation was greatest in C14:0 content.

A decrease in the ratio of hay to concentrate in complete diets affects all three adipose tissues, subcutaneous, perirenal and intramuscular. In subcutaneous fat even saturated straight fatty acids, mainly C18:0, and C18:3 decreased and C18:1 and odd and branched chain fatty acids were higher (Busboy *et al.*, 1981; Webb *et al.,* 1994; Casey and Webb 1995; Bas *et al.*, 1997). The pattern was the same in perirenal and intramuscular fat, but branched chain fatty acids were not significantly different. Odd numbered (C17:0 and C17:1) fatty acid content was very slightly higher in perirenal fat (Miller and Rice, 1967; Bas *et al.*, 1997).

Analysis of variance and multivariate analysis showed significant effects of diet on fatty acid profile when the different diets were divided into 5 groups, pasture, roughage and concentrate, milk, concentrate alone or complete diet, and alfalfa. The effect was very pronounced with more fatty acid and with a higher amount in subcutaneous fat than in the perirenal and intramuscular adipose tissue. A diet with a high proportion of forage stimulates rumen activity and, therefore, the biohydrogenation of fatty acids (Ziegler *et al.*, 1967; Kemp *et al.*, 1981). A milk diet results in high levels of C14:0 and C16:0, while pasture results in high levels of C18:0 and C18:3 fatty acids. With concentrate alone or cereal with little or no roughage, two factors, the rate of degradability of starch in the rumen and the content and nature of lipid in the diet, were found to have a great influence on fatty acid composition of adipose tissues. For example, in an experiment comparing barley and oats, Ørskov *et al*. (1975) found a 10% increase in the C18:0 content of subcutaneous fat and a reduction in odd and branched chain fatty acids, in lambs fed oats. With maize as grain or in pelleted concentrate and with a soybean rich concentrate, there was a marked increase in the C18:2 and a decrease in the C18:0 content of adipose tissues, which increased the flavour of the meat.

This analysis of published data indicates the strong links between all the factors discussed. Confounding of treatments in many experiments makes clear analysis difficult. Differences in diet composition had repercussions on the fatty acid composition of every adipose tissue. Differences in fatty acid composition may be more fully understood from studies of the characteristics of the lipogenesis of each adipose tissue and the evolution of each tissue from birth to slaughter, with the weaning period being particularly important. This type of study may enable the composition of adipose tissue to be predicted.

Conclusions

Quality of lamb meat for the consumer is defined by its colour, juiciness, tenderness and flavour. The initial choice is mainly influenced by the colour. Generally, tenderness is not a problem in lamb meat, unless carcasses are cooled too quickly after slaughter. The characteristic flavour of cooked lamb results from retronasal assessment of a number of volatile compounds, which are derived from a number of fat and water soluble precursors in the fat. Assessment of the factors influencing these precursors and hence the organoleptic quality of the meat is difficult and in many studies the effects of different factors cannot be clearly distinguished.

The meat from very light, milk-fed lambs in the Mediterranean region shows little variation in organoleptic quality. Meat from older lambs, fed, for a period of at least one and a half months before slaughter, on a predominantly cereal based concentrate diet, shows more variation. Exact definition is needed of the effects on organoleptic quality of diet components and of any interactions with other management factors and pre- and post-slaughter handling. These aspects could have an important bearing on the definition of regulations of PDO or PGI for lamb meat, if consumers are to be assured that quality, and particularly flavour, is always the same in the particular product.

Diet composition affects the fatty acid composition of every adipose depot. Studies of the lipogenesis and of the development of each depot during growth from birth to slaughter will lead to a fuller understanding of the differences and to the possibility of predicting adipose tissue composition. It may also be possible to devise diets that produce lamb meat with a more healthy fat composition.

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