GRASSLAND MANAGEMENT AND ANIMAL PRODUCT QUALITY

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Summary

The expectations of consumers ultimately determine the specification of product quality; and grassland systems produce a wide range of animal-based products. Therefore, to provide focus, this paper deals only with food products that are destined for markets that exhibit strong discretionary choice. Quality expectations of consumers have traditionally been based on product attributes such as taste, freshness, nutritional value and appearance, but customer expectations are expanding to encompass food safety, environmental care, animal welfare and biotechnologies.

Grassland forages and their management influence the intrinsic sensory properties of food. A dairy products case study is presented, indicating that pasture species and their interaction with local environmental factors, and the methods of forage conservation, can influence the chemical composition of milk, its ability to be processed into butter or cheese, and the final sensory characteristics of the product. These effects may result directly from compounds originating in the forage (e.g. carotenoids, aromatic terpenes) or indirectly through forage-related changes in animal physiology and enzyme production. Knowledge of these influences and the strict control of the determining factors are key elements in the granting of *Protected Denomination of Origin* (DMO) status and the benefits that accrue from marketing strategies that depend on this status.

Animal feeding regimes also influence the attributes of meat. Pasture-grazed animals have harder and yellower carcass fat than grain-fed animals. The daily energy intake of pasture-grazed animals is also generally lower; therefore there is less intra-muscular marbling. In addition, glycogen levels tend to be more marginal, which can negatively interact with psychological stress to produce a greater incidence of high ultimate pH carcasses. High pH levels (>5.8) result in reduced tenderness, dark muscle and reduced shelf-life of fresh and chilled meats. Early identification of product quality variation is key to placing meat into the correct supply chain, and maximising the total value of the carcass. The positive and negative aspects of fatty acid profiles, phenol and indole compounds, and antioxidants originating from forages are discussed in respect of meat flavour and animal health.

Tight planning and management protocols for both plants and animals are crucial to achieving quality raw material from grassland systems. Unlike feedlot and barn-based enterprises, variation in forage quantity and quality can severely impact on animal performance, timeliness of supply and raw product constituents. Control of a forage-based system requires the setting of performance targets and on-going monitoring. Such measures can signal when the tactical use of specialist forages, or of high-quality supplements, will be of most value in maintaining target performance and animal health. Consistently supplying products with desired attributes, attending to animal welfare expectations and caring for environmental integrity will all be required if the credibility of 'natural' grassland products is to be sustained in the market-place. Controlled grazing of animals will be invaluable in meeting these multiple market demands.

Introduction

Specification of product quality depends on what role the specifying person plays within the supply chain. Producers and processors may focus on physical aspects such as raw product form and yields, whereas wholesalers and retailers may give preference to visual attributes such as product shape and colour. Yet, in the end it is the expectations of the consumer that ultimately determine quality. These expectations will vary depending on whether basic life needs are to be met, or whether there is the opportunity for discretionary choice, as occurs in more sophisticated markets. The ISO definition of quality therefore seems appropriate – 'quality represents the features and characteristics of a product that bear on its ability to satisfy stated, or implied needs.'

The quality domains that need consideration will depend on the interested party and will be related to a raft of production, processing and consumption factors which are intrinsic (sensory, nutritional, safety) and extrinsic (image, ethical) in nature. Just as the specifications of quality can vary, a huge range of products can be derived from grassland systems. These include food, fibre, skin, and industrial and bioactive based products, all of which have their own quality specifications. For the sake of focus, this paper will deal only with animal products that are destined for food markets that exhibit strong discretionary choice. More specifically, the subject will be covered by three cases: the effect of plant composition and environment on cheese quality, the effect of animal diet and management on meat quality; and the role of farm system design and management in achieving the timely supply of specified product.

Consumer trends

Consumers have traditionally been interested in intrinsic attributes related to food quality such as taste, freshness, and appearance. These factors are largely subjective, and food producers and processors try to understand them by way of sensory testing for individual attributes. However, recent studies in a number of countries have shown that consumers are also becoming interested in food qualities that cannot be discovered by looking at, tasting or smelling the products (Dighe & Bezold, 1996; Oude Ophuis & Van Tirjp, 1995). Such quality attributes are related to the nutritional content and hygienic standards of foods, as well as to the presence of food additives, agrichemical residues and contamination from environmental pollution.

Consumers now expect, rather than hope for, high quality food products, and absolute food safety is assumed. Food safety is directly related to the integrity of the entire value chain, and breaches may be based on production faults, microbial contamination, exposure to temperature variations and poor handling. (Wood *et al.*, 1993). Recent food scares in export markets have eroded public confidence in modern high-input farming and production methods. Consumer concern is leading to a growing interest in food produced under low-chemical farming practices and a deepening mistrust over ingredients from genetically modified organisms in prepared foods (Lutzenberger & Halloway, 1999). Food retailers are taking an increasing interest in all these issues and are making purchasing decisions in anticipation of consumer response.

Consumers have also become interested in foods produced according to ethical aspects of resource use and animal management. Ethical issues that contribute to quality in the consumer's mind include soil and water degradation, agricultural emissions, energy use, pesticides, transport, growth hormones, antibiotics and biotechnology (Wandel & Bugge, 1997). Agricultural systems are increasingly required to be sustainable in the long term, while meeting the ethical and social needs of consumers. 'Organic', or 'natural' principles of food production are back in vogue, after being previously superseded in scale by efficiency principles aimed at mass production with high inputs. Some consumers are willing to pay higher prices for the perceived benefits of environmentally benign, lower-input production systems (Anon., 1997).

Biotechnology and/or genetic engineering are increasingly featuring in consumer perceptions of food quality. Even though there is no scientific proof that risks exist from consuming food associated with genetically modified plants and animals, consumers are extremely wary of ‘tampering with nature’ and in many cases are determined to boycott such products. As well, current labelling is imprecise in terms of source and practice and more accurate traceback systems are required. Full traceability is growing in importance, allowing source and system inputs to be rapidly identified (Feigenbaum, 1997). Traceability will play a part in reassuring consumers that they know where their food has come from and how it has been produced.

