Sheepmeat flavour and odour: a review

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1.1 Perception of flavour

Heymann *et al.* (1993) defined flavour as the "psychological interpretation of a physiological response to a physical stimulus". Noble (1996) echoed these sentiments and hypothesized that aromas and tastes do not compete at the receptor level, but do interact at the level of cognitive processing. Laing and Jinks (1996) describe the perception of flavour of foods as:

> "…a complex process that involves the senses of smell and taste, and chemesthesis (the common chemical sense; also called pungency or irritation)."

The perception of flavour stems from the detection of volatile compounds (odorants and irritants) by odour receptor cells in the nasal cavity and the nasopharynx and the sensation of taste via sensitive regions in the mouth (Laing and Jinks 1996). Odorants, which are detected by receptor cells in the nasal cavity, can be classified into many categories, but tastes have been categorised into sweet, salty, sour, bitter and umami. These five tastes can be sensed by receptor cells at the front, sides and rear of the tongue, as well as in the cheeks, soft palate and oesophagus (Laing and Jinks 1996). Most people are familiar with the first four categories of basic tastes, but few are acquainted with umami and what it represents. Umami describes a flavour characterised as rich, complex, mild, continuous and pleasurable (Fuke and Ueda 1996). Umami is generated by the synergy between free glutamate and phosphate nucleotides such as guanidine, adenosine or inosine monophosphate (GMP, AMP and IMP, respectively) (Fuke and Ueda 1996).

Taste and aroma do interact, as can be attested by anyone who has been unable to detect aromas or smells as a result of congested nasal passages. While eating, volatile odours are detected by the olfactory receptors and cannot be distinguished from those sensed in the mouth (reviewed by Noble 1996). By pinching one's nose, however, the taste one perceives declines dramatically as the retronasal receptors are prevented from contributing to the perception of flavour (Noble 1996).

Olfactory cells allow organisms to detect odour in a manner similar to that of auditory and photoreceptor cells, which provide hearing and sight (Torre *et al.* 1995). Odour consists of extremely small molecules of less than 1 kDa (Bell 1996). The brain detects these odours when the odourants or odour molecules are bound by receptor cells in the membranes of nerve cilia in the nose (Buck and Axel 1991). Once bound to the membrane, the odourant begins a cascade of chemical reactions that lead to the uptake of calcium (Ca^{2+}) and sodium (Na^{+}) into and the release of chloride (Cl^{-}) from the receptor cell, de-polarising the receptor nerve and sending an impulse to the brain (Torre *et al.* 1995). The cascade of these chemical reactions is poorly understood, but characterising the chemical structures of the receptors and identifying which odours they detect will ultimately lead to the design of specialised sensors for particular odours (Bell 1996).

The perception of flavour is affected by the partition coefficient, which is an estimate of the release of flavour from the food matrix into the gas phase (Taylor 1998). The partition coefficient is expressed as a ratio between the volatile compounds in the gas phase and those in the aqueous or solvent phase. The existence of this relationship exemplifies the interaction of the food matrix with flavour release during mastication. A food with volatile compounds with high partition coefficients, such as peanut butter, would have its characteristic flavour perceived immediately, whereas a food with low volatiles would require more time to be savoured than that of peanut butter. Meat is of the latter category, because the partition coefficients of its volatile compounds are reduced by the presence of large amounts of non-volatile biopolymers like protein (Taylor 1998). This relationship may compromise the perception of flavour in tough or dry meat because the relatively large amount of protein to volatile compounds reduces flavour release.

1.2 The measurement of flavour

Formal sensory testing of food is a recent historical development, having begun only within the last two hundred years (briefly reviewed by Stampanoni Koeferli *et al.* 1998). Scientists began examining flavour in the 1880's, relating taste and odour to physiological mechanisms (Stampanoni Koeferli *et al.* 1998). World War II prompted sensory acceptability testing in order to provide United States troops with palatable rations that had low microbiological risk, so development of descriptive methods began in the late 1940's (Powers 1984) during which time the Flavour Profile Method (FPM) was developed by Arthur D. Little and Co. (Cairncross and Sjostrom 1950). Flavour profiling was well developed and described by 1957 (Sjöström *et al.* 1957) and incorporation of the nine point hedonic scale into the FPM (Land and Shepherd 1984; Stampanoni Koeferli *et al.* 1998) resulted in FPM evolving into the Profile Attributes Analysis (PAA) (reviewed by Murray *et al.* 2001). Stamponini developed the Quantitative Flavour Profiling (QFP) method (Stampanoni Koeferli *et al.* 1998), which concentrated on the description and scaling of flavour. The advantage of this method was that the panel was highly trained in identification and description of flavours but the disadvantage was that the panel results were often not indicative of those from consumers because the panellists had such specialist training.

The last two methods, PAA and flavour profiling (QFP), are the descriptive methods most favoured for assessment of meat flavour (Chambers and Chambers 1999). Because meat flavour consists of many different aromatic characteristics blended together, descriptive sensory methods are therefore used because they "…aim to identify and measure the 'composition' of products, or to determine the presence or intensity of a particular characteristic" (Piggott *et al.* 1998). The first descriptive method, PAA, is scaled assessment of various characteristics and entails detection, identification and description of flavour characteristics of the test food. In this method, panellists identify and define the attributes of interest using samples selected for their attribute extremes (Chambers and Chambers 1999). These attributes are then "anchored" with reference samples so that the panellists share a common perception of the relative intensity of the scaling for each attribute. This is often the second step employed in training a flavour panel, with the first being selection of panellists on the basis of their abilities to detect and describe well known flavours (Sjöström *et al.* 1957).

Flavours perceived during eating can also change during the course of consumption as different volatile compounds are released during mastication and solubilisation, and this factor adds the dimension of time to the measurement of flavour (Taylor and Linforth 1996). To capture this aspect of flavour, the second method, flavour profiling, is employed (Chambers and Chambers 1999). Flavour profiling also incorporates the identification, description and referencing of flavour attributes by the sensory panellists, but this is done after the panellists have been first trained to identify flavours (Sjöström *et al.* 1957). This additional training in the identification and description of flavours allows flavour profile panels to detect subtle differences in attribute intensity as well as attribute onset (Chambers and Chambers 1999).

The major drawback with flavour profiling, however, is training the panellists sufficiently so that they, firstly, use the nine-point scale identically for each attribute to be assessed and, secondly, assess the attributes similarly. The first difficulty was subsequently overcome by mathematically scaling the scores of all panellists to a common scale using generalised Procrustes analysis (GPA) (Gower 1975). The generalised Procrustes analysis is a statistical technique that matches the configurations of the various attributes and reduces the variation due to the differences in use of the attribute scaling between sensory panellists (Piggott *et al.* 1998). In this way, it allows for even comparison of the intensity of the attributes by factor rotation, a statistical technique that adjusts qualitative data to a similar scale (Piggott *et al.* 1998). Following scaling and rotation of the data, attributes that account for most of the variation in flavour are identified using principal component analysis. The data can then be mapped or plotted against the two principal component axes that account for the most variation in flavour. This plot then clearly illustrates how the samples from various treatments compare to each other and the flavour attributes. GPA was initially used on sensory data to study meat classification (Banfield and Harries 1975).

The second difficulty with flavour profiling, which is restricting panellists to the assessment of set flavour attributes, was surmounted by pairing GPA analysis with the attribute vocabulary of each individual panellist, resulting in a sensory analysis method called Free Choice Profiling (Williams and Langron 1984). This method has become a preferred method of describing foods because it reduces the training time required prior to sample analysis and is particularly useful in cross-cultural analysis where flavour definitions may vary due to language (Murray *et al.* 2001).

The deciphering of the true meaning of the information imparted by panellists is simplified when their own words are used such as is practised in Free Choice Profiling. Mutton and lamb flavours have been rated using hedonic scaling of pre-determined attributes (Park *et al.* [illegible], 1976; Prescott *et al.* 2001; Rousset-Akrim *et al.* 1997; Young *et al.* 2003). The major disadvantage to these descriptive methods, however, is training the panellists sufficiently so that they, firstly, use the unstructured line scale identically for each attribute to be assessed and, secondly, assess the attributes similarly. The first difficulty can be overcome by mathematically scaling the scores of all panellists to a common scale using generalized Procrustes analysis (GPA) (Gower 1975). GPA is a statistical technique that matches the configurations of the various attributes and reduces the variation due to the differences in use of the attribute scaling between the panellists (Piggott *et al.* 1998). In this way, it allows for even comparison of the intensity of the attributes by factor rotation, a statistical technique that adjusts quantitative data to a similar scale (Piggott *et al.* 1998). The second difficulty with flavour profiling, which is the need to restrict panellists to assessing specific flavour attributes, can be surmounted by pairing GPA analysis with the attribute vocabulary of each individual panellist constructed during free choice profiling (Williams and Langron, 1984) so that panelists can each use different numbers of attributes to describe the same samples. By combining free choice profiling and GPA, untrained panellists may be used to describe sensory properties of food (Delahunty *et al.*, 1997). In this way, positive as well as negative characteristics of lamb and mutton can be identified and pursued.

The importance of measuring total (mg/100 g muscle) and percentage of total fatty acids is apparent in Sañudo *et al.* (2[illegible]) when large differences in total amount of fatty acids are not obvious when fatty acids were expressed as percentages of total. This is an important aspect of relating fatty acid content to flavour because sheer amounts of fatty acid could produce certain families of volatiles relative to others existing not only in less proportion but also in significantly decreased amounts. Measuring fatty acid composition before and after cooking, which has not been employed by any lamb flavour researchers to date, would also assist with elucidating the fatty acids and sugars that are contributing most to volatile production as they would be pinpointed by their absence following cooking.

2 Fatty acid composition of sheepmeat

Tichenor *et al.* (1970) stated that lamb fat is harder than of other meat animals due to higher levels of saturated fatty acids which may explain why many consumers do not find lamb fat organoleptically or nutritionally desirable. Specifically, the higher percentage of stearic acid in sheepmeat fat, compared with beef and pork, results in the higher melting point and the undesirable mouth-coating properties of sheepmeat fat (Cramer and Marchello 1964). Lamb fat also contains relatively high levels of oleic acid and low levels of linoleic and linolenic acids. Concentrations of individual fatty acids vary between each fat depot, increasing in saturation from subcutaneous through intermuscular and intramuscular fat depots (Wood 1984). During growth, the proportion of triacylglycerides to phospholipids increases as levels of endogenously synthesised fatty acids including myristic, palmitic, stearic and oleic acids increase. Wood (1984) suggested that fat quality may decline in leaner animals as the proportion of triacylglycerides to phospholipids would decrease due to declining levels of saturated fatty acids and increased levels of phospholipids and polyunsaturated fatty acids. Dugan (1971) stated that as total lipid in muscle decreases from about 5% to about 1%, the percentage of phospholipid in the total lipid increases from less than 10% to nearly 70%.

Lea *et al.* (1970) observed that the ratio of mono-unsaturated to saturated fatty acids of carbon chain length 16 and 18 were a better chemical index of fat softness than iodine number in pig fat. However, L'Estrange and Mulvihill (1975) found that a similar ratio to that described by Lea *et al.* (1970), including myristic acid as a saturated acid, was no better than stearic acid as a chemical index of softness in lamb fat. Oleic acid concentration was identified by Cramer and Marchello (1964) to be a major determinant of fat hardness of lamb fat. Hawke *et al.* (1977) found that high linoleic acid levels reduce the softening point of lamb fat. Miller *et al.* (1980) reported that fat hardness is influenced by the level of stearic acid present. In addition, Busboom *et al.* (1981) stated that lamb fat becomes firmer as the levels of capric acid, myristic acid, palmitic acid and especially stearic acid, increase.

