

Manipulating beef quality through feeding

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Abstract

This presentation provides an overview of beef quality and the manipulation of beef quality through feeding. Beef consists of edible muscle, connective tissue and associated fat. The most important quality attributes of beef include the tenderness, other sensory characteristics, convenience and safety of the product. Both genetic and environmental factors affect beef quality. Although breed or type contributes significantly to the genetic variation in beef quality, nutrition is one of the most important environmental factors (Melton, 1990; Webb, 2003). Nutrition significantly affects the rate of conditioning and consequently carcass composition, conformation, meat yield and meat and fat quality. In addition to tenderness, the importance of fat quality has increased because it contributes towards the appearance, palatability, nutritive value, processibility, shelf life and ultimately the acceptability of beef. Emphasis is increasingly placed on the production of edible lean with a minimum of excess fat, but reducing fat to too low levels may adversely affect eating satisfaction. Beef quality can be manipulated by a variety of nutritional interventions, many of which have been implemented successfully in feedlots world-wide. Perceptions of beef are often based on incorrect generalisations regarding its nutrient content and health implications. Although meat quality can reasonably be ensured through carcass evaluation, and the implementation of quality assurance systems (HACCP-system, ISO9001), the challenge is increasingly shifting to the implementation of appropriate technologies to produce consistently high quality beef. In this regard nutritional intervention is of the utmost importance, but emphasis should also be placed on pre- and post-mortem management, as well as farm conditions, transportation and using approved abattoirs that meet EU-requirements.

Keywords: Beef quality, feeding, muscle, beef fat, fatty acids, vitamins, minerals

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Introduction

Beef consists of edible muscle, connective tissue and associated fat. The most important quality attributes of beef include the tenderness, taste, juiciness, freshness, lean content, healthiness, nutrient content, safety and convenience. Both genetic and environmental factors affect beef quality. Although breed or type contributes significantly to the genetic variation in beef quality, nutrition is one of the most important environmental factors (Melton 1990; Webb, 2003). Emphasis is often placed on improving beef quality through feeding since both the intrinsic attributes e.g. nutrient composition, physical and sensory characteristics which are measurable, as well as the extrinsic attributes, which are difficult to measure, can be improved.

The extent of these dietary improvements depends on the species, breed, sex, duration of feeding treatment and cost. Although the magnitude of the effects of feeding is usually greater in monogastric animals like pigs or chickens, significant changes have been reported in ruminants, particularly the fatty component (Duncan *et al.*, 1974; Ørskov *et al.*, 1974; Miller *et al.*, 1980; Wood, 1984; Casey & Van Niekerk, 1985; Cazes *et al.*, 1990; Webb, 1992; Webb *et al.*, 1994; Webb & Casey, 1995a; b; Webb *et al.*, 1997).

Manipulation of beef quality through feeding is usually more practical and cost effective compared to new breeding strategies, management techniques, other animal biotechnologies or post mortem technologies used to improve beef quality. Post mortem techniques (e.g. trimming of excess carcass fat, extended ageing / cold storage) to improve beef quality are often time consuming and extremely expensive compared to appropriate feeding strategies, while the combined effects are often more beneficial or even essential in order to ensure consistent beef quality.

Unfortunately there is increasing pressure on the use of specific feedstuffs for animal feeding particularly those that can be directly used by humans or that can be used more efficiently by other species. However, it is accepted that roughly 67% of the world consists of permanent pastures (Flachowsky, 1999) that can be utilised only by ruminants and these animals are also able to utilise the increasing amounts of by-products or “unconventional” animal feedstuffs. The utilisation of these feedstuffs and by-products by ruminants agrees with the responsible use of resources such as fossil fuels, plants and water, and contributes to sustainable production systems. Manipulation of beef quality through feeding will only remain viable as long as it is practical, economical and does not detract from the intrinsic and extrinsic attributes of beef quality, or any other aspect relating to environmentally acceptable or ethical beef production.

Perception of beef quality

The perceptions and expectations of producers, retailers and consumers regarding meat quality differ (Webb, 2003). It is clear that consumer demand for lean meat will determine largely how cattle are fed in the 21st century (Spears, 1996). Consumers’ perceptions of beef quality, has changed considerably over the past two decades. In order to appreciate the influence of nutrition on beef quality, it is important to briefly review this shift in consumers’ perceptions of meat quality.