Dairy product quality

The quality of dairy products can be strongly modified by animal diet, from both an intrinsic and extrinsic perspective. Animal feed can affect the chemical composition of milk (e.g. the levels of fat, protein, vitamins or carotenoids), its ability to be processed into butter or cheese, and the sensory characteristics of the final product. In addition, feeding method also affects consumer perceptions of dairy products. Increasingly, producers and consumers seek to increase the use of pasture feeding for dairy cows because of its positive effect on sensory and nutritional characteristics of dairy products and/or because they believe grass feeding systems are less intensive and ‘more natural’.

The effect of feed type (e.g. maize silage vs. grass silage or hay) on milk composition is well known (Sutton, 1989, Coulon & Rémond 1991; Coulon *et al.*, 1997), but only a few researchers have studied the influence of pasture composition on milk composition (Hauwuy *et al.*, 1993). Even fewer data exist on the influence of pasture composition on the technological quality and sensory properties of dairy products, despite the fact that cheesemakers believe that animal diet has an important influence on cheese sensory properties (Urbach, 1990; Forss, 1993).

Determining the relationships between pasture characteristics and the sensory properties of dairy products is of growing importance for products that have been granted ‘Protected Denomination of Origin’ (PDO) status. The links between territory and product characteristics must be established to gain this status. In addition, any modifications to the original characteristics of the milk for cheese manufacturing are generally restricted, if not forbidden for these products. The influence of animal feeding and milk composition is important for the final characteristics of PDO dairy products. The fact that only limited research has dealt with this topic is partly due to the difficulty in accurately separating the influence of the factors linked to animal diet from that of the manufacturing process itself.

Environment and cheese characteristics

Recent research on environmental effects on cheese properties has either taken a holistic approach, determining the association between global characteristics of the territory, farmers’ practices and cheese properties; or taken a more controlled experimental approach focussing on the influence of pasture on cheese characteristics under constant milk production and cheesemaking conditions.

Research by a specialised panel for Comté cheese, an important PDO cheese in France, has taken a holistic approach. This research aimed to determine whether the sensory diversity of Comté cheese could be related to the natural environment where the cheese was made. Twenty factories were studied. The territory from where milk was collected was divided into small areas according to the natural conditions (climate, soil), the floristic composition of the pasture and the sensory characteristics of the resulting Comté cheeses. Three distinct zones emerged covering 70-85% of the supply-processing relationships (Monnet, 1996). This result showed that it is possible to define areas that influence the flavour of Comté cheese made by the different factories. As with wine, this finding provided an objective definition of 'zones de cru' for Comté cheese. The different areas that were defined according to cheese flavour corresponded to specific natural conditions and the floristic composition of the pasture.

In Switzerland a study was made on Swiss type cheeses produced by different factories and milk collected from either highland (n=14, animals fed on alpine grasslands) or lowland (n=20, animals fed on pasture) areas (Bosset *et al.*, 1994). The volatile compounds desorbing from the two groups of cheeses were analysed by gas chromatography and mass spectrometry. Highland cheeses were different from lowland cheeses (Table 1). In particular, some aromatic compounds (terpenes, alkanes) were less abundant in lowland cheeses. Similar results were also reported by Dumont and Adda (1978) for Beaufort cheeses. These variations are probably due to differences in the botanical and therefore biochemical composition of the grazed fields.

In the two studies just discussed, neither the processing factors nor the animal characteristics were controlled. A recent study (Martin & Coulon, 1995) undertaken with producers of Reblochon cheese (a PDO cheese from the Northern Alps) found that processing factors were the principal cause of variation in cheese characteristics that existed between farmers and seasons. Nevertheless, when these factors were similar, it was possible to associate some cheese characteristics with forage type within the residual variability of the cheese characteristics.. For example, winter feeding with first cut hay and concentrates was associated with very firm cheeses, whereas more desirable softer cheeses were obtained during winter with second cut hay, or during summer when cows were grazing mountain pastures with a high content of grass species such as *Dactylis glomerata, Festuca pratensis and Poa pratense* (Bornard & Dubost, 1992).

Influence of botanical composition

A recent study compared the chemical and sensory characteristics of Abondance cheeses (a French PDO cheese from the Northern Alps area) made with milk from a single herd that was grazing areas of highland pasture containing different dominant plant species (Buchin *et al.,* 1999). Nine cheeses made in the last three days of seven successive weeks were evaluated (Table 2). The animals grazed the south side of the highland pasture during the first period, the north side during the second period, and returned to the south side during the third period. The south side vegetation was predominantly graminaceous (55% content, 12 species), with *Festuca rubra* and *Agrostis capillaris* being the most common grasses. Interspersed in a dense, tall sward were 52 other species, of which *Thymus serpillum*, *Chamaespartium sagittale*, A*lchemilla xantochlora* and *Potentilla aurea* were the more abundant. On sloping areas of the north side, vegetation was composed of graminaceae (50% content, 9 species), comprising predominantly *Agrostis capillaris* and *Nardus stricta*, associated with 32 other species. Vegetation on the wet shelves of the north side contained few graminaceae (16% content, 7 species) and was dominated by moss, *Ranunculus* spp., *Carex* spp., *Caltha palustris* and *Mentha longifolia.*

The six 'north' cheeses were very similar, but differed significantly from the three 'south' cheeses. The sensory measurements indicated that the north cheeses were less firm, but stickier and fractured more easily than the south cheeses. The north cheeses were also saltier, more bitter and had an aroma more intensely characterised by sour, burned, toasted and fermented vegetables. The south cheeses were characterised by toffee, exotic fruit and acid milk aromas. These differences confirm the associations of diet and cheese characteristics observed by Martin & Coulon (1995) with Reblochon cheese. Some of these associations can be explained by different proteolysis resulting from different amounts of native proteolytic enzymes (plasmin and plasminogen) in the milk and cheeses. In Buchin *et al.*'s study, such enzyme differences could have arisen from the abundance of *Ranunculus* spp. and *Caltha palustris* on the wetter north side. These species are toxic and can affect cattle health.