Polyunsaturated fatty acids, which are most influenced by diet regimen, are generally associated with the phospholipid fraction. The fatty acid composition of phospholipids are characterised by a high content of C18, C20 and C22 polyenoic fatty acids (Scott and Ashes 1990). Higher levels of C22 and C24 polyenoic fatty acids present in the phospholipid component of intramuscular fat are formed by chain elongation and desaturation of both linoleic acid and linolenic acid. Scott and Ashes (1990) stated that these two essential fatty acids are selectively incorporated into plasma cholesterol esters and phospholipid membranes as this provides a suitable mechanism to preserve linoleic and linolenic acids for incorporation into structural lipids.

Although many studies have determined differences in fatty acid composition of sheepmeat, these studies have primarily focussed upon those fatty acids with ≥ 10 carbon chains and their degree of unsaturation. As short- to medium- chain fatty acids, that contribute to sheepmeat flavour and odour (eg. Wong *et al.* 1975a,b), are present at very low concentrations, analytical equipment and methods to accurately measure them have only been available in recent years.

2.1 Effect of sex

High stearic acid levels in subcutaneous fat can cause a sticky taste in cold lamb fat (Wood 1984). Lower concentrations of stearic acid have been found in subcutaneous fat from rams (Tichenor *et al.* 1970; Crouse *et al.* 1972; Kemp *et al.* 1981; Busboom *et al.* 1981; Solomon *et al.* 1991) and cryptorchids (Channon 1996) compared with wethers.

Ram carcasses have been shown to have softer subcutaneous fat, reflecting higher levels of polyunsaturated fatty acids (particularly increased deposition of medium to long-chain branched chain fatty acids (C10-C17)), compared with wether carcasses (Tichenor *et al.* 1970; Orskov *et al.* 1975; L'Estrange and Mulvihill 1979; Busboom *et al.* 1981) with this problem more apparent with increasing carcass weight (Busboom *et al.* 1981). Field *et al.* (1978) reported that soft, oily subcutaneous fat was produced in ram lambs fed high concentrate corn diets resulting from increased amounts of unsaturated and polyunsaturated fatty acids. Solomon *et al.* (1990) also noted that the firmness, colour and texture of subcutaneous fat of cryptorchid lamb carcasses was intermediate to that of rams and wethers. Higher levels of linoleic and linolenic acids were present in intramuscular fat of rams than wethers, with levels in cryptorchids intermediate with rams and wethers (Solomon *et al.* 1990). In contrast, Vesely (1973) reported that the fatty acid composition of subcutaneous fat of ram, cryptorchid and wether lambs was not significantly different and Channon (1996) found that linoleic acid and total polyunsaturated fatty acid levels in subcutaneous fat were not influenced by animal sex (cryptorchid and wether). It is suggested that the differences in intensively finishing lambs on diets containing higher levels of concentrates compared with managing lambs extensively grazing annual pastures may account for this variability in sex effects on fatty acid composition of subcutaneous fat.

A higher proportion of longer chain unsaturated fatty acids in subcutaneous fat has been linked to softer subcutaneous fat of ram carcasses (Miller *et al.* 1980; Kemp *et al.* 1981). In Australia, problems with soft, yellow subcutaneous fat of cryptorchid and wether lambs supplemented with grain over summer have been reported (Channon 1996), whilst discoloured, soft fat of cryptorchid lamb carcasses may be objectionable to lamb processors (Hopkins 1993) and retailers (Channon 1990; Jackson *et al.* 1992).

Channon (1996) found that feeding a lupin: wheat ration to lambs for a six week period over summer prior to slaughter at 10 months of age may have contributed to higher linoleic acid levels in subcutaneous fat. It is not known whether this resulted from increased synthesis of unsaturated fatty acids due to increased production of propionate in the rumen when feeding diets high in concentrates to lambs (Tichenor *et al.* 1970; Garton *et al.* 1972) or whether lupins, which have a high linoleic acid content (Hill 1977), may have bypassed ruminal degradation enabling higher linoleic acid levels to be available for absorption in the small intestine.

2.2 Effect of age

Age and slaughter weight of lambs was not found to influence either the iodine value (Callow 1958) or the fatty acid composition of subcutaneous fat (Crouse *et al.* 1972). Enser (1991) reported that as lambs approached 12 months of age stearic acid levels in subcutaneous fat increased while oleic acid levels declined. The amount of subcutaneous fat generally increases with increasing age and the fatty acid composition of depot fats becomes more saturated (Barnicoat and Shorland 1952; Spillane and L'Estrange 1977; Miller *et al.* 1986). The concentration of saturated fatty acids in fat tissue lipid has also been shown to decline with increasing age.

2.3 Effect of diet type

Linolenic acid, linoleic acid and oleic acid are the major fatty acids in pasture species comprising 53%, 13% and 10%, respectively, of the total fatty acids present (Shorland *et al.* 1955, Garton 1959; cited by Casey *et al.* 1988). These fatty acids are concentrated mainly in the leaf chloroplast. Dietary unsaturated fatty acids in feed consumed by ruminant animals are biohydrogenated in the rumen by bacterial lipases to saturated fatty acids (Harfoot 1981). Wood *et al.* (2003), in a review of the effects of fatty acids on meat quality, stated that the concentrations of linolenic acid (18:3) and EPA (20:5) in muscle phospholipids were higher from those animals that grazed pasture compared with those fed a grain-based, concentrate diet.

Fat texture is a function of fatty acid composition. The majority of polyunsaturated fats are converted in the rumen to saturated fats but differences in the composition and softness of fat from lambs on different diets may arise (Field *et al.* 1983; Wood 1984). Cramer *et al.* (1967) showed that lambs grazing a white clover pasture produced subcutaneous fat with a greater degree of unsaturation than those grazing ryegrass pasture. This possibly reflects that linolenic acid is a major constituent of white clover leaves and stems (Body 1974, cited by Larick and Turner 1990).

Fat colour of lambs grazing pasture may be influenced by dietary pigments including carotenoids, xanthophyll and lutein (Kruggel *et al.* 1982) leading to higher yellowness scores, particularly in ram lambs. Lutein is the main carotenoid pigment present in subcutaneous fat in lamb (Kruggel *et al.* 1982; Yang *et al.* 1992). Hopkins *et al.* (1995c) found that cryptorchid lambs that grazed lucerne produced yellowier subcutaneous fat than lambs fed chicory, indicating that lucerne may have higher lutein levels than chicory.

The content of saturated fatty acids present in lamb fat may be reduced, for human dietary considerations, by increasing the amount of concentrates in the diet, even though feeding of concentrate diets can increase carcass fatness (Miller *et al.* 1967). Increased proportions of concentrates in the diet can lead to an increase in propionate production in the rumen causing a shift toward unsaturated fatty acid synthesis (Garton *et al.* 1972). Lambs fed high concentrate diets have been found to have less saturated fat in subcutaneous and intramuscular fat depots than lambs fed low-concentrate diets (Miller *et al.* 1967; Shelton *et al.* 1972; L'Estrange and Mulvihill 1975; Orskov *et al.* 1975). The soft fat present on lamb carcasses (Duncan and Garton 1978; Busboom *et al.* 1981), particularly following intensive grain feeding, has been attributed to high levels of branched chain fatty acids rather than to polyunsaturated fatty acids and was not found to be a function of low fatness levels. Orskov *et al.* (1975) found that soft fat was prevented in wether lambs, but not in rams, when whole barley was fed. Solomon *et al.* (1991) demonstrated that by feeding ram lambs a diet of rapeseed meal, soybean meal or whole rapeseed-soybean meat, with 75% roughage, changes in fatty acid composition of both subcutaneous and intramuscular fat occurred without affecting fat quality.

3 Chemical compounds responsible for sheepmeat flavour and odour

Flavours associated with the various species of meat have been shown to reside primarily in the fat and the flavour of mutton in particular has been attributed to the carbonyl or other polar compounds found in sheep fat (Hornstein and Crowe 1963). Common carbonyl compounds are ketones, and all twenty amino acids have active carbonyl groups at physiological or neutral pH. The aroma characteristic of sheepmeat was detected in the non-acid (neutral) lipid fraction by Nixon *et al.* (1979), indicating that phospholipids also contribute to this aroma. The volatile flavour compounds of cooked meat are formed either by lipid oxidation or from Maillard reactions. Those compounds that arise from lipid oxidation include straight chain aldehydes, ketones, hydrocarbons, alcohols and alkylfurans. The volatiles produced from Maillard reactions include heterocyclic nitrogen and sulphur compounds (eg.. pyrazines, thiophenes, thiazoles, furanoses, furfurols) and also non-heterocyclic compounds (Elmore *et al.* 2000).

Mutton flavour has been described as *sweaty, sour, urinary, faecal, barnyard, oily, sharp* and *acrid* (Wong 1975). The compounds associated with these aromas and flavours have been identified as branched chain and unsaturated fatty acids having 8 to 10 carbon atoms (Wong 1975; Wong *et al.* 1975a,b). Compounds associated with mutton flavour identified by Wong *et al.* (1975a) were 6-methylheptanoic acid, n-octenoic acid, 4-methyloctanoic acid, 6-methyloctanoic acid, 2-octenoic acid, n-nonenoic, 4-methyl-nonanoic acid and 8-methylnonanoic acid. Wong (1975) noted that 4-methyl branched C_8 acid (4-methyloctanoic acid) was particularly associated with the 'sweaty' note and later concluded that the 4-methyl-substituted C_9 to C_{10} fatty acids such as 4-methyloctanoic and 4-methylnonanoic acids were primarily responsible for the characteristic aroma of mutton fat (Wong *et al.* 1975b). Young *et al.* (1997) published a list of volatiles that were strongly correlated with the three odour attributes of *sheepmeat, animal* and *rancid* using Principal Component Analysis (Table 1).

Table 1: Volatiles identified from Principal Component Analysis to be related to the three odour attributes of *sheepmeat, animal* and *rancid* (from Young *et al.* 1997).

Odour attribute	Associated volatiles
Sheepmeat	2-methylpyrazine
	Unknown (branch alkane?)
	3-ethyl-1,4-hexadiene
	4-methyloctanoic acid
	4-methylnonanoic acid
	Unidentified branched chain acid
	5-hydroxydecanoic lactone
	5-hydroxydodecanoic lactone
	Tetradecanoic acid
	Unidentified lactone
Animal	Dimethyldisulphide
	4-methylphenol
	4-methylnonanoic acid
	Unknown
	3-methylindole
	Unidentified methylalkane
Rancid	3-methylindole
	l-pentadecene
	l-hexadecene

Capillary or packed-column gas chromatography using various types of detectors is generally used for separating and identifying the components of volatiles from sheepmeat. Young *et al.* (1994) in a review detailed outlines of these methods. Although Elmore *et al.* (2000) were able to determine volatile compounds of cooked lamb from Soay and Suffolk lambs fed different supplements, it is unfortunate that sensory assessments were not undertaken to determine which of these are responsible for sheepmeat odours and flavours. Nevertheless, Elmore *et al.* (2000) details an exhaustive list of 187 volatile compounds that were found in the headspace of cooked lamb. Brennard and Lindsay (1992) found that 4-methyloctanoic acid, 4-ethyloctanoic acid and 4-methylnonanoic acid were always present in the condensates of the cooking vapour (when lamb was cooked by roasting, frying or boiling) and were present in sufficient concentrations to produce the characteristic *mutton* aromas and flavours.