Initially meat quality was determined by the quantitative aspects of modern livestock production e.g. amounts of animal produce like meat, milk, fibre and eggs relative to the inputs. According to Demeyer (1997), this unilateral approach generated a number of biological problems like the widespread and often indiscriminate / illegal use of growth promoting substances, carcass and meat quality defects like pale soft and exudate (PSE) pork, selection of muscular breeds or types, accumulation or excess animal wastes, food contamination with polychlorinated biphenyls (PCB’s), human health risks (BSE or bovine spongiform encephalitis and possibly antibiotic resistance), increasing concerns about animal welfare and working conditions of people working on farms, abattoirs and meat processing plants.

This emphasis on quantity soon resulted in a surplus production, so production-limiting measures were introduced and this prompted a completely different approach to the concept of meat “quality”, which exposed the multi-dimensional nature of consumers’ perceptions regarding beef quality.

A number of methods have been employed to study consumers’ perceptions of beef quality, but the “multi attribute approach” proposed by Grunert (1997) appears to be most appropriate, because beef quality is described by a set of intrinsic attributes or physical characteristics that are usually measurable (e.g. nutrient composition, tenderness, fat content and composition, sensory characteristics), and extrinsic attributes, which are associated with the production process, but are rarely perceptible or measurable (e.g. breed type and breeding strategies, origin of animals, type of production system, treatments, feeding regime). In addition, consumers often infer some attributes from others e.g. marbling and more tender meat which is not necessarily true (Grunert, 1997).

Consumers also link the intrinsic and extrinsic quality characteristics (e.g. lean beef or low fat content), with the physical and psychological consequences of consumption (e.g. less calories consumed / slimming) and more importantly, the attainment of life values (e.g. self confidence and social acceptance). In a recent study conducted in Europe, Bernués *et al.* (2003) found that the most important extrinsic attributes of red meat quality are animal feeding, origin of livestock, environmentally friendly production and animal welfare considerations. Animal feed assurance is regarded by European consumers as the most important indicator of nutritious and healthy / safe meat. It is clear that improvements in consumers’ perceptions of beef quality can only be upheld through the concerted efforts and responsible conduct of each and every sector involved in the beef industry, and in this regard animal feeding plays a pivotal role.

Effects of feeding on beef quality

Beef quality can be manipulated through feeding but the effects and the directions of the effects depend on the tissues studied, the composition of the feed and feeding regime, the duration of the feeding treatment and the age, sex and physiological status of the cattle fed or treated. Feeding affects the rate of conditioning and consequently carcass composition, conformation, meat yield and meat and fat quality. The effects of feeding on beef quality are generally studied in terms of the content and composition of the lean and fat tissues, and the subsequent effects on the colour, nutrient content (protein, fat mineral and vitamin content), tenderness, aroma, flavour, acceptability and taste of the final product. A summary of the effects of feeding on beef quality is provided in Table 1.

The effects of feeding on beef quality are generally more significant in terms of the lean colour, while the effects on the protein content and amino acid profile are almost negligible. By contrast, the effects of feeding on beef fat content and composition, including fatty acid composition, n-6/n-3 ratio and conjugated linoleic acid (CLA) content are generally small but highly significant (see section 4.2.2). The dietary effects on beef fat, although small, are often so important in terms of either the nutritive value, colour of the product or quality or consistency of the fat, that it is worth including the feed components or additives in the diet at relatively high costs, provided that consumers are aware of the intrinsic quality and added benefits of the product. This means that beef contains the complete range of essential nutrients (i.e. essential amino acids and fatty acids), while plant sources are often low in one or more nutrient (Webb, 2003), and that modern feeding practices also provide the opportunity to improve the mineral and vitamin content of beef and subsequently the shelf life, keeping characteristics and sensory attributes (these aspects will be discussed the forthcoming sections).