Research discussed in the previous sections demonstrates that the characteristics of matured cheeses depend on the original characteristics of milk used for manufacture, which in turn can be modified by animal feeding. Farmers' practices and the animals' natural surroundings influence cheese sensory characteristics and determine the link between territory and cheese characteristics. These relationships are important for PDO cheeses. However, it is important to note that differences observed between treatments have always been greatest in trials with northern Alps and Comté cheese. This may be due to the manufacturing process (e.g. hard pressed cooked cheeses), which allows greater expression of sensory differences derived from animal diet, or to the differences among the forages being more extreme.

Effect of forage conservation

The PDO cheese industry is not unanimous on how silage conservation method might affect cheese quality. Some specific defects can be observed with low quality silages (Urbach, 1990; Forss, 1993), especially in hard-cooked cheeses where the presence of spores of butyric acid organisms in silage milk can cause serious defects such as late swelling and unpleasant taste and odour (Demarquilly, 1998). Verdier-Metz *et al.* (1998) conducted an experiment where pasture from the same field was harvested on the same day and conserved as either silage (with acid preservative) or hay (barn drying) (Table 3). In both situations the quality of the conserved forage was excellent and nutrition levels of the cows were similar. Experimental Saint-Nectaire cheeses (a PDO cheese made in the Auvergne) made from silage-produced milk were yellower because of a higher carotene content in the silage, and tended to be more bitter. The other chemical and sensory characteristics examined did not differ between the two treatments. These results have been confirmed by farm observations (Agabriel *et al.,* 1999) and demonstrate that when forage conservation is good, the method of conservation has little effect on cheese attributes except colour.

In contrast, important sensory differences were demonstrated between cheeses made with milk from cows that were fed with either conserved grass (hay plus grass silage) or spring native pasture in mountain areas (Table 4). Saint-Nectaire cheeses produced from mountain pastures had a more intense taste and odour that involved a sour and piquant taste and a rancid and mustier odour (Martin *et al.,* unpublished data). This result is consistent with the quality of farmhouse cheeses that are produced when herds are turned out to pasture in the spring. Similar results were obtained by Buchin *et al.* (1998) in a trial comparing Comté cheeses made with milk from hay fed and spring pasture fed cows. The differences in cheese characteristics could be explained in part by a large change in the composition of the fatty acids in the milk (i.e., an increase in the proportion of long and unsaturated fatty acids) when cows were turned out to pasture. This change explains the well-known influence of spring feeding on butter characteristics such as lower melting point and reduced hardness.

Mechanisms influencing cheese quality

The influence of pasture composition on milk and cheese characteristics can be explained by two main mechanisms: a direct influence of certain compounds originating from the herbage and/or an indirect influence of the herbage on animal physiology and cell metabolism. For example, the carotenoid pigments that cause yellow coloration of dairy products are present in large amounts in pasture-based forages. When pasture is cut, they are destroyed during drying and conservation (Table 5). Carotenoids are very sensitive to ultraviolet light. According to the season and the type of forage eaten by cows, the colour of dairy products varies. For example, products are more yellow when cows are fed spring pasture compared with conserved forages, or when they are fed grass silage during winter compared with hay or maize silage.

Aromatic plant compounds like terpenes and sesquiterpenes can also be detected in matured cheeses, and when concentrated, these compounds produce important odour notes. A trial comparing cheeses made with milk from cows fed either cocksfoot hay or natural mountain hay (Viallon *et al.,* 1999) showed that the higher diversity and abundance of volatile compounds in mountain hay could be found in the corresponding cheeses (Figure 1). This result confirms the previous work of Dumont & Adda (1978), Bosset *et al.* (1994) and Moio *et al.* (1996), which showed that differences between cow or ewe cheeses can be traced to different types of forages. More recent studies have shown that the composition and abundance of terpenes and sesquiterpenes in a pasture depend mainly on its botanical composition (Mariaca *et al.,* 1997; Bugaud *et al.,* 2000; Cornu *et al.,* 2000). Graminae species generally have few aromatic compounds, unlike species such as *Meum athamanticum*, *Thymus serpillum* or *Achillea millifollium*. Within species, the phenologic stage of the plant and the micro-site conditions where the plant is growing can also affect the composition of volatile compounds (Mariaca *et al.,* 1997). The volatile compounds of plants, and more generally their metabolism, are believed to be part of an adaptive response of plants to their surroundings (Dorioz *et al.,* 2000).

Some plants contain compounds that can induce small changes in animal physiology and cell metabolism, which then impact on the transfer of cheese ripening enzymes (proteolytic and lipolytic enzymes) from blood to milk. In addition, it is possible that particular micro-organisms linked to plant species and forage conservation methods could affect cheese sensory characteristics.

Whatever the mechanisms that link forage and cheese sensory properties, the preservation of the biodiversity of grasslands is probably one of the key factors in the high aromatic specificity of PDO cheeses. Unfortunately, the intensification of grassland systems (fertilisation, early cutting) can lead to a reduction in this botanical biodiversity. This intensification is often the result of farm systems requiring high quantities of nutritive forages to achieve high milk production levels in situations where pasture area is very limited. This approach can undermine the commercial advantages intrinsic to PDO-linked dairy industries.

Meat quality

Diet and environmental factors can have subtle effects on meat and animal fat composition and properties, with marked economic consequences. These factors are particularly important to pasture-based producers of sheepmeat and beef. The properties – or quality attributes – of interest, which are often interrelated, include meat ultimate pH, meat and fat colour, other fat properties, and flavour arising from a pastoral diet. This section discusses these factors, describes meat and fat quality attributes with respect to pastoral production, and discusses ways of overcoming feed-related quality problems and of capitalizing on any advantages over grain-finished equivalents.

The challenge for pastoral production of meat is not to emulate grain-finished systems, but rather to control the variability that is inherent in extensive pasture-based production and its principal drivers, weather and season. The value of meat from pasture-finished animals can be increased by reducing variability and raising the average quality. These are essentially precision and accuracy issues. By reducing variability, producers have the opportunity to break away from the commodity trap through branding of meat, perhaps with PDO status. At the same time, however, the cost advantage of pastoral production must be maintained.