3.1 Carbonyls

Meat flavour develops during cooking from the degradation and reaction of water soluble compounds of adipose tissue and the presence of fat-soluble carbonyls to give sheepmeat its characteristic species-specific aroma (Hofstrand and Jacobsen 1960; Hornstein and Crowe 1963; Jacobsen and Koehler 1963). It has been postulated that species differentiation in meat flavour may be due to different types and concentrations of carbonyls from lipid oxidation. Although carbonyls may play a role in sheepmeat flavour, Hornstein and Crowe (1963) did not find that carbonyls were primarily responsible for *mutton* flavour.

A decrease in meaty flavour determined by taste panels can be associated with increasing pH from 5.5 to 6.5, reflecting a change in the nature of the major flavour volatiles from sulphur-containing to nitrogen-containing constituents (Walker 1976). Braggins (1996) found that mutton with a moderate or high ultimate pH (6.26 and 6.81, respectively) had a significantly lower flavour intensity than mutton of a lower pH (5.66). Braggins (1986) also reported that trained taste panelists found that desirable odour and flavour notes decreased and undesirable ones increased with increasing ultimate pH. In contrast, Graafhuis et al. (1991) found that sheepmeat odour and flavour was not influenced by pH (5.84 vs. 6.38).

3.2 Sulphur compounds

Sulphur compounds may also influence sheepmeat odour and flavour. When meat is cooked, sulphur-containing volatiles are generated primarily as a result of degradation of sulphur amino acids. Cramer *et al.* (1970) observed that the flavour intensity of lamb increased with increased wool fineness that may result in unique mechanisms for sulphur storage, particularly in fatty tissue. During cooking, meat lipids act as a solvent for volatile compounds that may accumulate (Melton 1990). High levels of intramuscular fat have also been reported to influence the flavour of lamb (Smith *et al.* 1970; Cross *et al.* 1972; Purchas *et al.* 1979). Cramer (1974), cited by Baines and Mlotkiewicz (1984), hypothesised that the specific odour of lamb was caused by sulphur containing compounds, particularly the release of hydrogen sulphide, with higher amounts of hydrogen sulphide found to be present in lamb fat than beef fat. Kunsman and Riley (1975) reported that more hydrogen sulphide was liberated upon heating of depot fat tissue than muscle and also that sheepmeat produced moe hydrogen sulphide than beef. In contrast to Kunsman and Riley (1975), Young *et al.* (1994) reported that more hydrogen sulphide was released from lean than fat, however it must be noted that different cooking methods were used in these two studies which may account for these differences. Nixon *et al.* (1979) also identified a number of sulphur compounds unique to sheepmeat volatiles; however these compounds were not singularly important for sheepmeat odour. Young *et al.* (1997) also excluded sulphur compounds, various pyrazines, pyridines and a range of phenolic compounds from being the primary cause of sheepmeat odour. Nevertheless, many of these sulphur compounds assist in the development of sheepmeat odour and flavour.

3.3 Branched chain fatty acids

Branched chain fatty acids are peculiar to ruminants and they are thought to be the result of the use of methylmalonyl CoA from propionate metabolism, rather than malonyl-CoA, during fatty acid chain lengthening in the liver (Wong *et al.* 1975b). Ruminal propionate is the main source of liver gluconeogenesis. However, branched chain fatty acids are produced when propionate levels exceed the capacity of the liver to normally metabolise it. Methylmalonate then compensates with malonate for inclusion into fatty acid synthesis.

The accumulation of branched chain fatty acids in subcutaneous fat of sheep therefore results from this variation in the metabolic pathway during fatty acid synthesis (Duncan and Garton 1978). In fact, how the bacteria in the rumen metabolise the fatty acids and proteins from the feed ingested and what happens to those metabolites in the liver and tissues of the ruminant remains poorly understood. For example, as linolenic acid is not synthesised by mammals (Ray *et al.* 1975), it can accumulate in subcutaneous fat and lead to the formation of various volatiles during cooking. Ha and Lindsay (1991) suggested that a specific selectivity in the action of enzymes involved in the synthesis of some branched chain fatty acids between different ruminant species.

In a review of species-specific flavours and odours of meat, Pearson *et al.* (1994) stated that *iso* ($H_3C-CH(CH_3)-R-COOH$) and *ante-iso* ($H_3C-CH2-CH(CH_3)-R-COOH$) acids are the most common long-chain branched chain fatty acids present in sheepmeat and beef fat. Iso-acids are formed biosynthetically through methylmalonyl Co-A (Smith *et al.* 1979) and occur in the highest concentrations in fat of pasture fed lambs and cattle (Hansen and Czochanska 1976).

As previously stated, Wong *et al.* (1975a) demonstrated that medium branched chain fatty acids were responsible for the odour and flavour of sheepmeat. The most dominant of these are 4-methyloctanoic acid, 4-methylnonanoic acid and 4-ethyl-analogues. These fatty acids are present at low, but detectable concentrations in subcutaneous fat of sheep (Brennard and Lindsay 1992). Wong *et al.* (1975a) found that 'sheep-like' odours were predominantly associated with branched chain fatty acids with 8-10 carbon atoms. Brennard and Lindsay (1992) found that 4-methylnonanoic acid concentration in subcutaneous fat from different lambs varied from non-detectable levels to levels exceeding the threshold value. This suggested that 4-methylnonanoic acid may not always contribute to the characteristic flavour and odour of sheepmeat.

Other fatty acids that may be related to muttony or lamb flavours and odours include 2-methylpentanoic (described as having a *sheep pen* or *sheep wool* odour), 4-methylhexanoic (*sheepy*) and 6-methylheptanoic (*sheep wool*) aroma (Pearson *et al.*, 1994).

3.3.1 Differences in branched chain fatty acid concentrations in different subcutaneous fat layers

Branched chain fatty acids also have a softening effect on lamb fat. Johnson *et al.* (1988) reported that the outer layers of subcutaneous fat are softer compared with the inner layers and this was due to a higher concentration of odd-numbered and branched chain fatty acids (particularly 4-methyloctanoic and 4-methylnonanoic acids). Brennard and Lindsay (1992) suggested that selective trimming of subcutaneous fat layers may be a means of altering the intensity of sheepmeat flavours of different cuts.

Branched chain fatty acids are highly volatile resulting in odours generated during cooking, particularly during roasting at high temperatures. During roasting, the very high temperatures that the outer layers of subcutaneous fat are exposed to result in the promotion of triglyceride hydrolysis and increased fatty acid volatility (Young *et al.* 1997). Ha and Lindsay (1991) found that most of the volatile branched chain fatty acids occur as moieties in triglycerides and part of these acids would be released upon cooking.

Miller *et al.* (1986) showed that concentrations of branched chain fatty acids were lower in intramuscular fat than subcutaneous fat. Subcutaneous fats are strongly implicated in mutton odour (Young *et al.* 1994). Baines and Mlotkiewicz (1984) found that branched chain fatty acids dominated the fatty acid component in the volatiles of cooking sheepmeat, however this is not true for beef or pork. However, Crouse *et al.* (1983) did not find that lamb flavour intensity and 4-methylnonanoic acid were significantly correlated with one another. Furthermore, Purchas *et al.* (1986) found that no individual fatty acids, or groups of them, had significant relationships with sheepmeat flavour characteristics.

3.3.2 Effect of diet type

Young and Braggins (1998) stated that diets high in energy result in higher concentrations of branched chain fatty acids than pasture diets. Brennard *et al.* (1989) reported that panellists described both 4-methyloctanoic acid and 4-methylnonanoic acid as *goaty* and *muttony*. It is considered that the *muttonness* characteristic of sheepmeat limits both the marketability and the acceptability of sheepmeat. Table 2 shows that differences in the relative proportions of branched chain fatty acids in mutton can also result from differences in diet type (from Wong *et al.* 1975a).

Priolo *et al.* (2001) stated that an extensive grazing regime could result in a reduction of branched chain fatty acids in sheep as the higher fibre content of forages compared with concentrates will increase the acetate/propionate ratio in the rumen.

Table 2: Concentrations of volatile fatty acids in mutton, lamb and beef fat (from Wong *et al*. 1975a).

Diet	Fatty acid concentration (ppm)						
	n6	n7	n8	n9	n10	4MeC8[a]	4MeC10[b]
Barley	28	28	148	58	2030	38	36
Sunflower oil protected supplement	136	24	165	17	1860	6.9	9.6
Clover pasture	41	3.1	121	8.3	990	2.0	1.0
Grass pasture	49	5.7	190	12	1395	4.8	2.4
Mutton	57	7.3	111	15	92	10.5	4.6
Lamb	124	6.7	164	22	784	4.7	2.6
Lamb	145	4.9	122	13	850	2.0	1.6
Beef	58	8.4	115	14	596	-	0.7

3.3.3 Effect of age

This may account for why consumer taste panels do not consider flavour of denuded, boneless loin steaks from older animals to be a major problem affecting overall liking of sheepmeat (Gee, pers. comm., Thompson *et al.*, 2002). This recent work, however, does not address issues relating to consumer acceptability of sheepmeat cuts with a higher level of subcutaneous and/or intramuscular fat. Additionally, the use of sheepmeat in manufacturing of processed meat products suitable for both the Australian and export markets, particularly the use of mutton trunks (forequarters and briskets) with chemical lean percentages of about 70% has not been reported. Wong and Mabrouk (1979), in a study conducted to determine whether mutton odour can arise from lean mutton, found that the amino acid fraction was the major source of the odour. The specific components responsible, however, were not identified.

3.3.4 Effect of sex

Priolo *et al.* (2001) considered that the effect of diet on the concentrations of branched chain fatty acids deposited in subcutaneous fat is not as great as sex effects. Busboom *et* *al.* (1981) showed that fat of 300-day-old ram lambs had higher concentrations of 4-methylnonanoic acid and other branch acids compared with castrates. However, in a study of 200-day-old ewe and castrate lambs, no sex effect on the concentration of branched chain fatty acids was found, suggesting that puberty may result in the increased concentration of branched chain fatty acids in sheep fat. However, the effect of increased age (>18 months) on the development of sheepmeat odour and flavour remain unknown. Sutherland and Ames (1997), found that rams (200 d of age) had higher concentrations of 4-methyloctanoic acid than castrates. In addition, both Rousset-Akrim *et al.* (1997) and Young *et al.* (1997) reported that both 4-methyloctanoic and 4-methylnonanoic acids were higher in males slaughtered at 215 d of age compared with those slaughtered at 100 d of age or less.

Although effects of animal age (up to 18 months) on meat flavour and acceptability were investigated by Channon (1996) using heavyweight second-cross cryptorchid and wether sheep, it is unfortunate that no analyses of branched chain fatty acids concentrations in subcutaneous fat were undertaken. Young *et al.* (1997) found that meat from 8.5 year old ewes was not the most '*sheepy*'. Therefore, volatile compounds other than branched chain fatty acids may be responsible for the stronger odours and flavours of meat from older sheep. Young *et al.* (1997) concluded that the role of puberty and age (as an independent factor) on the development of sheepmeat flavour and odour would be a worthwhile area requiring further investigation.