Table 1: Summary of the effects of feeding on beef quality

Constituent	Extent of the effect
Lean	
Protein content	Negligible effect
Amino acid profile	Negligible to small effect
Lean colour	Large effect
Fat	
Fat content	Large effect
Fat colour	Large effect
Fatty acid profile	Small, but significant effect
n3/n6 fatty acid ratio	Small, but significant effect
Conjugated linoleic acid (CLA)	Small, but significant effect
Minerals	Small, but significant effect on certain minerals only
Vitamins	
Fat soluble vitamins	Large effect
Water soluble vitamins	Negligible effect
Sensory characteristics	
Aroma	Small, but generally significant effect
Juiciness	Small, but generally significant effect
Tenderness	Small, but variable effect
Flavour	Small, but generally significant effect
Overall-acceptability	Small, but significant effect

Nutritional effects on beef quality will also depend on the criteria used to evaluate beef quality and will probably be perceived differently by consumers compared to butchers, retailers and wholesalers (Webb, 2003). In a study conducted in Europe it was found that the quality attributes of beef depend mainly on the tenderness and other sensory characteristics, but that consumers base their evaluation of beef quality (intent to purchase) mainly on fat content and colour (Grunert, 1997). Since the perception of fat is generally negative, the positive effects of fat on taste and tenderness are not perceived. By contrast, butchers generally prefer carcasses with moderate amounts of very firm carcass fat (that generally contains a larger proportion of saturated fatty acids), which improves the “cut-ability” of the carcass because it is easy to trim. Carcasses that contain soft fat are more difficult to cut and often result in a greasy appearance, while the fat may even become rancid and result in off flavours. Although off flavours have been reported in beef, it is not common.

It follows that manipulation of beef quality through feeding should be limited to those attributes that are conceivable by consumers and that will contribute to either the intrinsic or extrinsic attributes of beef. Of course improvements in both the intrinsic or extrinsic attributes should be indicated by means of labelling or

a specific brand name e.g. “like it lean”, because most of the extrinsic attributes are not conceivable, for example consumers will have no idea if cattle were grain fed or reared on pastures, if this is not indicated on the packaging or brand name.

Manipulation of muscle content and composition by feeding

The effect of feeding on the physical properties of muscle is negligible (Forrest *et al.*, 1975), but the growth of animals can be manipulated through the energy and protein content of the diet, which also results in changes in muscle composition (bone, muscle and fat content) (Lawrie, 1998; Lawrence & Fowler, 2002). It is well known that animal performance is improved by intensive feeding. Simmental cattle fed concentrate diets (Sami *et al.*, 2003) had significantly higher growth rates, average daily gains, final body weights and feed efficiencies compared to their pasture fed counterparts. Improvements are usually associated with better carcass conformation scores and a higher carcass fat content, while shear force values often decrease slightly as the time on feed increase. These results agree with those of Maloney *et al.* (2003). Vestegaard *et al.* (2000) also reported differences in muscle fibre types (more Type I, IIA and less Type IIB fibres) and a shift towards slow contracting fibres, with better vascularisation and more oxidative metabolism in muscles of pasture fed bulls compared to concentrate fed bulls of ca. 360 kg body weight. These differences were less noticeable at heavier body weights of about 460 kg.

Although the effects of intensive feeding on the sensory characteristics are variable, the tendency is towards marginally higher flavour scores and sometimes slightly lower acceptability scores due to the higher visible fat content of samples, although the effects of fat thickness is rather controversial. In a comprehensive study on this topic (Luchak *et al.*, 2003), it was found that the external fat trim level exerted almost no effect on the palatability traits of beef. Although a popular perception is that the degree of marbling improves the sensory characteristics of beef, the results are also variable, probably because longer feeding periods are required during which time muscle toughness may increase noticeably.

Feeding may affect meat colour (Lawrie, 1998). Muir *et al.* (1998) reported darker coloured meat in cattle finished on pastures compared to intensively fed cattle, while French (2000) found no difference in the meat colour of cattle of the same age and energy intake regardless whether they were fed grass or concentrates. These conflicting results are mainly due to the fact that meat colour is more dependant on the process of anaerobic glycolysis post-mortem during the normal conversion of muscle to meat. This involves the conversion of glucose reserves in muscle to lactic acid, which accumulates rapidly because the circulatory system is no longer functional. The acidification of muscle increases and pH decreases below the isoelectric point ($\text{pH} \cong 6.0$) where myofibrillar protein molecules have no electrical charge, which eventually affects the muscle enzymes, integrity of cell membranes, decrease in water binding capacity, rigor mortis and normal development of meat colour. The rate at which muscle pH decreases is of the utmost importance in terms of the normal development of meat colour.