Meat ultimate pH

After slaughter, skeletal muscle becomes oxygen depleted, and muscle acidity then increases by way of breakdown of muscle glycogen to lactate, simultaneously generating hydrogen ions. In bovine muscle, the normal glycogen concentration translates to an ultimate pH between 5.4 to 5.6 in rigor muscle as meat (Bendall, 1973). If muscle glycogen is deficient at slaughter, the ultimate pH is higher than normal. As the pH of meat increases above pH 5.6, its water-holding capacity increases and light reflectivity decreases. As a result, the meat can have a darker colour, variable tenderness (Figure 2), reduced flavour and reduced microbiological stability.

Pastoral production generates more high ultimate pH meat than grain-based production. In the latter, high pH is not identified as a significant issue, so data are understandably scant. Equally, in pasture-finishing systems, the problem is difficult to quantify, because quality-inspired measurements are made sporadically and data are often unreliable. Graafhuis and Devine (1994) surveyed the pH of beef and sheepmeat throughout New Zealand, and found that for 3000 cattle and 7000 sheep, 30% of each species had a pH above 5.8.

Psychological stress can induce glycogen depletion. This is particularly true for bulls (Tarrant, 1981; Figure 3), and is exacerbated by fighting and mounting. When pasture-raised bulls from different mobs are mixed before transport to a slaughterhouse, the confines of transport and holding pens contrast with the high distance between animals on farm. Psychological stresses become high and glycogen loss is accelerated by fighting to restore social hierarchy. By contrast, feedlot animals are raised close together and are usually slaughtered in feedlot groups. Careful handling of animals in the weeks, days and final hours before slaughter can greatly reduce the incidence of high pH meat. An understanding of animal behaviour as it affects good animal welfare practice is important in minimizing the condition.

Because high ultimate pH is largely peculiar to pastoral farming systems, diet may also be involved. Experiments on the effect of diet on muscle glycogen concentration can be confounded by differences in energy intake, but in general, grain diets promote the accumulation of muscle glycogen (Melton *et al.,* 1982). The implication for pasture-finishing is that whereas the level of glycogen from grassland systems is nominally sufficient to produce a normal ultimate pH, the concentration of glycogen to buffer against stress-induced losses is marginal. Add to this the greater potential for stress in the day(s) before slaughter for pasture-raised animals and it is clear why high ultimate pH is such an important issue in grassland systems. Dietary supplementation with carbohydrate-rich feeds is clearly one way of minimizing the problem, but unless well controlled this approach will tend to defeat the cost advantage of pastoral finishing.

One key problem affecting the occurrence of high pH meat is its detection. The condition is obvious when cuts of meat are on retail display, but by that time the trail to source has often disappeared. Detection in the abattoir is much more useful. The traditional method of collecting pH data is to measure muscle pH with probe electrodes one day after slaughter, but this method is too slow for high-throughput abattoirs and it is deceptively difficult to produce reliable data. The patented Glycoprobe™ technology (Young *et al.*, 1999) detects carcasses that will yield high pH meat within 15 minutes of slaughter. While the technology will not necessarily solve the pH problem, quality systems can be created to send clear price signals to pastoral producers. For example, the carcasses of bulls raised on pasture (see Figure 3) could be segregated into table cut (low pH, high value) and manufacturing grades (high pH, lower value), thereby increasing returns to superior producers and allowing meat processors to reduce variability within grades.

Fat and constituent fatty acids

In monogastrics like pigs, the fatty acid profile of storage fats strongly reflects the dietary fatty acid composition. In ruminants like sheep and cattle, unsaturated fatty acids tend to be hydrogenated by rumen microflora and deposited as saturated fats. Nonetheless, diet does affect ruminant fatty acids to some degree. Melton *et al.* (1982) provide a good example of the typical difference in the fatty acid composition of ruminant triglycerides from pasture and maize diets (Table 6). The table lists only fatty acids that dominate the profile, or are important in odour/flavour. The largest differences occur in stearic and oleic acids, respectively higher and lower from a pasture diet. Linolenic acid content is higher from a pasture diet and derives directly from pasture after escaping hydrogenation in the rumen. The lipids of pasture plant species are dominated by linolenic and linoleic acids, whereas oleic and linoleic acids dominate maize lipids (Hitchcock & Nichols, 1971).

Dietary carbohydrate is also important in ruminant fatty acid composition. Carbohydrate is fermented in the rumen to short chain fatty acids; the proportion of the three-carbon propionic acid increases with carbohydrate intake. In sheep and goats, propionic acid promotes branched chain fatty acid formation in body fats (Duncan & Garton, 1978). Branched chain acids lower melting point, contributing to a softer, oiler fat. Shorter chain analogues like 4-methyloctanoic acid and 4-methylnonanoic acid are responsible for the characteristic species odour of sheep fat and thus of sheepmeat as a food (Wong *et al.*, 1975). Therefore a pastoral diet, which is lower in carbohydrate than a grain diet, can produce reduced sheepmeat species flavour (Table 7), a commercial advantage in some markets.

The fatty acid profile of fats affects eating quality. Higher proportions of saturated fatty acids like stearic increase the melting point of the fat, leading to a harder, less oily mouthfeel. Oxidation of fatty acids during cooking generates many intense odours. In a pasture/maize comparison, Melton *et al.* (1982) showed that stearic and linolenic acids were positively correlated with undesirable odours and flavours, while oleic was correlated with desirable notes. Other work has confirmed this general theme (Romans *et al.*, 1995). More positively, however, a low ratio of n-6 fatty acids (linoleic for example) to n-3 (linolenic for example) is important in suppressing atherosclerosis in humans. Pasture gives a lower n-6:n-3 ratio in fat than does maize. Fish is always a better source of n-3 fatty acids than ruminant fats, but some human diets contain no fish and few vegetables. For these diets, linolenic acid from animal fats is important.

