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Producing tender and flavoursome beef with enhanced nutritional characteristics

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The perception of healthiness and/or safety, tenderness, juiciness and aroma or flavour are important quality criteria that influence the decision of a consumer to purchase beef. Beef production systems represent the combined and interacting effects of genotype, gender, age at slaughter and nutrition before slaughter. The present paper highlights recent information on how beef production systems can be modified to enhance the tenderness, flavour and healthiness of beef. Carcass management post-slaughter has a larger effect on meat tenderness than gender, genotype or feeding systems. Optimum ‘pasture to plate’ management systems are being established to ensure beef tenderness. The chemistry underlying beef flavour is complex, with in excess of 140 components identified in cooked beef volatiles. Flavour of beef is influenced by cattle diet, but assessment of flavour by a taste panel is subject to the previous experiences and preferences of the panellists. Modern lean beef can have an intramuscular fat concentration of 25–50 g/kg and can be considered a low-fat food. As the quantity of grass in the diet of cattle is increased, there is a decrease in saturated fatty acid concentration, and an increase in the *n*-3 polyunsaturated fatty acid and conjugated linoleic acid concentrations. It is concluded that there is opportunity to exploit the diet of cattle to produce tender flavoursome beef that has an increased conjugated linoleic acid concentration, a lower fat concentration and a fatty acid profile more compatible with current human dietary recommendations.

Beef: Tenderness: Flavour: Fatty acids: Healthiness

Beef has been gradually losing market share to competing meats and other protein sources throughout the developed world. For example, The National Food Survey in the UK indicates that beef and veal consumption fell from an average of 175 g/d in 1990 to an average of 145 g/d in 1997 (Ministry of Agriculture, Fisheries and Food, 1991, 1998). This decline in consumption reflects consumer concerns about the safety of beef as a food, the animal welfare and environmental perceptions of beef production, consumer concern about diet and health, changing consumer lifestyles and the availability of more conveniently prepared foods. The beef industry is striving to address these consumer concerns to ensure secure access to markets and to win consumer preferences in the future. Efforts are directed at all points in the production chain, with the goal of producing beef that is compatible with the humane treatment of cattle, with environmentally-sustainable production and which is healthy, wholesome and safe (Tarrant, 1998). In the present paper the effects of modern production practices on the sensory perception, i.e. taste or eating quality, and perceived healthiness of beef are reviewed.

Tenderness

Consumer research indicates that tenderness and flavour are among the most important elements of eating quality of

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Abbreviations: CLA, conjugated linoleic acid; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids.
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meat (Becker *et al*. 1998). The post-mortem conversion of muscle to meat and the underlying biochemistry of muscle tenderness and toughness have been reviewed (Koohmaraie, 1996; Tarrant, 1998). Increased knowledge of the biochemistry of meat tenderness has stimulated the development of post-slaughter technologies for improving tenderness, reducing variability and enhancing desirable biochemical changes during conditioning of meat. Among these technologies are slow chilling and electrical stimulation, the tenderstretch and tendercut methods of ageing beef, $CaCl_2$ injection, high pressure or ultrasound treatment, very fast chilling, the hydrodyne (explosive shock) process and the injection of organic acids (Troy, 1995).