Ha and Lindsay (1991) found higher concentrations of alkylphenols (including *o*-cresol, *p*-cresol, 2-ethylphenol, 2-isoprpoylphenol, 2,4-dimethylphenol, thymol and 3- or 4-isopropylphenol) and thiophenol in heated sheep fat. Rhee *et al.* (1999) postulated that these alkylphenols and thiophenol could function as antioxidants resulting in an increased oxidative stability of extrudates that contain sheepmeat and concluded that further investigation of this is needed.

3.3.5 Effect of cut/primal

Brennard and Lindsay (1992) found that concentrations of volatile fatty acids vary across the carcass, with rump subcutaneous fat found to have the highest volatile fatty acid content and also the highest concentration of 4-methyloctanoic acid. 4-ethyloctanoic acid concentrations were lowest in the rump and highest in subcutaneous fat in the shoulder. It is noteworthy that this coincides with sensory perceptions of different cuts, with cuts from the shoulder generally more strongly flavoured that those from the leg.

3.4 Heterocyclic compounds

Pyrazines are found in a range of foods and have been described as *chocolaty* and *meaty.* Both pyrazines and pyridines are heterocyclic volatiles that are produced from any cooking meat. Buttery *et al.* (1977) considered 2-ethyl-3,6-dimethylpyrazine and 2-pentylpyridine to be specific contributors to mutton odour, proposing that 2-pentylpyridine could be formed from ammonia, produced from the breakdown of amino acids present in lamb muscle and a fat oxidation product, deca-2,4-dienal. Although, no other studies have reported that heterocyclic compounds are primarily responsible for sheepmeat flavour and odour, it is accepted that these compounds contribute to the characteristic odour of sheepmeat. Lactones are common in meat and fat volatiles (Min *et al.* 1979; Bailey *et al.* 1994) and Young *et al.* (1997) stated that 5-hydroxydecanoic lactone and 5-hydroxydodecanoic lactone smell like peach and coconut, respectively. However, it is not considered that these compounds contribute to sheepmeat odour and flavour.

3.5 Skatole (3-methylindole)

Young *et al.* (1997) also linked 3-methyl-indole (skatole), 4-methylnonanoic acid and 4-methylphenol' to the *animal* note identified by the test panel and were thought to exacerbate the undesirable sheepmeat odour. It is not known how these compounds are generated, however it is most likely that they originate from rumen metabolism of the pasture species eaten. Young *et al.* (1997) speculated that these compounds may be linked specifically to ryegrass and clover pastures , in New Zealand as they are currently the only authors to have noted these compounds in sheep fat. Young *et al.* (2003) identified these compounds in the same pasture combination, supporting this hypothesis.

Methylindole, commonly known as skatole, has been implicated in conferring 'boar taint' in pork from uncastrated male pigs. Skatole results from tryptophan degradation in the hind gut. Prescott *et al.* (2001) stated that the presence of the compound 3-methylindole (commonly known as skatole) in sheep fat is a good indicator that animals were fed a pasture diet. However, it is unclear why skatole levels are higher in pasture fed sheep. It is known that diet type can influence the populations of different micro-organisms species present in the rumen and different micro-organisms may degrade tryptophan differently resulting in skatole production (Priolo *et al.* 2001). Rancid odour was found by Young *et al.* (1997) to be linked to 3-methylindole. Overall, the New Zealand research (Prescott *et al.* 2001) shows that BCFA and skatole combine synergistically to produce flavours described as *barnyard, sour* and *milky*, while samples with increased BCFA levels were associated with sheepmeat flavour intensity.

Prescott *et al.* (2001) modelled the effect of branched chain fatty acid (BCFA) and skatole concentrations on the acceptability of red meat by using minced beef lean and subcutaneous fat. Their results showed that both BCFA and skatole contributed significantly to undesirable flavours in meat, with Japanese consumers being sensitive to both sources but New Zealand consumers found skatole more disagreeable than BCFA. Further research by Young *et al.* (2003) emphasized that the BCFA were less indicative of *mutton* and *barnyard* flavours than the skatole compounds 3- and 4-methylindole, but this result may have also reflected the use of a New Zealand sensory panel, which was shown in Prescott *et al.* (2001) to associate BCFA with the expected flavour of lamb. Young *et al.* (1997) suggested that both skatole and branched chain fatty acids were most strongly linked to sheepmeat odour and flavour and skatole may augment the flavour qualities produced by branched chain fatty acids. Interestingly, Sañudo *et al.* (2000a) showed that the most important factor affecting the acceptability of lamb flavour was the previous flavour experience of the panellists, suggesting that flavour description rather than acceptability would be the best and most consistent method of characterising lamb flavour.

Enhancing positive flavour notes of sheepmeat is a viable alternative to eliminating unfavourable ones. This may be the easiest route to improve sheep meat flavour, particularly since skatole and BCFA are a direct result of essential rumen metabolism pathways. There is evidence that other volatile compounds may mask undesirable notes within in lamb and sheep meat and exploration of increasing the concentrations of these desirable flavour notes warrants further investigation. Young *et al.* (2003) noted, for example, that there was a sweet note in some of the lamb that they tested that was very easily detectable by their taste panel, yet no volatiles were associated with this descriptor as a result of their analyses. Some research has addressed these alternatives, most notably by Hudson and Loxley (1983) who investigated the effect of pentose sugars on the flavour of minced mutton and showed that the acceptability of mutton was improved with the addition of xylose and pentose at 0.5% (w/w). The *sweet* flavour attribute may not be a desirable note, however, as Park *et al.* (1978) found that *sweet* was associated with reduced acceptability of mutton. Perhaps, in this case, the *sweet* was also 'sickly' rather than the 'sugar sweet' of Hudson and Loxley (1983). The trends in the panellists of Park *et al.* (1978) suggested, however, that the 'sweet' note was found desirable by tasters that did not like mutton, and was only perceived as unfavourable by those who liked mutton and, therefore, had a preconception of how it should taste.

Overall, Young *et al.* (1994), from a review of sheepmeat flavour and odour, concluded that there is no consensus of the cause of the characteristic odour and flavour of sheepmeat. Pearson *et al.* (1994) also stated that much research ahs focussed upon identifying the undesirable flavour and odour components of sheepmeat, whilst very little focus has been on determining desirable flavour and odour components.

3.6 Oxidation of sheepmeat fat and effects on flavour

The evidence for the 'mutton' flavour being produced by BCFA and skatole is compelling (Wong *et al.* 1975a, b; Young *et al.* 1997, 2003) and no other research has refuted the relationships established. Although the research relating various volatiles to sheep meat flavour is also compelling, fatty acids are not the only components of meat that produce distinct aromas and flavours. Almost invariably, the fatty acid must be oxidised and combine with a Maillard product (amino acids with sugars) in order to produce a meaningful volatile.

Priolo *et al.* (2001) concluded that n-3 PUFA oxidation products were responsible for the particular flavour of grass fed lamb. Melton (1999) highlighted the lack of consideration of other chemical constituents besides fatty acids in the examination of sheep meat flavour, and suggested that quantitation of amino acids and reactive sugars should be included in any analyses. Jamora and Rhee (1999), in their review, noted that inhibiting lipid oxidation in sheep meat during cooking actually increased the *mutton* flavour, and this result emphasised the importance of the development of other, desirable flavours through lipid oxidation that may mask the undesirable *mutton* flavour. The result of this study also indicated that antioxidants do not prevent the formation of the mutton flavour during cooking.

3.7 Aroma volatile analysis in meat with modified fatty acid profiles:

While alteration of the fatty acid composition of meats such as beef and sheep have been achieved through altered lipid composition of the animals diet (Wood *et al.*, 1999) such changes can affect the flavour characteristics of the meat (Ford and Park, 1980; Melton 1990). Early studies of beef fatty acid composition and flavour from animals on pasture versus grain diets identified higher levels of saturated FAs (SFAs) and *n*-3 polyunsaturated FAs (PUFAs), and lower levels of monounsaturated FAs (MUFAs) and *n*-6 PUFAs in grass-produced beef (Melton *et al*, 1982). Levels of flavour volatiles were compared for each, and correlated with sensory evaluations of flavour (Larick *et al.,* 1987; Bolton, 1987). Amongst compounds positively correlated with intensity of cooked beef flavour were saturated aldehydes (hexanal and octanal), alcohols (1-hexanol) and hydrocarbons (alkane), all derived from fatty acid oxidation. Based upon these analyses, Bolton (1987) proposed a model whereby differences in the concentrations of pentanal, 1-ethyl-2-methyl benzene, ethyl benzene, toluene and an unknown compound explained 51% of the variation in intensity of beef fat flavour in grass- and grain-produced beef. The importance of pentanal and toluene were later confirmed by Varner *et al.* (1988) by spiking of grass-produced beef with concentrations of these compounds equivalent to that found in grain-produced beef. A trained sensory panel was unable to differentiate between the samples. These studies provided early evidence of the important role of fatty acid oxidation in flavour intensity of meat.

The production of aroma volatiles in meat occurs in the following manner. Lipolysis of phospholipids and triglycerides generate, through the action of various lipases, fatty acids that are susceptible to oxidation. This is followed by the oxidative degradation of fatty acids and leads to the appearance of free radicals and various molecules (alkanes, ketones, acids, alcohols, furans and aldehydes) that can affect intrinsic flavours of the meat (Mottram and Edwards, 1983).

Muscular lipid oxidation is also preceded by myoglobin oxidation (the oxidation of Fe^{3+} within this molecule) which can lead to the formation of brown metmyoglobin (MMb) (Monahan *et al.*, 1994). This browning effect at the surface of meat results in the meat becoming unacceptable to the consumer. In beef this process has been demonstrated to play a catalytic role in the deterioration of flavour by promoting lipid oxidation (Rhee *et al.*, 1987). Iron released from ferritin also catalyses lipid oxidation (Apte and Morrissey, 1987), although unlike haemoglobin this only occurs during the cooking process. Furthermore, these degradation products can also react with Maillard products during cooking (Elmore *et al*, 1997). Maillard products are initially generated from denatured proteins on the surface of the meat recombining with the sugars to produce a browning effect. These include thiazoles, pyrimidines, and pyrazines which, as well as affecting flavour, may have potential health implications for consumers. Therefore to control oxidation of lipids, one must also control oxidation of myoglobin.

The nutritional value of *n*-3 polyunsaturated fatty acids in the human diet is well characterised. Increased consumption of these fatty acids, particularly eicosapentaenoic acid (EPA, C20:5 *n*-3) and docoeahexaenoic acid (DHA, C22:6 *n*-3), is recommended by bodies such as the UK Department of Health (1994) due to their beneficial roles in lowering cholesterol and reducing heart disease. As a result efforts have been made to manipulate meat fatty acid composition. However these *n*-3 fatty acids have been observed to be particularly susceptible to oxidation. High levels of α-linolenic acid

(C18:3*n*-3) observed in grass-fed ruminants has been identified as partially responsible for the pastoral flavour their meat (Young and Baumeister, 1999). Likewise in animals that have undergone fish oil and linseed-fish oil feeding regimes to increase the ratio of *n*-3 to *n*-6 acids in the muscle, high levels of aroma volatiles were observed (Elmore *et al.*, 1999; Elmore *et al.*, 2000). The effect of PUFA composition on the profile of aroma volatiles in beef was assessed by Elmore *et al.* (1999). Groups of steers were fed on diets including supplementary fats such as palm oil, bruised whole linseed, fish oils, or equal amounts of linseed and fish oil. Fatty acid analysis revealed that meat from steers fed the whole linseed regime had higher levels of α-linolenic acid and EPA, meat from animals fed the fish oil diet had higher EPA and DHA and animals fed the linseed-fish oil regime had higher levels of all three PUFAs compared to those animals fed the palm oil-based diet (control). The aroma profiles of meat from each treatment group were also assessed. Volatile compounds formed via the Mailliard reaction such as heterocyclic nitrogen and sulphur compounds (pyrazines, thiophines and thiazoles) as well as furanones and furfurals were unaffected by the different diets. The cooked beef samples with increased PUFA levels all showed higher concentrations of lipid oxidation products, particularly saturated and unsaturated aliphatic aldehydes. Most of these compounds were derived from the autoxidation of the more abundant mono- and di-unsaturated fatty acids during cooking. These compounds were then observed to interact with products of the Maillard reaction. Therefore, in beef, autoxidation was demonstrated to be promoted by increased levels of PUFAs.