Meat from grain-finished cattle is purportedly more tender than pasture equivalent. The reputation is partly deserved, and arises from marbling (less lean tissue to resist a bite), a lessened chance of cold shortening in abattoirs (Locker & Hagyard, 1963), and usually lower animal age. The slower growth rates of pasture-fed animals mean they are often older at slaughter than grain-finished equivalents. Connective tissue becomes increasingly crosslinked with age, or when growth is arrested, so yielding tougher meat. However, an optimised meat production system based on pastoral finishing, coupled with well-controlled abattoir processing, will produce lean meat of superb tenderness.

With its low intramuscular fat content, meat from pasture-fed ruminants is promoted as a ‘healthy’ food. While all claims for healthy foods are logically flawed (a food is confused with diet), low fat content allows consumers to control their fat consumption through the controlled use of cooking oils. It also allows consumers better control of flavour since the basic flavour of cooked lean tissue, which is generated from membrane fats and low molecular weight metabolites, is not swamped by flavours from intramuscular storage fats. Lean meat is therefore more versatile that fatty meat.

Fat-soluble carotenoids, particularly β-carotene, accumulate in the fat of ruminants, especially certain breeds of cattle (Yang *et al.*, 1992). The pigment derives from green pasture, which contains up to 500 μg carotenoids/g dry weight. In contrast, grains contain less than 5 μg/g, which is why grain finishing yields non-yellow fat. The incentive to produce white fat is driven by market demand. Several methods have been tried to reduce carotenoid accumulation in pasture-finished animals, but none has been commercially applied. Because the tendency to accumulate carotenoids has a genetic component, selection for pale fat may be possible. However, in New Zealand at least, where surplus calves from the dairy industry are often raised for meat, criteria for genetic selection are dominated by dairy needs. The challenge for marketers of pasture-finished beef is to persuade consumers that yellow fat is not a defect, but is an indicator of a desirable ‘natural’ diet. Yellow fat can thus indicate ‘organic’ meat in the popular sense. Carotenoids are significant antioxidants in human diets, but the dietary significance of beef fat-borne carotene is minor compared to that of carotenoids from vegetables. Nonetheless, the presence of carotenes in fat has not been exploited in market promotion.

Pastoral flavours

Meat from animals raised on a pastoral diet has a characteristic flavour variously described as ‘pastoral’, ‘milky’, ‘fishy’, ‘metallic’, ‘rancid’ and ‘barnyard’. These terms share an image of unpleasantness, yet many consumers enjoy the flavour complexity of pasture-derived meat and describe the grain equivalent as flavourless. The challenge is to provide pasture-produced meat of consistent flavour, and to position such meat as desirable in the minds of consumers.

As to the source of pastoral flavour, fat is an obvious candidate, because it changes with diet. Since linolenic acid can generate ‘fishy’ notes, its link to pastoral flavour has been examined. Although linolenic acid represents less than 3% of the fatty acid profile of beef fat, its oxidation products (e.g. 4-heptenal) are particularly odorous. Nonetheless, there are no hard quantitative data to prove a causal link between linolenic acid and pastoral flavour. Ha and Lindsay (1991) showed that alkylphenols, like 4-methylphenol, were constituents of volatiles from ovine and bovine fat, and suggested they might be important in pastoral flavour. These phenols could derive from the abundant protein of a pastoral diet (see later).

Young *et al.* (1997) showed that the headspace above fat from lambs on a pastoral diet had high concentrations of the faecal-smelling compound skatole, which was statistically associated with ‘animal’ odour and flavour. More recent studies have confirmed and extended this observation (Figure 4) with compounds identified as odorous by odourport sniffing. A principal components analysis showed that the classes of compounds responsible for ‘barnyard’, ‘mutton’ and other unpleasant notes by a group of odour panellists were not associated with the ‘lamb’ flavour note. Figure 4 also shows that many odorous compounds identified by odourport sniffing are clearly irrelevant to the panel descriptions.

The accumulation of volatile indoles and phenols from a pasture diet may be due to the high ratio of protein to readily-digestible carbohydrate found in pasture diets, particularly in spring (Moller *et al.,* 1993). Such diets favour deamination of protein amino acids by rumen microbes, resulting in indoles and phenols. The amino acid tyrosine is the likely source substrate for phenol, 4-methyl- and 4-ethylphenol. Skatole and indole stem from tryptophan in dietary protein.

Flavour problems due to skatole suggest that pasture breeding might be directed at increasing the ratio of carbohydrate to protein. However, it is important to restate that the mission is not to emulate the flavour (or lack of it) of grain-finished meat, but rather to capitalize on the full flavour of the pasture-finished product.

Some toxic conditions from pastoral grazing that affect meat quality

Pastoral finishing is more prone to the vagaries of climate and season than grain-finishing, and this can lead directly, or indirectly to flavour problems. For instance, brassicas are often used in winter diets as a useful source of carbohydrates and proteins. However, they can cause adverse flavour changes in sheepmeats (Park *et al.,* 1972) through toxic conditions. Similarly, *Phalaris tuberosa*, which can be used as the basis of drought tolerant pastures can be responsible for 'foreign' flavours in meat (Young *et al.,* 1994); *Phalaris* contains indole akylamines that cause metabolic disturbances.

Ryegrasses, fescue and other desirable pasture grasses are often in symbiotic relationships with fungi that produce secondary metabolites which induce staggers in grazing animals. Preliminary studies in New Zealand indicate that serious staggers conditions can affect meat pH, but there are no data on flavour effects. Facial eczema, another disease of grazing animals, is caused by the spores of a fungus that contains the free radical-generating toxin sporidesmin. Kirton *et al.* (1979) found significant flavour deterioration for sporidesmin-affected lamb (Table 8). The biochemical mechanism for the flavour effect is not known, but clearly liver damage, a key event in the condition's development, might have adverse effects on other tissues like muscle. Unlike pastoral flavour, which can be viewed as a positive attribute if its variability is controlled and its complex full-flavoured qualities are extolled, flavour changes from toxic conditions are all likely to be deleterious. The solution to the flavour and tenderness problems discussed in the preceding sections centres on good management at all levels of production, processing and products distribution.