Feeding affects the glycolytic potential of muscles and consequently the normal conversion of muscle to meat and the red colouration of meat. Stressed, fasted or undernourished cattle will result in a depletion of muscle glycogen reserves, so that the normal decline in muscle pH does not occur, resulting in dark, firm and dry (DFD) meat. The glycogen content of longissimus muscle samples from pasture fed steers is also lower (ca. 63 $\mu\text{mol/g}$) compared to those from concentrate fed steers (70 $\mu\text{mol/g}$) (Vestergaard *et al.*, 2000). DFD meat is more susceptible to spoilage and may reduce consumer acceptability (Viljoen *et al.*, 2002). These researchers confirmed that the general appearance, colour and acceptability of normal steaks are preferred to those of DFD steaks, but found no significant differences in the sensory characteristics of fried normal and fried DFD steaks. The prevalence of DFD meat can be greatly reduced by improved management during the finishing, loading and transportation of livestock, as well as better feeding and feed supplements like antioxidants.

By contrast, stress susceptible animals are more prone to a condition resulting in pale, soft and exudates meat. This condition is not common in cattle, but in certain pig breeds stressful conditions like lairage result in abnormally high concentrations of catecholamines which trigger a rapid depletion of muscle energy reserves, accumulation of lactic acid, fast pH decline and rapid development of rigor mortis (Lawrence & Fowler, 2002). The meat becomes pale in colour and the sensory characteristics are usually undesirable.

Effect of vitamin E supplementation to the feed

It is accepted that the oxidation of muscle and lipid pigments in meat are the major causes of unacceptable meat colour, poor shelf life, the development of rancid flavours and eventually the deterioration in meat quality. The quest for leaner beef and in particular the modification of beef fatty acids, resulted in higher concentrations of poly-unsaturated fatty acids (PUFA), especially n-3 fatty acids, which further reduce the oxidative stability of beef.

Dietary supplementation of antioxidants like vitamin E (e.g. α -tocopherol acetate) and even selenium during the fattening period appears to alleviate this problem (Arnold *et al.*, 1993; Robbins *et al.*, 2003), while some success has also been achieved with vitamin A and selenium supplementations. This is particularly effective in cattle fed concentrate diets or where attempts are made to modify the fatty acid composition of beef fats (PUFA's, n-6 / n-3 fatty acid ratio), which often result in more unstable beef fat with a poor consistency. The results of Yang *et al.* (2002a; b) and Realini *et al.* (2004) confirm that fatty acid oxidation was reduced and lipid stability improved in concentrate fed feedlot steers.

Lately the manipulation of the conjugated linoleic acid (CLA) content of meat from pasture fed ruminants received a lot of attention, firstly because of CLA's anticarcinogenic properties (Realini *et al.*, 2004), and secondly because the fats of pasture fed ruminants contain biologically significant concentrations of CLA, like the cis-9, trans-11 CLA isomer (Ha *et al.*, 1990). Pasture fed cattle are also reported to contain a more favourable n6 /n3 fatty acid ratio (ca. 1,4) compared to concentrate fed cattle (ca. 3,0) (Enser *et al.*, 1998). Unfortunately the meat of beef cattle fed on pastures is often reported to be darker than usual, while the fat has a typical yellow colour. Realini *et al.* (2004) reported that the inclusion of 1000 I.U. vitamin E per steer per day improved lipid stability (TBARS) and colour (a*=redness; b*=yellowness) of beef from pasture fed cattle. The inclusion of vitamin E in diets for beef cattle has been employed quite successfully in the past and is viable.

Effect of vitamin D supplementation to the feed

Dietary vitamin D supplementation was first employed to treat milk fever in dairy cattle, because it plays an important role in calcium transport and homeostasis. Vitamin D supplementation was also employed to improve the tenderness of beef from cattle treated with certain growth promoting substances like β -adrenergic agonists (Morgan, 1998; Webb, 1998). It was found that β -agonists may result in higher shear force values, which suggest tougher meat (Casey *et al.*, 1997).