Relatively little research has been conducted to identify volatile compounds responsible for flavour generation in sheep meat. Increased levels of (*E,E*)-2-4-decadienal, an oxidation product of linoleic acid, was observed in lambs fed diets high in linoleic acid (Park *et al.*, 1975bk). Comparison of clover-fed versus corn-fed lamb fat identified differences in many lipid-derived flavour volatiles (Suzuki and Bailey, 1985). Higher concentrations of most lipid-derived volatiles were observed in fat from clover-fed lambs, particularly 2,3-octanedione, medium-chain fatty acids (C_2, C_5, C_6, C_7, C_8, C_9, C_{10} and C_{12}), terpenoids and several aldehydes. Apart from terpenoids, all compounds can be the result of fatty acid oxidation. Fat from corn-fed lambs had higher concentrations of γ-dodecalactone. Higher levels of α-linolenic acid (*n*-3 PUFA) were observed in grass-fed than grain-fed lamb, and positively correlated with lamb flavour intensity (Sañudo *et al.*, 2000).

An extensive study was recently conducted investigating the effect of varying n-3 PUFA composition of lamb muscle on the formation of aroma volatiles during cooking (Elmore *et al.*, 2000). As well as a comparison of dietary effects on aroma volatiles, this research provided an opportunity to compare breed effects, and also provided useful comparison to a similar study performed in steers (Elmore *et al.*, 1999). Meat was obtained from four groups of Suffolk and Soay lambs fed different supplementary fats. Diets including a palm oil control, bruised whole linseed, fish oils or equal amounts of linseed and fish oil. Fatty acid analysis revealed that compared to the palm oil-based control, meat from animals on the whole linseed regime contained increased α-linolenic acid (C18:3*n*-3), animals of the fish oil diet had increased EPA and DHA, and animals on the linseed-fish oil regime showed increased in all three PUFAs. Highest quantities of lipid oxidation products were found in the aroma volatiles of fish-oil fed lamb compared to control animals. Unsaturated aldehydes, unsaturated hydrocarbons and alkylfurans, derived from autoxidation of PUFAs during cooking were increased up to fourfold. The largest increases were observed for highly unsaturated volatiles (octatriene, 2-ethylfuran, 2-(2-pentenyl)-furan, 1-penten-3-ol and 2-ethylpyridine) which were derived from decomposition of DHA and EPA upon cooking. Combined linseed-fish oil di*et al*so increased lipid-derived volatiles significantly although to a lesser degree than fish oil only, while linseed oil diets generated only moderate levels of these compounds. The most significant differences between breeds were the higher levels of Maillard reaction-derived products in Soay sheep. Pyrazines and sulphur-containing compounds dominated and these were deemed to significantly lower the aroma and flavour scores of meat from this breed when compared to the Suffolks. Lipid oxidation was demonstrated to have occurred to a higher extent in beef than lamb. This could possibly be due to the higher levels of haem iron in beef muscle compared to lamb muscle (Hazell, 1982).

4 Genetic effects on sheepmeat flavour and odour

Variation within individuals contributes greatly to variation in meat quality. These differences may be due to combinations of any of a number of factors including metabolic differences (Buttery *et al.*, 1997), social or behavioural traits, morphology, stress tolerance, disease susceptibility or numerous other genetic and environmental effectors. There is little doubt that the genetic contribution to meat quality is significant. Selective breeding of based upon fattening capacity has been performed (Alfonso and Thompson, 1996). A gene causing muscular hypertrophy in sheep (callipyge gene) is being extensively studied, with the mutation recently being identified (Freking *et al*, 2002). To date no research has been carried out in ruminants to identify genes that directly affect flavour. However many genes such as those involved in fatty acid metabolism and oxidation have the potential to be significant effectors of flavour due to their roles in determining fatty acid profile and aroma volatile production respectively.

No known research has been published to identify genes that directly affect flavour in ruminants. However many genes such as those involved in fatty acid metabolism and oxidation have the potential to be significant effectors of flavour due to their roles in determining fatty acid profile and aroma volatile production respectively. To date the most characterised animal in respect to the genetics of flavour is the pig. A molecular genetics approach has been used to identify chromosomal regions that contain quantitative trait loci (QTLs) controlling meat quality and muscle composition traits in a resource family (Malek *et al.*, 2001). Sensory evaluation of meat for degree of juiciness, tenderness, chewiness, pork flavour and off-flavour were done using three highly trained professional sensory panels. Flavour and off-flavour had a substantial negative correlation in the study with higher flavour scores tended to be associated with higher pH, less glycolytic potential and greater lipid concentration, while the opposite was observed for off-flavour (Huff-Lonergan *et al.*, 2002). Three suggestive QTLs were identified for off-flavour, and two QTLs found for flavour (Malek *et al.*, 2001). QTLs for flavour and off-flavour were mapped to chromosome 2, but at different positions. The QTL for flavour was located within a region of chromosome 2 containing a cluster of QTLS associated with tenderness, colour and reflectance. The QTL for off-flavour was not associated with QTLs for other traits. An additional QTL for flavour was detected on chromosome 15, in the same region as QTLs for reflectance, pH, and glycogen metabolism, and was near to the previously characterised Rendement Napole (RN) gene. Allelic variation within this gene has significant effects on meat quality, with the dominant allele producing meat of reduced quality (Lundstrom *et al.*, 1996). A QTL for off-flavour score was also observed on the X-chromosome and is associated with boar taint. These studies showed that there were significant correlations between biochemical traits, instrumental measures of quality, and sensory characteristics of pork. Phenotypic correlation of similar traits in sheep could be the basis for future studies aimed at elucidating the biological mechanisms responsible for the development of many quality traits including flavour in sheepmeat.

Furthermore, little research has been conducted to determine the molecular aspects of α- and β-oxidation in ovine mitochondria and peroxisomes. Muscle-type carnitine palmitoyltransferase I, a key enzyme in the control of β-oxidation of long-chain fatty acids in mammals, is the only enzyme thus far characterised at the molecular level in sheep and other ruminants (Van der Leij *et al.*, 2002). Knowledge of the transcription patterns of ovine homologues of genes involved in lipid oxidation would provide valuable insights into the regulation of oxidation within meat tissues. Identification of enzymes involved in the formation and oxidation of these compounds could potentiate means of limiting the formation of these compounds or oxidative byproducts that have deleterious effects on sheep meat flavour.

5 The role of vitamin E and other antioxidants

Increasing the PUFA:SFA in ruminants through dietary supplement can lead to increased oxidation of unsaturated fatty acids and the generation of undesirable flavours. To overcome these problems, supranutritional Vitamin E may provide benefits.

The dietary supplementation of vitamin E and selenium in ruminant diets has been demonstrated to strongly reduce myoglobin and lipid oxidation in meats (Lynch *et al.*, 1999). This is due to the antioxidant effects of vitamin E, which increases the membrane concentration of α-tocopherol and glutathione peroxidase of which selenium is a major constituent (McDowell *et al.*, 1996). By protecting membrane phospholipids and cholesterol against oxidation, these compounds increase the shelf life of meat by preventing its discolouration (Lynch *et al.*, 1999). The mechanisms by which α-tocopherol acts to prevent oxidation remains poorly characterised. Vitamin E has been found to improve the quality of many farmed animal products. Feeding with Vitamin E-supplemented diets reduced lipid peroxidation in turkey muscle (Bartov *et al.*, 1996), in chicken meat (Galvin *et al.*, 1997), in pork (Buckley *et al.*, 1995), in fish (Frigg *et al.*, 1990) and in beef (Lavelle *et al.*, 1995). Furthermore in beef, increased α-tocopherol was found to prevent not only lipid peroxidation, but also oxymyoglobin oxidation (Arnold *et al.*, 1992) hence improving the colour of the meat . No studies have been published documenting the effects of Vitamin E supplementation on sheepmeat quality.

The different flavours of beef and lamb produced from grass-based and grain-based diets are largely due to the differences in tissue fatty acid profile, especially the *n*-6:*n*-3 fatty acid ratio, and the resultant oxidation of these fatty acids before and during cooking. To date no extensive studies have been carried out to determine whether dietary Vitamin E supplementation will significantly affect these flavour variations. Such studies would not only provide possible rationales for overcoming flavour deterioration of PUFA-enriched lamb, but could also open the way to elucidating the molecular mechanisms by which fatty acid oxidation can be inhibited.

Nitrites have also been demonstrated to be powerful antioxidants in meat, and are especially important during the curing process for pork. However they may also have applications in sheepmeat. Cho and Rhee (1997) studied the effects of lipid oxidation in cooked mutton on species-related flavour and warmed-over flavour (WOF) intensities when using various additive treatments and post-cooking storage (versus no additive/no storage) as means to produce samples of varied lipid oxidation. Samples treated with 200 ppm sodium nitrite showed the least lipid oxidation, although the intense “muttony” flavour was increased in the nitrate-treated samples. Reid et al.

(1993) examined the effects of curing and oxygen exclusion on odour and flavour of sheepmeat. Curing did not influence trained panellists abilities to distinguish between the flavour of meat from mutton, beef, pork and chicken whilst storage and cooking of uncured mutton fat in an anoxic environment enhanced mutton odour intensity. It was concluded that lipid oxidation products did not contribute significantly to mutton odour from adipose tissue.

6 Production factors that can influence sheepmeat flavour and odour

6.1 Effect of breed

Many studies have been carried out characterising breed effects in domesticated animals for meat quality. However little research has been carried out evaluating genetic contribution to meat flavours, and conclusions differ significantly with regard to genotypic effects on meat quality. Within Australia, there are industrial perceptions of differences between breeds with respect to meat quality, with the Merino being less favoured than crossbred (Hopkins, 1993). In an age-controlled study of flavour in merino versus Coopworth lambs, flavour in the lean was stronger in Coopworth and foreign flavour was stronger in Merino (Young *et al.*, 1993). However, this difference may be age-related rather than a breed effect. Since Merino sheep are primarily a wool breed, Merinos at slaughter are likely to be older than other breeds (Young *et al.*, 1994). Differences in stage of maturity between sheep of different genotypes as well as differences in production and management systems between wool and meat-type sheep, may also account for this age effect. A recent study investigating eating quality of diverse breeds in Australia found that flavour strength was the only significant difference between three genotypes when evaluated by sensory panel assessment, with the Merino x Merino lambs having significantly higher flavour strength than Merino x Border Leicester lambs (Safari *et al.*, 2001). Overall, it was concluded that there was no difference in eating quality between lambs of different genotypes (Safari *et al.*, 2001). This is in agreement with other sheep studies (Notter *et al.*, 1991) and conclusions in derived from study of other livestock (Cameron *et al.*, 2000).