Antioxidants from pasture

One of the compounds determining the oxidative stability of muscle is α-tocopherol, also known as vitamin E. With meat, oxidative stability is important for maintaining good colour stability and for slowing rancidity development. Colour stability is particularly important for Southern Hemisphere beef producers, whose products must appear bright red rather than brown in supermarket chillers after many weeks of storage and transportation. In beef, concentrations of vitamin E below 3.5 μg/g lead to early metmyoglobin formation (browning) on display (Arnold *et al.*, 1993). This value of 3.5 μg/g has become a benchmark for grain-finishers to exceed by supplementation, which is not cost free. The concentration of tocopherol in dried grains is typically below 10 μg/g, whereas green pasture contains up to 300 μg tocopherol/g dry matter. Cattle on green pasture ingest up to 3 g/day of vitamin E (Rammell, 1983). There are many data on tocopherol concentrations in tissues of ruminants on feedlot diets, but few on pasture-raised animals, as the concentration in the pasture situation has never been an issue. West *et al.* (1997) reported that the mean tocopherol concentration in beef *longissimus* (pasture diet, three seasons, various New Zealand locations) was 4.96 ± 1.7 μg/g.

Tocopherol concentration declines markedly in grasses as they mature. This decline with herbage age is not a problem in pastoral finishing, because animal tissues are buffered against losses (or gains) in tocopherol, so seasonal differences in muscle tocopherol concentration are likely to be minor. The oxidative stability of tissue in general, and muscle in particular, is not determined by dietary tocopherol alone. Other factors include the fatty acid profile in animal fats, and other antioxidants in the diet. Ascorbic acid concentration is also markedly higher in green leaf tissue than in grains (Spector, 1956) and might contribute significantly to the colour stability of meat from pasture-finished livestock.

The challenge

The main advantage of pastoral finishing is its low cost, but as described in this paper, some meat quality attributes can suffer. Although several of the quality problems are intrinsically related to the biochemical nature of grasses and legumes that drive the system, weather and season are overarching factors that add variability to the meat quality attributes. The main challenge of pastoral meat production is to reduce this variability as far as is economically possible, so marketers can present meat products with tightly defined characteristics. This goal will require validated systems of objective measurement and traceability, so the problems can be eliminated at source. For example, an online fat colour meter would allow processors to reward farmers who present cattle with fat colour in a specified range. Yellow fat might not be eliminated, but outliers would. Technology to predict ultimate pH immediately after slaughter is now available, enabling sorting of carcasses on the basis of pH. Flavour prediction at slaughter presents more of a challenge, but would be a worthwhile objective since one unacceptably flavoured outlier could deter a consumer permanently. Systems of traceability and measurement come at a price, and costs have to be recovered in the market. This can be achieved only by some form of branding, perhaps PDO. As quality systems are increasingly applied to meat pastoral industries, branding is sure to follow.

Systems management of product quality

The previous sections have provided examples of how product quality can be influenced by dietary features of pasture-based systems, and how product traits can be altered and controlled to improve customer acceptance. At a supply systems level, the major challenge for pastoral farming is to manage between-season and between-year variations in both forage and animal performance. While an overwhelming advantage of pastoral farming is its low cost structures, seasonal and geographical variations in both the edaphic and climatic drivers of system performance are significant impediments to production and quality control (McCall *et al.*, 1993; Pleasants *et al.*, 1995). The supply of specified product in a timely manner and at agreed quantities is essential for any branded product to command and sustain high value.

Animal growth rates

At both an individual animal and a farm systems level, the efficiency of converting pasture into saleable product increases as the proportional investment of energy and protein into growth, rather than body maintenance, increases. Therefore, higher growth rates of young animals and/or the lower maintenance requirements of animal breeding systems are advantageous to farm system output and profitability (Milligan *et al.,* 1987). In addition, rapid growth of young animals and the opportunity to slaughter at an earlier age is also of advantage to meat quality. Most of the quality traits that consumers seek are enhanced in the meat of young animals. For example, lean meat is more tender and for pasture-fed animals the fat is less yellow in younger animals (Morgan & Everitt, 1969; Boom & Sheath, 1997). On this basis, it has been argued that much of the improved meat quality of feedlot cattle relative to pastoral systems, is simply explained by the greater energy and protein levels of concentrate feeds, resulting in faster growth rates and earlier slaughter ages (Muir *et al.,* 1998).

Growth rates of sheep and cattle in pastoral systems are determined by the interactions of herbage allocation, utilisation levels and herbage quality (Rattray *et al.,* 1987). While high herbage allowances should intuitively lead to high feed intakes and high animal growth rates, this is not necessarily the case in a systems sense, because resultant low levels of pasture utilisation and quality can ultimately restrict animal performance. For this reason, performance of some animal classes in 'pasture-only' systems is generally kept below maximum, to ensure that herbage quality is (Bryant & Sheath, 1987). Alternatively, expensive mechanical topping, or conservation of surplus forage must be employed to enhance young animal performance.

Improvements in pasture quality through changes in botanical composition (e.g. more legumes) or the use of new cultivars are commonly advocated. While improved pastures can certainly promote animal growth rates and reduce slaughter age, it is important to recognise the negative impact of dead herbage in the diet on animal growth rate (Rattray & Clark, 1984; Hyslop *et al.,* 2000). Senescent herbage is very low in digestability and reduces intake rates. In predicting performance, and thereby planning the grazing of pastures, a knowledge of green herbage fractions (percent) and of green herbage allowance (kg DM/animal/day) is most useful. A simple predictive equation arising from recent research in bull beef systems (Sheath, unpublished) illustrates this point:

$$\text{Live weight gain} = a. \log_n (\text{green allowance}) + b. \log_n (\text{percent green /percent non-green}) + c$$

$$r^2 = 0.81$$

Providing an adequate amount of quality forage when climatic conditions are hot and/or dry is a very significant challenge to high performance, pastoral farming. This challenge is exacerbated when these stresses are unpredictable and strategic farm policy designs are unable to cope with between-year variation. The tactical use of high quality supplements can certainly improve animal growth rates and ensure that target slaughter dates are achieved (Boom & Sheath, 1998), but there are additional costs associated with such practices. It could also be expected that supplementary feeding of concentrates to animals that are concurrently grazing pastures would also influence meat quality traits. However, numerous studies with cattle indicate that a high proportion (>80%) of the diet must be concentrate feedstuffs and the duration of supplementation needs to approach 80-100 days before sensory quality factors are significantly changed (Griebenow *et al.,* 1997). Similarly for lambs, the majority of the diet needs to be grain before fat characteristics and odour are markedly influenced (Hopkins *et al.,* 1995).