It appears that the deterioration in tenderness in β -agonists treated cattle is linked to the calpain system. Calcium plays an important role in the normal activation of muscle proteases and it is thought that vitamin D facilitates this process. Unpublished results of Webb & Morris suggest that dietary vitamin D supplementation significantly reduced the shear force values of longissimus samples (from ca. 120N to \leq 90N) from β -agonist treated feedlot steers in South Africa. These results were obtained by supplementing feedlot diets with a relatively high concentration of vitamin D₃ just before slaughter. The effect of vitamin D supplementation in feedlot diets is small if carcasses are aged for extended periods (> 5 days).

Manipulation of beef fat through feeding

The findings which suggest that the risk of chronic heart diseases is aggravated by the consumption of sugar-rich foods (excessive energy intake) as well as meat and other animal products rich in saturated fat and dietary cholesterol, resulted in a significant effort by the meat industry world wide to reduce carcass fat content. Unfortunately conventional wisdom has translated "saturated fatty acid" to mean "saturated fat" and that meat fat is all saturated. Webb *et al.* (1994a; b, 1998; 2003) showed that the saturation levels of red meats vary between 45 and 55%. This means that a moderate consumption of lean meats should not necessarily give rise to dangerously high blood cholesterol levels. Nevertheless, the drive towards improving the fat in beef focussed mainly on the following aspects:

- Reducing the total carcass and beef fat content,
- Reducing the saturated fatty acid content in beef,
- Increasing the poly-unsaturated fatty acid content in beef,
- Increasing the n-6/n-3 long-chain fatty acid ratio of beef fat,
- Manipulating the cis / trans fatty acid ratio of beef fat,

- Increasing the CLA content of beef fat.

It is important to note that feeding does not change the body fat composition in ruminants as much as in monogastric animals, but diet-induced changes in the fat composition of ruminants have been reported in ovine and bovine species (Duncan *et al.*, 1974; Ørskov *et al.*, 1974; Miller *et al.*, 1980; Wood, 1984; Casey & Van Niekerk, 1985; Casey & Webb, 1995; Cazes *et al.*, 1990; Webb *et al.*, 1994a; b; Webb & Casey, 1995a; b; Banskalieva, 1996; Webb *et al.*, 1997; Webb *et al.*, 1998). The quantity, quality and composition of ruminant fat may be affected by nutrition, in particular the kind and nature of the cereals, the mode of presentation of the cereals and the kind and presentation of roughage.

Manipulating the amount of carcass fat through feeding

Feeding significantly affects the amount of fat deposited in the carcass. According to Webb (2003), these fats occur in most tissues in the body, but the bulk of it is localised in four important anatomical locations namely internal (inside the body cavity), subcutaneous (all the fat on the external surface of the carcass underneath the skin or *m. cutaneus trunci*), intermuscular (between muscles) and intramuscular (within muscles). Although the emphasis of beef production is now on the production of edible lean with a minimum of excess visible fat (Forrest *et al.*, 1975), it is certain that fat in meat contributes to eating quality (Wood, 1990).

It is feared that reducing fat to too low levels may adversely affect eating satisfaction. In this regard the media is often to blame for incorrect generalisations regarding the fat content of meat compared to other foods (Webb, 2003). Unfortunately data on the fat content and composition of meat often refer to the carcass rather than the saleable or edible portion of meat. The trimming of carcasses and the removal of excess fat are standard procedures during meat processing. Consumers often remove the remaining visible subcutaneous fat before consumption. It is safe to say that South African beef compares favourable with that from other countries in terms of the amount of carcass and beef fat.

Cattle are fed to different levels of carcass finish in different countries due to different meat grading or classification systems. Marbling (visible intramuscular fat located in the perimysial connective tissues between muscle fibre bundle) is an important quality attribute of beef carcasses in the USA and the best grades are obtained in heavy feedlot cattle (*ca.* 400 kg carcass weight) with a high carcass fat content (*ca.* 25 to 30%). South African beef carcasses weigh appreciably less (*ca.* 220 kg) and therefore contain less fat (*ca.* 18%) compared to their American counterparts (Webb, 2003).