Recent work by Elmore *et al.* (2000) also explored the effect of feeds with different levels of fat saturation on cooked flavour of lamb from two breeds, and the experiment was well designed and analysed. Unfortunately, the results of the experiment were completely negated by the experimenters cooking the meat on one day and re-warming and analysing it the following day. This meant that the volatiles measured would have been those associated with warmed over flavour; thus, the experimenters measured the extent to which warmed over flavour was generated in the meat from the different breeds and diets rather than simply the flavour associated with those breeds and diets.

Studies of more geographically distinct and genetically diverse sheep species do suggest differences in eating quality relative to breed. Looking at the influence of breed on carcass and meat quality traits of suckling lambs of the Churra, Castellani and Manchega Spanish breeds and Awassi crosses, Sanudo *et al.* (1997) found significant breed effects for carcass (fatness, fat colour) and meat quality (meat colour, tenderness and juiciness). A recent study was carried out to investigate the effect of breed and production system in regards to meat flavour (Fisher *et al.*, 2000). Four groups of ram lambs were used: Welsh mountain grazed on upland flora, Soay grazed on lowland grass, Suffolk crosses grazed on lowland pasture and Suffolk crosses fed grain concentrates. Forage-fed lambs all had high levels of *n-3* PUFA including α-linoleic acid compared with high levels of *n-6* PUFAs (linolenic and arachidonic acids) in Suffolk sheep fed concentrates. Soays were high in both *n-3* and *n-6* PUFAs. Flavour panels gave the Soay and concentrate-fed Suffolk low scores for flavour and overall liking, and high scores for abnormal lamb flavour (metallic, bitter, stale and rancid), compared with the other two forage-fed groups. Despite Soay also being forage-fed, this breed had very high scores for livery flavour, due to high myoglobin levels. The study demonstrated a preference for forage-fed lamb in Britain, and identified specific breed effects on the quality and flavour of meat from forage-fed lambs.

Unfortunately research in breed effects on meat quality and flavour are compounded by the fact that results will vary depending upon the criteria used for comparison: equal live or carcass weight, equal age, equal degree of maturity etc. Different breeds mature at different rates which will be reflected by differences in fat content (Pollott *et al.*, 1994; Beerman *et al.*, 1995). Indeed, McClelland *et al.*, (1976), in a study of four breeds that differed significantly in maturation rates, demonstrated that most of the differences in meat quality associated with breed and sex were eliminated when tissue weight was expressed as a proportion of carcass weight and compared at equal proportion of mature weight or growth rate. Petit and Castonguay (1994) presented similar findings. Therefore any study of breed effect must be carefully designed to take these parameters into consideration.

6.2 Effect of age

The flavour of sheep meat from older lambs can be more intense (Sink and Caporaso 1977). Paul *et al.* (1964) and Misock *et al.* (1976) found that with increasing age lamb become more strongly flavoured and was most flavoursome at 12 months of age. Field *et al.* (1978) also reported that the flavour of older 68 kg ram lambs was less desirable than younger 41 kg ram lambs. In contrast, Batcher *et al.* (1962) reported no effect of age on meat flavour whilst Weller *et al.* (1962) found lambs of greater than 6 months of age to have milder flavoured meat than younger lambs. Corbett *et al.* (1973) also reported no differences in flavour intensity of meat from cryptorchids, rams and wethers of 3 to 42 months of age. Channon (1996) also found that aroma, flavour and overall acceptability of meat from both cryptorchid and wether animals of 6 to 18 months of age did not become stronger and less acceptable with increasing age. Kirton *et al.* (1983) also found that both flavour and tenderness of pasture-fed ewes and wethers of 12 to 48 months of age were not affected by animal age.

However, consumer scores for flavour scores of the denuded and defatted *longissimus thoracis et lumborum* (loin), *semimembranosus* (topside) and *serratus ventralis* (rib) were higher (ie. more acceptable) from lambs compared with those from old wethers of up to 48 months old (Thompson *et al.* 2002). Unfortunately, reasons for these differences in flavour scores due to animal age were not investigated as a consumer panel was used. Jacobsen *et al.* (1962) concluded that the variation among individual animals was greater than the variation in age.

Young *et al.* (1994) stated that the odour difference between old sheep and lambs is noticeable during carcass dressing. Although this suggests that odorous compounds accumulate with age, these compounds have not been identified. Furthermore, Young *et al.* (1994) stated that it is not clear whether the odour of sheepmeat is distinct at any age of the animal or whether it changes with animal age. Studies conducted to determine this must be mindful that results obtained may vary depending upon whether consumers who assess sheepmeat flavour and odour actually like or dislike eating sheepmeat. Some consumers also have different sensory perceptions of lamb and mutton.

6.3 Effect of fatness

Increased fatness is usually associated with increased age in ruminants, unless significant feed manipulation is undertaken (Vipond *et al.*, 1993). It is generally accepted, although not categorically proven, that meat from older animals has more intense flavours and stronger odours. With regards to sheepmeat, a number of studies support this statement (Batcher *et al.*, 1969; Misock *et al.,* 1976; Channon *et al.*, 1997), while other studies report contradictory findings (Weller *et al.,* 1962, Sanudo *et al.*, 1996). All of these studies are however somewhat limited in that all sheep were younger than 16 months. The aging effect on sheepmeat odour and flavour may not be obvious until animals are much older.

Physiological changes within the aging sheep's body may have significant roles in flavour. For example, the lean and commonly consumed cuts of meat from sheep concentrate haem iron with age. As reported in the earlier section on fatty acid oxidation, haem iron acts as a catalyst for fatty acid oxidation during cooking (Rhee, 1988), and this process may produce compounds deleterious to consumer acceptance. Also as sheep age they become fatter and the composition of FAs within the body become more saturated (Miller *et al.*, 1986). Differences in branched fatty-acid content have been observed (Bensadoun and Reid, 1965; Spillane and L'Estrange, 1977), and whilst these studies present conflicting findings they both hypothesize that changes in fatty acid composition will affect meat flavour through fatty acid volatiles and oxidation products. Neither study investigated the roles of medium-chain branched C8 to C10 fatty acids as implicated by Wong and colleagues (1975). Meat pH must also be considered as a contributing factor affecting age-related odour and flavour changes. Higher meat pH results in more sulphur compounds such as H_2S being generated during cooking (Johnson and Vickery, 1964). These compounds are implicated in playing a significant role in sheepmeat flavour (Cramer, 1983). In sheep there is evidence to suggest that rigor pH increases as sheep age (Shorthose, 1989), possibly due to the greater susceptability of older animals to stress.

Sañudo *et al.* (2000) reported that flavour intensity increased with increasing fat score, with flavour intensity of the *M. longissimus lumborum* muscle from lambs with no to low fat cover was 5.2 units lower (ie. less acceptable) than lambs with a slight fat cover. Flavour quality, however, was not influenced by fatness level. Overall, lamb from carcasses with an average fat cover scored highest for overall acceptability. Jeremiah (1972) suggested that the deposition of more than 2.0 mm fat may increase the flavour desirability of lamb.

Flavour differences between lambs of different carcass weights have been reported (Solomon *et al.* 1980; Butler-Hogg *et al.* 1984) however, these differences may be confounded by the higher fatness levels of the heavier carcasses. Channon (1996) found that neither carcass weight nor fat depth resulted in significant problems in flavour, odour or overall acceptability of sheepmeat. Jeremiah (1998) concluded that the role of fatness in lamb quality and its relationship to palatability is not well understood and is still a contentious issue.

In the MLA Sheepmeat Eating Quality Program (SMEQ), consumer sensory work conducted has been with denuded loins from lamb, hogget and mutton. Little work has been conducted to determine the effects of fatness on consumer acceptability of sheepmeat, particularly the relationship between flavour and overall liking of sheepmeat with a higher level of fat and whether this is influenced by animal age. Furthermore, the effect on the relative importance of flavour, tenderness, juiciness and odour on overall liking of sheepmeat has not been determined on sheepmeat of different fat levels obtained from animals of varying ages.

6.4 Effect of sex

Due to the faster growth rates of rams compared to wethers (Dransfield *et al.*, 1990), uncastrated male sheep are not uncommon meat sources. While there have been numerous studies into the effect of animal sex on sheepmeat flavour differences, conclusive results have proven difficult. While some studies suggest no significant difference between meats from ram, wether or ewe (Kirton *et al.,* 1983), several others have found higher consumer acceptance of ewe or wether meat compared with ram (Cramer *et al.* 1970; Kemp *et al.*, 1972; Misock *et al.*, 1976; Field *et al.*, 1983). Kemp *et al.* (1972) found meat flavour of wethers to be more desirable than meat from rams, however, all scores were in the desirable range and no differences in flavour with increasing carcass weight were found. These equivocal findings on sheepmeat flavour may reflect the preferences/backgrounds of panellists involved in the sensory evaluation studies. For examples, although both Kirton *et al.* (1983) and Dransfield *et al.* (1990) found differences in flavour between rams, wethers and ewes with increasing carcass weight, the consumers participating in these studies often preferred ram flavour.

The likelihood that the flavour of ram meat will be less acceptable than ewe or wether meat was considered by Misock *et al.* (1976), Crouse *et al.* (1981) and Field *et al.* (1984) to increase with animal age. Corbett *et al.* (1973) found that the flavour intensity of meat from cryptorchids, of three to 42 months of age, and rams and wethers of similar ages was significantly different. Crouse *et al.* (1981) found that the concentration of branched chain fatty acids in subcutaneous fat of heavy rams was higher compared with wethers, with rams also producing softer fat. Studies by Busboom *et al.* (1981) and Vimini *et al.* (1984) investigated fatty acid profiles from rams and ewes, demonstrating that fat rams contained more branched-chain fatty acids, and consequently softer fat, than that of wethers. Sutherland and Ames (1996) reported significantly higher concentrations of free branched-chain fatty acids in 30 week old rams compared with wethers of the same age, and further proposed that these BCFAs may act as male sex pheromones. A more recent study by Young *et al.* (2003) found that the concentration of BCFAs were not significantly increased in pasture-fed rams versus castrates at 232 days, nor were odour/flavour intensity characteristics affected. No significant correlation between testes weight and BCFAs was observed, suggesting that BCFAs are not pheromones. This is in contrast with other research that suggests flavour intensity is greater in males than females (Channon *et al.*, 1997) and others that demonstrated effects of sex on eating quality of Mediterranean sheep breeds (Arsenos *et al.*, 2002). During assessments by taste panel testing, Arsenos *et al.*, (2002) found no significant effects of sex on eating quality characteristics with the exception of flavour. Also they found that independent of breed, female lambs gave more desirable meat flavours than male, and this sex effect increased with increasing maturity of the animals. Similarly Rousset-Akrim *et al.* (1997) found that flavour differences of males and females increased with age.

6.5 Plane of nutrition

Field *et al.* (1983) concluded that plane of nutrition, resulting in differing levels of subcutaneous fat coverage at the same age, did not influence sheepmeat flavour. This is despite considerations of Crouse *et al.* (1967) who noted the interaction between fat and lean on mutton odour.

6.6 Diet type

6.6.1 Pasture based diets

Ryegrasses and clovers are the major pasture species present in lamb producing regions in Southern Australia and New Zealand. Prescott *et al.* (2001) stated that pasture based diets can impart a distinctive flavour note to sheepmeat that has been described, unfavourably, by trained sensory panellists as *barnyard* and *animal*. Roussel-Akrim *et al.* (1997) found that these typical *animal* flavours were higher in slow-grown pasture fed animals compared with lambs fed a grain-based diet. Young *et al.* (1997) also reported that a diet of ryegrass and clover resulted in sheepmeat with *rancid, animal* and *strong* sheepmeat odours. In an earlier study, Cramer *et al.* (1967) found that meat from lambs fed on clover had a more intense flavour and odour compared to animals fed grass (unfortunately, the term *muttonness* was not used as a sensory descriptor in this study).