Quality feed, planned grazing and tactical supplementation are key ingredients to supplying young animals at a prescribed time, weight and number. But of equal importance is the need to establish target liveweights during the animal's lifetime; and to operate a disciplined monitoring procedure that keeps a regular track of achieved performance (Sheath *et al.,* 1999). Only with the knowledge of differences between actual and intended performance is the farmer able to take corrective action and learn through reflecting on previous decisions and actions. As in the manufacturing industry, regular monitoring of the process and resultant products is key to achieving consistency, a prerequisite of any quality system. The use of industrial procedures (e.g. a Cusum chart) to establish acceptable variance limits will become important in precision farming of the future (Pleasants *et al.,* 1998).

Seasonal variation in product fitness

The seasonal nature of many biological processes that operate within pasture-based systems can make the supply of specified products a difficult, inefficient and costly business. Seasonality of reproduction in farmed sheep and deer can strongly influence the supply patterns from the perspective of liveweight specifications (Wilson *et al.,* 1998). While reproductive activity can be manipulated with hormonal treatments, a common way of achieving continuous, consistent supply is to plan and implement different growth paths that align to sequential slaughtering dates (Figure 5). As in this example, where further processing is unable to remove the effect of seasonal variation (e.g. meat cut size) then the added costs, or decreased efficiencies associated with uniform supply, generally remain on-farm.

In contrast, the added costs associated with seasonal variation in milk yields and composition occur in the processing and storage phase of the dairy supply chain. Processing capacity must be able to handle peak yields, and storage facilities must be able to hold product in order to provide more uniform distribution to the marketplace. The impact of declining milk fat and protein yields during lactation is experienced to the greatest extent in seasonal supply systems where calving is controlled and concentrated to coincide with the onset of spring pasture growth (Bryant, 1981). While spreading calving through the year is a possible solution to the need for a more uniform flow of product, it is a practice that reduces pasture utilisation and/or increases feeding costs, an outcome that defeats the purpose of low cost, pasture-based farming.

Seasonal variation in the micro-composition of milk also influences the functionality and quality of dairy products (Dalgleish, 1992). For example, relative to spring and autumn, levels of unsaturated fatty acids are lower in summer and the resultant butter is harder (MacGibbon & McLennan, 1987; Thomson & van der Poel, 2000). This pattern does not appear to be a stage of lactation effect (Auldist *et al.*, 1998). Rather, it is a combined result of changes in the lipid constituents of the pasture and/or mobilisation of fatty acids from body tissue. Supplementation of pasture to counterbalance these seasonal patterns is possible, but the feedstuffs need to contain high levels of long-chain, unsaturated fatty acids (Murphy *et al.*, 1995; Mackle *et al.,* 1997), and they obviously add cost. To fully exploit the neutraceutical and pharmaceutical opportunities associated with micro-constituents such as conjugated linoleic acid, hyper-immune milk and colostrum, the inherent seasonal variations in their concentrations will most likely need to be managed on-farm. A continuous supply of suitable raw material to small, dedicated processing plants will be required. Such developments pose significant farm-systems and farmer-learning challenges for the future.

Natural low-chemical systems

High value, niche products that are derived from more natural and/or low-chemical farming systems embody numerous extrinsic features that consumers value. These features often centre on the acceptance of the production system, rather than the intrinsic properties of the product, such as texture and flavour. Food safety, the use of synthetic chemicals and genomes, animal welfare and environmental impact are the primary domains of consumer concern and scrutiny.

In terms of the debate between penned-intensive and natural-extensive production systems, there are pros and cons for each position. From a food safety perspective, *E. coli* O157 is more prevalent in intensive housing and feedlot systems (Phillips, 1999), yet animals in less controlled environments are more open to wildlife infections such as tuberculosis and *Salmonella*. Effluent disposal from housed, or feedlot systems is a major concern, yet nitrate leaching from urine patches in intensively grazed pastures is significant (Breembroek *et al.*, 1996; Ledgard *et al.*, 1997). Grazed pastoral systems allow animals the freedom to exhibit natural behaviour, yet shelter from harsh climatic conditions must be provided. The essential pin that will hold these natural, low-chemical value chains together will be the integrity of their associated quality assurance schemes. Agreed best practices must be feasible, traceability systems must be low cost, and records of actions must be straightforward if integrity is to be maintained and the associated value chains sustained in the longer term.

Where synthetic chemicals are withdrawn from conventional pastoral systems, the major challenges will centre on maintaining soil fertility, managing animal health problems and controlling pasture pests and weeds (Mackay *et al.,* 1998). The use of natural elements such as fertilisers (e.g. rock phosphate, elemental sulphur) should allow the long-term maintenance of soil fertility in legume-based pastures, but maintaining animal health in the absence of vaccines and drenches will be more problematic. From a meat quality perspective, the potential danger is slower growth rates of animals and an older age at slaughter. Quality problems associated with animal stress will be compounded if energy and protein supply is also restrictive, but conversely specialist forages of high quality may counteract the impact of disease challenge. For example, the feeding of high protein supplements or legume pastures, particularly if condensed tannins are present to further protect ingested protein (e.g. *Lotus* spp.) will buffer the negative effects of endoparasites in lambs (Niezen *et al.,* 1998; Datta *et al.,* 1999). However, the effect of high protein diets on pastoral flavour through skatole formation must also be considered. The systems challenge for the future is to determine how these specialist forages are best integrated into the overall grazing regime.