An increase in carcass fat content often results in a lower polyunsaturated to saturated fatty acid (P/S) ratio, in other words a greater proportion of saturated fatty acids accumulate in the fat depots with fattening (De Smet *et al.*, 2000). When excessive amounts of fat accumulate, the consistency of the subcutaneous fat may decrease again (Wood *et al.*, 2003) due to the accumulation of greater proportions of oleic acid (C18:1). Webb *et al.* (1997) found that the pelleting of high-maize diets alleviate this excessive accumulation of carcass fat and improves the consistency and colour of subcutaneous fat in sheep, and may also be applicable to beef cattle. These effects are mainly due to improved animal performance and shorter finishing periods in the feedlot. It is therefore possible to manipulate both the amount of carcass fat and also the proportion of polyunsaturated fatty acids (PUFA) and saturated fatty acids (SFA) simply by feeding animals to a predetermined degree of fatness. This is an important tool available to the beef industry to meet consumers' demands for lean healthy meat.

Manipulating beef fatty acids through feeding

Beef fat quality is determined by the fatty acid composition, which affects the degree of saturation of the fat, the shelf stability and flavour. The chemical and physical properties of fat influence the eating and keeping qualities of meat (Kempster *et al.*, 1982). The interest in fatty acids in relation to consumer health lies in the content of essential fatty acids (EFA's), polyunsaturated/saturated fatty acids ratio (P/S), n-6/n-3 ratio and conjugated linolenic acid (CLA) and cholesterol. The basic EFA's are linoleic (C18:2n-6) and linolenic (C18:3n-3) acids. These fatty acids cannot be synthesised in human tissues but are required for the synthesis of prostaglandins, prostacyclins and thromboxenes. An intake of 1-2% of total calories as EFA is recommended (Mead *et al.*, 1986).

The successful manipulation of EFA's, PUFA's and n-6/n-3 ratio in beef by dietary means has been confirmed in various studies (Raes *et al.*, 2003; Wood *et al.*, 2003). Dietary manipulation of PUFA's, eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and CLA's in monogastric animals are

quantitatively more significant and practical compared to ruminants, because of the extensive biohydrogenation in the rumen and formation of saturated fatty acids. The disadvantage of meat from monogastric animals is that it contains appreciable amounts of n-6 fatty acids (e.g. high n-6/n-3 ratio, which impact negatively on human health) because they are fed high grain diets rich in linoleic acid.

The proportion and ratio of n-3 long-chain fatty acids in meat have been increased (up to 1g/100g of total fat) by including fish oil (ca. 0,5-2%), fish meal (ca. 150-200 g DM / animal / day) and linseed oil (ca. 0,5-2%) in the diets of cattle and sheep. Vegetable oils may provide a good source of linolenic acid (C18:3n3) like rapeseed oil (7% C18:3n3), canola oil (11% C18:3n3), soybean oil (7% C18:3n3), wheat germ oil (7% C18:3n3), while corn and safflower oils are poor sources of linolenic acid (Raes *et al.*, 2003). Grains contain appreciable amounts of linoleic acid (C18:2n6) which may again increase the n-6/n-3 ratio, which is less acceptable from a health point of view.

Fish oil and fish meal contain high concentrations of EPA and DHA, while linseed oil and forages contain high concentrations of linolenic acid (C18:3n3) compared to other feed sources. Dietary inclusion of these components invariably results in small but significant improvements in the n-3 long-chain fatty acid content of beef. The effects of these supplements on the P/S ratio, particularly in the muscle appear to be more variable. PUFA's may be further increased by feeding protected dietary oils by means of the formaldehyde treatment of dietary proteins which protects the PUFA's (Scott *et al.*, 1971). PUFA's may also be increased in ruminant fats by including a mixture of soya oil and linseed oil (2:1 ratio) in the feed (Enser *et al.*, 2001), but this also increased the n-6/n-3 ratio which is not desirable. Unfortunately ruminants are sensitive to the inclusion of high concentrations of unprotected polyunsaturated oils (>5% of diet), which obviously limits the extent to which beef fats can be manipulated. The results of Webb *et al.* (1998) also suggest that the composition of the subcutaneous fat of feedlot steers is affected by β -agonist treatment.

Linoleic acid is one of the most abundant PUFA's, particularly in animals raised on grain based diets. In recent years there has been increased interest in its geometric isomer, conjugated linoleic acid (CLA) which is a group of C18:2 isomers with both cis and trans double bonds. CLA occurs naturally in meat particularly that of ruminants. The acid is a product of the normal biohydrogenation of linoleic acid to stearic acid, through C18:1-trans in the rumen.