Many studies (eg. Cramer *et al.* 1967; Shorland *et al.* 1970; Nicol and Jagusch 1971; Park *et al.* 1972a, 1975b,c; Purchas *et al.* 1986) have shown that meat from lambs fed on legume pastures, particularly lucerne and white clover, has a more intense flavour and odour than lambs fed on grass. Park *et al.* (1972a) found that 'foreign aroma' and 'foreign flavour' were higher for lucerne-fed than grass-fed lambs. Nixon (1981), however, found off-flavour to be more noticeable in meat from lambs grazing a predominantly grass pasture than those grazing legume based pastures. Suzuki and Bailey (1985) found that fat from clover-fed lambs had higher concentrations of terpenoids (including γ-dodecalactone) compared with that from corn-fed lambs and this was considered to result from the fermentation of phytol or chlorophyll in the rumen. Hopkins *et al.* (1995c) found that meat flavour of cryptorchid lambs grazing chicory or lucerne was not significantly different. Overall, Young *et al.* (1994) considered that although diet type (legumes vs. grasses) can influence flavour and odour of sheepmeat, these differences are not related to *muttonness.* Studies in both beef and sheep have implicated alkylphenols (Ha and Lindsay, 1991), 3-methylindole (skatole) (Young *et al.*, 1997), and fatty acid oxidation compounds such as 4-heptenal (Young *et al.*, 1999) that have been demonstrated to be present in higher concentrations in pasture-fed animals.

A change in fat consistency can result from feeding sheep a high energy grain diet. This results from the increased propionate concentrations in the rumen leading to increased concentrations of odd-chain and branched chain fatty acids in storage fats (Garton *et al.* 1972). Therefore, the type of diet consumed may cause foreign flavours. Diets that can cause an increase in the level of polyunsaturated lipids in meat, such as lupins, may increase the likelihood of the development of rancidity and off-flavours during storage due to increased levels of unsaturated fatty acids in intramuscular fat depots (Park *et al.* 1975a; Ford and Park 1980). However, it is not known whether these changes in fatty acid composition result in a reduction or masking of the muttonness of sheepmeat to increase its acceptability to consumers (Young *et al.* 1994). Barley-fed lambs were found to produce meat that was more *muttony* compared with animals fed the control, pasture-based diets and this was considered to be due to the higher concentrations of C9 and C10 branched chain fatty acids in fat of barley-fed animals (Wong *et al.* 1975b).

As the flavour of sheepmeat can be influenced by the diet immediately prior to slaughter, a period of about two weeks on a neutral feed was suggested by Park *et al.* (1972b) to be sufficient to overcome flavour problems. Both Park *et al.* (1972b) and Wheeler *et al.* (1974) found that flavour of meat from sheep fed rape had a nauseating flavour and aroma described as *cabbage* and therefore was of lower acceptability than pasture-fed lamb. Hopkins *et al.* (1995a) also reported that short-scrotum lambs grazing forage rape produced meat with a stronger flavour and aroma than meat from lambs grazing irrigated pasture. As stated by Hopkins *et al.* (1995b), retailers and consumers cannot identify between meat from lambs grazing different pasture/forage species prior to slaughter. Thus, any flavour taints detected by consumers may contribute to a decline in consumption of lamb.

6.6.2 Grain supplementation

Cereals and lupins can be used as supplements in Australia to finish lambs over summer or during periods of poor pasture quality and/or quantity. Bray *et al.* (1991) found that lambs fed pasture produced meat with a milder flavour than lambs solely fed lupins. Although Channon *et al.* (1993a) identified a change in the fatty acid composition of subcutaneous fat of cryptorchid lambs supplemented with a lupin: wheat ration for up to 6 weeks prior to slaughter, potential effects on meat flavour were not determined. Hopkins *et al.* (1995d) found that cryptorchid lambs fed an oat: lupin diet for 89 days prior to slaughter produced meat of a significantly stronger flavour and aroma and of lower acceptability than that from lambs fed lucerne-based diets. In contrast, lambs fed concentrate diets either alone or as a supplement to pasture produced meat of a more acceptable flavour than lambs grazing pasture alone (Summers *et al.* 1978; Kemp *et al.* 1981).

Crouse *et al.* (1983) reported that lambs fed a soybean meal diet produced meat with an intense musty flavour with a more intense aftertaste compared with lambs fed on a lucerne diet. Many studies (eg. Summers *et al.* 1978; Kemp *et al.* 1981; Crouse *et al.* 1983; Vimini *et al.* 1984; Hopkins *et al.* 1995d) have been conducted to determine the effect on meat flavour of feeding high-energy diets to lambs in comparison to pasture-based diets.

However, trained or experienced taste panellists rather than consumers were used and samples were not generally assessed for *sheepmeat* or *muttony* flavours. Melton (1990) considered that further work is needed to determine which volatiles are responsible for flavour differences detected by sensory analysis when animals are fed different diets.

In the review by Young *et al.* (1999), the authors stated that grain-based diets promoted branched chain fatty acid formation, which would ultimately increase the mutton flavour in sheep meat. This statement is in direct contrast to the work of Rousset-Akrim *et al.* (1997) and Young *et al.* (1997; 2003) where grain-fed lamb had the least off-flavours. The study of Young *et al.* (2003) showed that ryegrass/clover pasture produced lamb described as *sheep meat* and *sweet* than lambs raised on lucerne, while meat from lambs raised on lucerne and maize were described as *barnyard* and just that from those lambs on lucerne were noted to be *oily/fatty*.

6.6.3 Lipid-protected dietary supplements

Work in the 1970's by CSIRO Food and Meat Research Laboratories studied the effects of lipid-protected dietary supplements on lamb flavour. The research from these laboratories showed that an important component of high linoleic acid lamb was 4-hydroxydodec-*cis*-6-enoic acid lactone, and that it had a *sweet-oily* aroma. Presumably the occurrence of this constituent was linked to the high amounts of linoleic acid found in the meat of the supplemented lamb; however, for Park *et al.* (1974) the origin of the lactone was unclear. From its structure, the lactone would have been the result of spontaneous oxidation of the hydroxyl group in the precursor compound 4-hydroxydodec-*cis*-6-enoic acid that precipitated the cyclisation of the carboxyl and alcohol groups on the *n*-12 mono-unsaturated fatty acid. The *n*-12 itself would be a product of the spontaneous oxidation of a poly-unsaturated fatty acid with more than 12 carbons and a double bond at C6. These criteria would suggest that this compound was from arachidonic acid, which has double-bonds at C6, C9 and C12 and allows for a double bond to remain at C6, a hydroxylation at C9 and for the molecule to be cleaved and carboxylated at C12, rather than linoleic acid as might be thought on the basis of the treatment imposed by Park *et al.* (1974). The work of Nixon *et al.* (1979) confirmed the importance of this lactone in contributing to mutton aroma, but they did not speculate on its origins.

6.6.4 PUFA supplementation

Many of the results of recent large scale experiments investigating effects of various diets on fatty acid profile and meat quality are discussed in detail in the oxidation section of this review. However to generalise the findings of these studies, differing diets have been shown to have profound effects upon fatty acid composition within sheep, resulting in the uptake and oxidation of numerous compounds that have significant effects upon flavour (Wood *et al.*, 1999). As an example, an extensive study was conducted investigating the effect of varying n-3 PUFA composition of lamb muscle on the formation of aroma volatiles during cooking (Elmore *et al.*, 2000). As well as a comparison of dietary effects on aroma volatiles, this research provided an opportunity to compare breed effects, and also provided a useful comparison to a similar study performed in steers (Elmore *et al.*, 1999). Meat was obtained from four groups of Suffolk and Soay lambs fed different supplementary fats. Diets including a palm oil control, bruised whole linseed, fish oils or equal amounts of linseed and fish oil. Fatty acid analysis revealed that compared with the palm oil-based control, meat from animals on the whole linseed regime contained increased α-linolenic acid (C18:3*n*-3), animals on the fish oil diet had increased eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), and animals on the linseed-fish oil regime showed an increase in all three PUFAs. Highest quantities of lipid oxidation products were found in the aroma volatiles of fish-oil fed lamb compared to control animals. Unsaturated aldehydes, unsaturated hydrocarbons and alkylfurans, derived from autoxidation of PUFAs during cooking were increased up to fourfold. The largest increases were observed for highly unsaturated volatiles (octatriene, 2-ethylfuran, 2-(2-pentenyl)-furan, 1-penten-3-ol and 2-ethylpyridine) that were derived from decomposition of DHA and EPA upon cooking. The combined linseed-fish oil diet also increased lipid-derived volatiles significantly although to a lesser degree than fish oil only, while linseed oil diets generated only moderate levels of these compounds. The most significant differences between breeds were the higher levels of Maillard reaction-derived products in Soay sheep. Pyrazines and sulphur-containing compounds dominated, and these were deemed to significantly lower the aroma and flavour scores of meat from this breed when compared to the Suffolks. Lipid oxidation was demonstrated to have occurred to a higher extent in beef than lamb. This could possibly be due to the higher levels of haem iron in beef muscle compared to lamb muscle (Hazell, 1982).

6.7 Interaction of diet, breed and sex on meat flavour

Rousset-Akrim *et al.* (1997) recently showed that the flavour of mutton was most intense in slow growing, pasture-fed ram lambs regardless of initial weight. In their companion paper (Young *et al.* 1997), which presented GC-MA data and related it to the sensory evaluation performed in Rousset-Akrim *et al.* (1997), they confirmed that methylated branched chain fatty acids produced the undesirable sheep meat flavour and that their concentration increased in ram lambs as the lambs approached puberty. Interestingly, the old ewes also tested in this study did not produce the classic mutton flavoured meat but their meat was described as tasting of liver. These results suggested that the *muttony* flavour associated with old sheep is very much associated with old wethers and not old ewes, and is due to an increase in methylated branched chain fatty acids. This hypothesis suggests that rams have a different fat metabolism than ewes that may be linked to their testosterone levels. The effect of testosterone on levels of the deposition of methylated branched chain fatty acids was confirmed by Ames and Sutherland (1999), who found that the levels of these fatty acids increased as age and entirety of the male lamb increased.

Further work on the interaction of diet and breed on lamb flavour by Fisher *et al.* (2000) was difficult from which to draw meaningful conclusions because the sensory analysis was performed on the *longissimus dorsi* while the lipid profile analysis was done on the *semimembranosus*. Despite this error in experimental design, significant differences in flavours could be attributed to diet and breed, but whether they related to the level of unsaturation in *semimembranosus* muscle phospholipids fatty acids was unclear and not examined statistically.

6.8 Other production factors

There are numerous other factors that may affect quality and flavour of sheepmeat. These include the amount of exercise whereby increased exercise translates to decreased fat relative to muscle volume (Aalhus *et al.,* 1991). This may have an impact on flavour through changes in the fatty acid oxidation profile. Environmental conditions can have a similar effect as can flock size and stress, all of which may be applied independently but are more likely to be interrelated, and as such can be grouped under the general animal welfare umbrella. Research identifying ways to improve animal welfare of high intensity production systems such as feedlots without loss of production has the potential to improve animal welfare in these systems. Should such measures be identified and adopted, improved or at least more consistent flavour characteristics of sheepmeat could be one desirable outcome.