Integrated grazing of different animal species can help reduce the challenge and potential impact of diseases in low-chemical systems. For example the inclusion of cattle in the grazing sequence of lambs and/or goats will lower worm burdens in the latter two species and reduce the necessity to drench with anthelmintics (Bown *et al.,* 1989). The principle of breaking disease cycles of one species by another should ultimately lead to low-chemical systems that contain several livestock types. This diversity of animals will also be of benefit in the control of weed species. Many undesirable plants that are avoided by one livestock type are grazed and eliminated by another. The control of *Ulex europoeus* by goats in sheep systems (Rolston *et al.,* 1982), and the elimination of *Senecio jacobaea* by sheep in cattle and deer systems (Betteridge *et al.,* 1994) are good examples.

The more integrative nature of future low-chemical systems will require farmers to have a high level of biological understanding of their farm system. The ability to predict future challenging events that can no longer be rectified by chemical intervention, and to plan and implement early action will be the hallmark of successful low-chemical farmers. This scenario poses a challenge to the way we undertake our future research and education. Operating within isolated disciplinary boxes will not lead to success.

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Table 1 - Effect of pasture type (alpine grasslands *vs* lowland pasture) on the composition of aromatic constituents of cheeses (from Bosset et al., 1994).

	Highland		Lowland	
	Relative aromatic level	Cheeses tested	Relative aromatic level	Cheeses tested
Terpenes				
Nerol	2.0	14	0.4	11
Pinene	2.6	7	-	0
Limonene	0.8	8	0.3	4
Alkanes				
Decane	0.3	4	-	0
Undecane	1.6	14	0.9	19
Nonane	0.3	4	-	0

Table 2 - Influence of botanical composition of pasture and hay on cheese sensory properties (from Buchin et al., 1999 and Verdier-Metz et al., 2000).

Abondance cheese				Saint-Nectaire cheese			
	Pasture				Hay diet		
	North side	South side			Cocksfoot	Natural mountain grassland	
Firm texture	4.3	3.6	*	Melting texture	5.4	4.7	*
Bitter taste	1.9	2.6	*	Bitter taste	2.5	2.0	+
Fruity aroma	1.0	0.7	+	Intense aroma	5.4	5.1	*
Sour aroma	0.8	1.4	*	Rancid odour	1.5	1.2	*
Animal aroma	0.8	1.1	+	Musty odour	1.6	1.0	*

Statistical symbols have the usual meaning.

Table 3 - Effect of conservation method on the characteristics of cheese (from Verdier-Metz et al., 1998).

	Diet		Statistics[¶]
	Hay	Grass silage	
Milk composition (g/kg)			
Fat	36.3	35.3	NS
Protein	33.5	33.6	NS
Cheese dry matter (g/kg)	548	546	NS
Sensory characteristics (1-10)			
Curd colour	4.9	6.0	**
Elastic texture	5.1	5.3	NS
Sticky texture	3.3	3.1	NS
Melting texture	3.8	3.6	NS
Firm texture	4.5	4.6	NS
Odour intensity	5.2	5.2	NS
Pleasant odour	5.6	5.7	NS
Taste intensity	5.3	5.4	NS
Acid taste	2.1	2.0	NS
Bitter taste	3.2	3.5	+
Taste persistence	5.2	5.5	NS

[¶] Symbols have the usual meaning.

Table 4 - Effect of grass conservation on Saint-Nectaire cheese characteristics (from Martin et al., unpublished data).

	Grass silage plus hay	Spring pasture	Statistics[¶]
Milk composition (g/kg)			
Fat	36.4	37.1	**
Protein	28.8	33.6	**
Cheese fat (g/kg dry wt.)	542	504	NS
Sensory characteristics (1-10)			
Firm texture	4.3	3.4	**
Taste intensity	5.0	5.6	**
Sour taste	0.7	1.4	**
Bitter taste	1.5	1.9	*
Piquant odour	1.3	0.2	**

[¶] Symbols have the usual meaning.

Table 5 - Carotenoid content of forages and milk and corresponding yellow coloration of matured cheeses (from Coulon and Grolier, unpublished data).

	Bareground dried hay	Barn-dried hay	Hay plus grass silage	Pastured grass
Forage carotenoids (mg/kg DM)	10	20	45	85
Milk carotenoids (µg/L)	75	80	130	220
Cheese yellowness index	20	25	28	30

Table 6 - Selected fatty acids in total beef fat from steers finished on maize after pasture (from Melton et al, 1982).

Fatty acid		Days on maize after pasture						Statistical effect of days on maize[¶]
		0	28	56	84	112	140	
Palmitic	C16:0	24.7[□]	25.8	26.2	25.3	25.1	26.4	*
Stearic	C18:0	18.3	12.7	11.3	11.4	9.70	8.40	*
Oleic	C18:1	40.9	44.7	45.1	44.9	44.6	48.1	*
Linoleic	C18:2	2.64	2.22	2.65	2.61	2.56	2.26	NS
Linolenic	C18:3	2.16	1.90	1.68	1.46	1.30	0.86	*
	C20:3	0.17	0.16	0.14	0.22	0.19	0.17	NS
Arachidonic	C20:4	0.10	0.07	0.03	0.03	0.08	0.02	*

[□] Data are means of percentages. [¶] Symbols have the usual meaning.

Table 7 - Concentration of species-characteristic branched chain fatty acids in storage fat from ram lambs grazed on pasture or fed concentrates (from Young et al., 2001).

Fatty acid(µg/g fat)	Diet treatment				Statistical effect of diet[¶]
	Pasture	Pasture[‡]	Lucerne	Maize	
4-Methyloctanoic acid	23	13	98	68	**
4-Methylnonanoic acid	2	1	15	11	*

[‡] These lambs were castrates. [¶] Statistical symbols have the usual meaning.

Table 8 - Effect of sporidesmin-generated eczema on the palatability of lamb (from Kirton et al., 1979).

Palatability attribute	Treatment		Statistical significance[¶]
	Control	Sporidesmin	
Flavor preference	6.2[□]	5.1	**
Tenderness prefence	6.3	4.9	**
Juiciness preference	6.1	5.2	**
Overall preference	6.3	4.8	**

[□] Hedonic means (1 = dislike intensely, 9 = like intensely), 12 lambs, 12 panellists.
[¶] Statistical symbols have the usual meaning.