CLA production is enhanced by a low forage:concentrate ratio, which decreases biohydrogenation by lowering the rumen pH (Jiang *et al.*, 1996). Manipulation of CLA has been demonstrated simply by including grass in the diets of beef cattle (French *et al.*, 2000; Yang *et al.*, 2002). Forage based diets increase CLA production (Shantha *et al.*, 1997) possibly through the inhibitory effect of linolenic acid and other n-3 PUFA on biohydrogenation (Enser *et al.*, 1999).

Manipulation of CLA has also been achieved in mutton by dietary supplementation with safflower seed containing 37 % oil with 79% linoleic acid (Kott *et al.*, 2003). In this study, the CLA content of mutton was doubled (from ca. 4000 ppm to ca. 8000 ppm), while small but significant changes were also observed, namely a 2.3 % decrease in oleic acid (C18:1), 2.6% increase in linoleic acid (C18:2) and 0.25 % decrease in linolenic acid (C18:3). Commercial feed supplements are now available to manipulate CLA's through the feed in monogastric and ruminant animals, but the livestock industry is still weary to include these in diets because it is uncertain whether it will be feasible. The manipulation of CLA's in ruminants has lots of potential in terms creating a more acceptable and healthy product, but with the added benefit of using a larger variety of feed supplements (n-3 rich diets containing linseed, fishmeal or fish oil, grass, or even high concentrate diets rich in linoleic acid) without significantly increasing the n-6/n-3 ratio because of the synthesis of CLA's subsequent to biohydrogenation in the rumen.

Manipulation of the mineral content of beef through feeding

Selenium, iodine, chromium, zinc and copper have been supplemented in the diets of ruminants to improve beef quality. Although the concentrations of these minerals included in the diets may be reflected at a tissue level, the effects on beef quality are variable. This is probably due to the fact that the form (organic vs. inorganic) in which minerals are supplemented affect their biological activity.

The most important effect in terms of beef quality have been observed by supplementing diets with selenium which acts as an antioxidant and generally yields similar results compared to vitamin E supplementation. Again, the effects depend on the animal's nutritional status, type of diet fed, presence of natural antioxidants like β -carotenes and xanthophyll pigments, as well as interactions with other minerals. Animals with mineral deficiencies like selenium, which result in white muscle disease, often respond well to

supplementation. Supplementation of zinc to cattle feeds in either an organic form (Zn proteinate, Zn polysaccharide) or inorganic form (Zn oxide) was evaluated in beef steers, but the effects on meat quality were negligible (Kessler *et al.*, 2003) and similar results were also observed with dietary chromium supplementation in steers (Luseba, unpublished).

Manipulation of the sensory characteristics of beef through feeding

The sensory characteristics of beef are usually described in terms of the aroma, flavour, juiciness, tenderness and acceptability of a specific cut or portion. Different muscles differ in terms of all the above characteristics, but samples of the longissimus muscle are usually used as reference in meat science research. Tenderness is probably the most important quality attribute of beef, but consumers base their evaluation of beef quality mainly on fat content as well as fat and lean colour (Grunert, 1997). Consumers prefer beef with white or creamy fat. Yellow fat is often perceived as indicative of an old, diseased or a dairy type animal (Webb, 2003), which may create serious marketing problems due to consumer resistance. It is interesting to note that these yellow fat pigments may contribute to the typical flavour of meats (Webb, 2003).

As far as beef fat content is concerned, there is definitely more emphasis on the production of lean beef with a minimum amount of excess fat. This noticeable trend continues despite the fact that the fat content in edible lean beef in South Africa is relatively low compared to the USA. Wood (1990) warned that reducing fat to too low levels might adversely affect eating satisfaction. It appears to be quite difficult to meet the consumer's demands for lean and healthy beef, whilst at the same time provide a consistently tasty product and acceptable eating experience.