7 Processing factors influencing sheepmeat odour and flavour

Thompson *et al.* (2002) reported a decline in sensory scores for flavour, juiciness and overall liking of sheepmeat with extended ageing (up to 14 d post-slaughter). This was also more evident in cuts from tenderstretched carcasses compared with those hung from the achilles tendon.

Several patents have been registered to suppress the specific lamb/mutton flavour. These have mainly been with further processed sheepmeat rather than for fresh product. These include:

- Brun et al. (1989) – French Patent Application. This patent details a method for processing of sheepmeat based on an initial post-mortem holding period, pumping with a special curing brine (that contains preservartives, flavouring and nitrite), holding for brine equilibration, drying, deboning and smoking using wood (from either the Pinaceae, Fagaceae or exotic trees).
- Lequette (1987) - French Patent Application. The ‘tallow-like’ flavour in mutton based products was masked by a prior treatment involving maceration with ‘herbes de Provence’, maceration in olive oil and brief smoking.

- Roberts et al. (1987) – PCT International Patent Application. This patent describers the method and equipment required to remove odours and flavours from strong-smelling meat with minimal denaturation of proteins, fat melting, colour changes or comminution. Meat is treated by passing steam at subatmospheric pressure and of temperatures of 45-60C through the comminuted meat for 0.5 to 3.0 h.
- Toyota et al. (1986) - European Patent Application. Cooked sausage (prepared from mutton, horseflesh, pork or chicken) and fish products (prepared from surimi, kamaboko and chikuwa) are dipped in a solution containing 0.1-1.0% 5'-ribonuclotides, at pH 2.5-4.8, for 0.5-1 min, prior to packaging. Preferred nucleotides are sodium 5'-inosinate and sodium 5'-guanylate. This treatment is claimed to greatly enhance the flavour of the product.
- Montagner-G (1981) -French-Patent-Application. This patent describes a potted mince or preserved-meat type product, particularly intended for Arab countries, which is incorporated into a bouillon prepared from sheep bones. Flavourings (particularly pimento) are added to give a final product with the appropriate humidity, consistency, flavour and keeping properties for its consumption in hot countries. The products are packaged in jars or cans.
- Ajinomoto Co. Ltd (1979) - Japanese-Examined-Patent. The flavour of mutton and lamb is improved by the addition of asparagine, glutamine, alanine or glycine prior to cooking.
- Anon (1974) - British-Patent. The flavour of mutton or lamb is improved by a coating of a mixture of corn flour and baking soda, and subsequent preparation with a sauce containing a variety of specified seasoning materials.
- Sew Hoy and Sew Hoy (1973) - New-Zealand-Patent. The characteristic flavour of mutton and lamb can be made more attractive by blending the meat firstly with cornflour and baking soda and secondly with a flavouring and a vegetable extract. The flavouring contains salt, sugar, a glutamate salt, aniseed, garlic powder, ginger powder and black pepper, and the vegetable extract contains soya bean sauce, vegetable oil, green ginger juice and garlic.

- Hayama, S. (1971) - Japanese-Patent. Mutton or goat were boiled in aqueous compositions containing ginger and then treated with compositions containing soya, sugar, sake and beaten egg before drying at 140 °C for 20 min prior to packaging.
- Ieche and Ieche (1993) - French-Patent-Application FR 2 680 302 A1, FR 91-10457 (19910814). This patent details a process for curing of mutton and other strong-flavoured red meats that involves processing the meat in a press system to reduce colour intensity and decrease the content of characteristic flavour compounds. Treated meat can then be conventionally further-processed, eg. into dry smoked products.
- Tsuji and Takahashi (1989) – United States Patent; US 4 851 241, JP 85-112291 (19850527) [Kikkoman, Noda, Japan]. Meat, such as beef, mutton, pork, or poultry, is treated with a raw soy sauce that retains the flavour of soy sauce and the well-balanced enzyme activities (proteinase, collagenase, elastase) acquired during brewing. The treatment eliminates the powdery (roughened) surface and other disadvantages attributable to conventional tenderising agents. The raw soy sauce acts intensively on the connective tissue of the meat, and to a lesser extent on myofibrils, producing meat with good flavour and tenderness.

8 Acceptability of sheepmeat for manufacturing of processed meat products

Brennard and Mendenhall (1981) and Bartholomew and Osuala (1986) suggested that beef and/or pork fat should be added to decrease lamb flavour as lamb products are usually assessed as acceptable only when lamb fat is equal or less than 10% in the mix. Wenham (1974) also found that a trained taste panel could not identify the predominant meat in mixed-species (beef and mutton) patties, however the acceptability of mutton patties declined at additions of mutton fat greater than 10% in the mix. Importantly, Bartholomew and Osuala (1986) found that flavour had more effect on overall acceptability of processed products made from mutton than texture and appearance. Sephton and Clegg (1993) conducted a study to determine the acceptability of sausages containing mutton fat. Sausages were made using lean beef, salt and spices as well as the test fat. Sausages containing mutton fat were acceptable to the trained sensory panel, however sausages made with pork fat were slightly preferred. Mutton fat flavour was found to intensify with increasing fat addition, with sausages containing 30% mutton fat judged to have a significantly stronger sheep fat flavour than those containing 15 or 25% fat, although flavour of any the 3 formulations was not considered extreme. Consumers also preferred sausages containing 11 or 19% mutton fat to those containing 27% mutton fat, although panellists scores indicated that all 3 fat levels were acceptable. Untrained panellists found that sausages prepared from sheep fat with 0.5% skim milk powder had a significantly improved aroma, texture and juiciness compared with sausages made with pork fat. Overall acceptability of mutton fat sausages made with skim milk solids however, was not significantly different from sausages containing either pork fat or mutton fat only.

Beriain *et al.* (1997) conducted a study to determine the technological suitability of using mutton and pork for the production of cured dry sausages. It was found that whilst mutton was technologically suitable for this purpose, it would be necessary to use lamb instead of ewe meat and/or replace ewe fat with beef and/or pork fat to decrease the undesirable aroma and flavour of the cured meat products.

Bartholomew and Osuala (1986) found that using spices, smoking and/or curing also reduced objectionable mutton flavour whilst Vemulapalli (1985) found that the addition of 0.2% monosodium glutamate failed to mask mutton flavour. As stated by Young *et al.* (1994), rosemary and garlic are commonly added to sheepmeat prior to roasting as a whole piece by Western consumers of sheepmeat whilst mint sauce and/or jelly can also be added to cooked, sliced meat on the plate. The reasons for this are unclear, but it was postulated that these condiments can reduce or mask cooking odours and/or act as an antioxidant. Klettner *et al.* (1989), as quoted by Young *et al.* (1994), found that high levels of mutton would be acceptable for the manufacture of processed meat products in Germany if an appropriate seasoning, such as garlic, is added. However, it is not known whether this would improve the suitability of mutton with a chemical lean content of <85% for the manufacture of processed meat products.

Ground meat patties made from hind legs of lambs fed a pelleted mixture of 85% oat hay, 7.5% barley and 7.5% molasses had a lower total unsaturated fatty acid content and were more colour stable (redder) during retail display compared with lambs from the pasture or feedlot diets (Rhee *et al.* in press). However, more oxidation occurred in cooked patties compared with lambs from the pasture or feedlot diets. This may be explained by diet type as Yang *et al.* (2002) also reported that the levels of natural antioxidants (including α-tocopherol and β-carotene) in pasture fed beef cattle were higher compared with feedlot cattle. It was considered that some unknown factors were responsible for the higher susceptibility of patties from the lambs fed the oat hay, barley and molasses-pelleted mixture to lipid oxidation as PUFA concentrations were similar to those lambs from the feedlot treatment.

9 Perceptions of sheepmeat flavour and odour of consumers from different demographic and ethnic groups

Differences in palatability and acceptability may differ both within and between human populations (Hopkins *et al.* 1995a; Prescott *et al.* 2001) which in turn can influence taste panellists ratings and account for differences observed between studies.

The low consumption of sheepmeat in Asian countries is considered to result from the poor acceptability of sheepmeat odour, particularly whilst cooking, and its flavour when eaten. Wong *et al.* (1975a) reported that the hedonically negative word *soo* was used in China to describe the cooking odour of sheepmeat. Prescott *et al.* (2001), in a study conducted to determine whether differences in liking of meat existed between Japanese and New Zealand female consumers, found that the liking of meat by Japanese consumers was influenced by the presence of branched chain fatty acids, when present at both low and high concentrations in a model meat system. Rather than sheepmeat being used in this study, very lean beef *supraspinatus* muscle and subcutaneous fat from grain-finished beef destined for the Japanese market were separately diced into ≤ 2.5 cm cubes and then mixed in a 19:1 ratio. These samples were then ground twice through a 5 mm plate (following the incorporation of branched chain fatty acids and skatole in different concentrations), vacuum packaged and frozen at –35°C. Prescott *et al.* (2001)

stated that there was some evidence for an interaction between branched chain fatty acids and skatole.

Market research conducted by the Victorian Institute of Animal Science (unpublished) found that Muslims find the strong flavour of mutton offensive and, if mutton is used, it is mixed with lamb and/or beef to mask its flavour. Herbs, spices (including chilli and/or pepper depending on regional influences) and phosphates are also used to mask mutton flavour. Continuing emphasis on the development of export markets in the Middle East, South East Asia and Japan for mutton (MLA 2001) necessitates that further work be undertaken to further understand sheepmeat flavour and odour and develop potential ways of minimising flavour and odour problems to enhance sheepmeat exports. Young *et al.* (1993) highlighted a number of registered patents, mainly from Japan, that aim to reduce sheepmeat odour.

10 Conclusions and recommendations arising from this review

This literature review highlighted that there are still many knowledge gaps in the cause and contribution of different volatiles to sheepmeat flavour and odour. Furthermore, those volatiles that are important for the desirable odours and flavours of sheepmeat have not been quantified. The characteristic odours and flavours of sheepmeat remain a problem limiting its appeal to many meat consumers.

In particular, no relevant literature on the use of sheepmeat in the manufacture of processed meats, the effect(s) of its inclusion on final product quality and consumer acceptability and the use of possible masking agents to neutralise/minimise sheepmeat odour and flavour was found. Although many patents have been registered, particularly in Japan, on methods to minimise odour and flavour of sheepmeat, they have not been commercially adopted to any significant degree.

The MLA Sheepmeat Eating Quality Program generated a vast database of consumer sensory data of tenderness, flavour, juiciness, odour and overall liking of sheepmeat.

Although flavour was assessed, neither liking and strengths of flavour (and off-flavours) were not established nor descriptors used to describe these flavours. This means that in cases where sheepmeat flavour and odour was poorly rated by consumers, we have little knowledge of whether this merely reflects a halo effect (ie. product was tough and /or dry) or, in fact, real problems with flavour and odour.

Furthermore, little research has been published detailing the effect of increasing fatness level on the acceptability of sheepmeat (both lamb and mutton), particularly in relation to potential changes in flavour and odour. The majority of work that has been done in this area has been with denuded or heavily trimmed cuts. This is an area that also warrants further study and is particularly pertinent due to the deregulation of the use of the lamb brand in some Australian states.

It is suggested that a proposal be developed in this area following the critical review of this literature review and then presented to the Sheep CRC Board for funding in 2003/04.

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