Changes in the composition of ruminant fat may contribute substantially to the sensory properties of meat, by mainly affecting the degree of saturation of the fats and the proportion of specific long-chain fatty acids. Kemp *et al.* (1981) for example, found no definite relationship between the fatty acid content and organoleptic scores of lamb. Westerling & Hendrick (1979) reported a negative correlation between saturated fatty acids in both the subcutaneous and intramuscular fat with the flavour of beef. However, the fatty acids were not associated with either the juiciness or tenderness of beef.

Oleic acid improved the flavour while both stearic and palmitic acid reduced the flavour of beef *M. longissimus* muscle. Dryden & Marchello (1970) reported a negative relationship between palmitic acid and the overall palatability of bovine *m. longissimus*. The proportion of C18:1 in the subcutaneous fat correlated positively with both the aroma and initial juiciness, while fatty acids of the *trans*-configuration do not contribute to the sensory properties of lamb (Webb *et al.*, 1994b). These researchers also reported a negative correlation between the aroma of lamb and the ratio of saturated to unsaturated fatty acids. Similar correlations were obtained by Field *et al.* (1978) and Miller *et al.* (1980). Wood *et al.* (2003) found that the concentration of C18:3 (which occurs predominantly in grass lipids), improves the odour and flavour intensity of beef. It is evident that the long-chain fatty acids affect beef quality and that these components can be manipulated through feeding.

Genetically modified plants and beef quality

The use of genetically modified plants (GMO's) in animal agriculture is controversial and there are few scientific reports on the possible effects on the quality of animal products. At present the Food and Drug Administration in the USA do not require feeding studies with livestock to test crops produced through the use of biotechnology. Faust (2002) did an overview of some of the independent studies on the effects of GMO's in animals. These studies suggest no significant effects on the performance of livestock, and no transgenic plant source-DNA was detected in meat, milk or eggs. Due to the negative perceptions and controversy regarding GMO's, more research is required.

Manipulation of beef quality, quality assurance and traceability

Major concern in manipulating beef quality through improved diets to meet consumers' demands include the evaluation and testing of beef quality, specification of quality attributes on the packaging, or utilisation of brand names and quality testing and assurance of the end products.

The South African beef classification system, HACCP and ISO9001 play an important role in ensuring consistently good quality products in terms of beef carcass composition. There are also a variety of analytical

techniques that can be used to analyse the chemical composition of beef carcasses as well as more complex aspects of specific beef cuts to determine whether the beef in fact contains the promised components.

Although traceability of beef is ensured by the identification of cattle, carcasses, abattoirs and the final product, new technologies make it possible to determine the geographic origin of cattle and feeding diet (Renou *et al.*, 2003). This involves isotope ratio mass spectrometry which is accepted as an official method for guaranteeing the origin of food products, and also the very recent “multi-isotopic fingerprinting” of meat or carcass samples by means of magnetic resonance spectroscopy (MRS). $\delta^{15}\text{N}$ values and $\delta^{13}\text{C}$ ratios can be used to give a very accurate indication of the type of diet that was fed to livestock, e.g. $\delta^{13}\text{C}$ ratios give a very accurate indication of the maize content of diets (Renou *et al.*, 2003). The composition of animal fats (composition of triacylglyceroles and position of fatty acids on glycerol) can also be monitored by means of ^{13}C NMR spectra, which distinguishes between the unsaturated carbon atoms of mono- and polyunsaturated fatty acids in beef.

Conclusions

Beef quality can be manipulated through feeding and this field of research has opened up a variety of new and exciting possibilities that will benefit the beef industry. Consumer demand for leaner meat containing acceptable proportions of EFA's, PUFA's, n-6/n-3 fatty acids, CLA's and cholesterol will determine to a large extent how cattle will be fed in the 21st century. Feeding affects the rate of conditioning and consequently carcass composition, conformation, meat yield and meat and fat quality. Modern feeding practices provide the opportunity to improve the nutrient content (vitamins, minerals, EFA's, PUFA's, n-6/n-3 fatty acids and CLA's) of beef and subsequently the shelf life, keeping characteristics, sensory attributes wholesomeness and consumer acceptability. New technologies like MRS also make it possible to determine the origin of food products, in order to improve traceability and guarantee that the quality of beef products comply with the required specifications. Manipulation of beef quality through feeding will only remain viable as long as it is practical, economical and does not detract from the intrinsic and extrinsic attributes of beef quality, or any other aspect relating to environmentally acceptable or ethical beef production.

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