Among the on-farm factors which may influence beef tenderness are the age, gender or genotype of the animal and nutritional management (type and quantity of ration) before slaughter. While it is generally accepted that animal maturity is negatively correlated with meat tenderness (Dransfield, 1992), cattle in many beef production systems are relatively immature (< 30 months of age) and changes in age within these production systems appear to have little effect on tenderness (Sinclair *et al*. 1998; Moloney *et al*. 2000*a*). Furthermore, when grown to a similar degree of fatness or when data are adjusted to a common fatness level, there are few differences in tenderness between breeds, between intact or castrated males or between male and female cattle (Homer *et al*. 1997; Sinclair *et al*. 1998). The possible impact of fatness on meat tenderness has been the subject of much discussion. As the animal matures, fat is deposited first in subcutaneous and intermuscular sites, which could provide extra insulation for muscles against the effects of refrigeration and so prevent ‘cold-shortening’ (induced toughness). Fat subsequently accumulates in muscle (intramuscular or marbling fat) in the perimysial connective tissue. At high intramuscular fat concentration, e.g. in Kobe beef, when the intramuscular fat concentration can exceed 200 g/kg muscle, the dilution of fibrous protein by soft fat may decrease the resistance to shearing or chewing. Also, fat cell expansion in the perimysial connective tissue can open up the muscle structure (Wood, 1990). European beef tends to have lower intramuscular fat than US beef and lower than the 30 g/kg threshold value suggested in the USA to be necessary for optimum tenderness (Smith *et al*. 1984).

From a synthesis of published data from primarily US beef production systems, Owens & Gardner (1999) concluded that ‘when fed to similar body weights and ages, differences in tenderness between ruminants fed forage or those fed concentrate generally disappear’. A similar observation was made by French *et al*. (2000*b*) for a more typical Western European beef production system (Table 1). Moreover, when grown to different carcass weights and fatness, but to a similar age, ration composition (*ad libitum* grass, *ad libitum* concentrates or various combinations of grass and concentrates) did not affect tenderness (French *et al*. 2000*a*). Aberle *et al*. (1981) proposed that faster growth rate is associated with greater tenderness, based on the assumption that *in vivo* the rate of protein synthesis and rate of protein degradation is positively correlated, and so greater post-mortem protein degradation would also occur in carcasses from faster-growing animals. However, Calkins *et al*. (1987) manipulated energy supply to cause weight loss or weight gain in young bulls, and observed no relationship between daily gain and either shear force (an instrumental assessment of toughness) or sensory panel estimates of tenderness. In a recent study (Moloney *et al*. 2000*b*; Table 2), steers were offered sufficient concentrates and hay to achieve a preslaughter growth rate of 0·72 kg/d continuously for 17 weeks (continuous), 0·36 kg/d for the first 8 weeks and 1·08 kg/d for the final 8 weeks (low–high), 1·08 kg/d for the first 8 weeks and 0·36 kg/d for the final 8 weeks (high–low), or 0·36 kg/d for the first 2 weeks, 0·72 kg/d during weeks 4 to 14, and 1·08 kg/d for the final 2 weeks (pulse). Preslaughter growth rate did not affect carcass weight or fatness or improve any measurement of

Table 1. The effect of diet (D) and ageing time (T) post mortem on Warner Bratzler shear force (WBSF) and taste panel assessment of beef (data from French *et al*. 2000*b*)

	Grass silage and concentrates			Grass (g/kg DM)												Statistical significance of effect of:		
				0			510			770			1000						
T(d) ….	2	7	14	2	7	14	2	7	14	2	7	14	2	7	14	SE	D	T	D × T
WBSF (N)	51·9	37·1	35·6	55·0	37·8	33·3	49·7	36·1	37·5	38·9	33·2	31·4	53·4	38·4	39·1	2·39	NS	***	*
Percentage cook loss	31·3	34·6	32·4	33·1	33·5	32·9	31·7	34·5	33·6	30·9	33·2	31·3	30·2	32·1	31·8	0·570	NS	***	NS
Tenderness†	4·62	5·02	5·34	4·44	5·43	5·73	4·25	4·84	5·63	5·10	5·83	5·60	4·77	5·15	5·65	0·187	NS	***	*
Texture‡	3·57	3·68	3·70	3·42	3·69	4·03	3·41	3·78	3·90	3·77	3·91	3·57	3·48	3·72	3·67	0·123	NS	**	NS
Flavour§	3·79	3·94	3·69	3·76	3·97	3·99	3·74	4·01	3·86	3·83	3·90	3·72	3·69	3·58	3·80	0·112	NS	NS	NS
Juiciness‖	4·97	4·27	3·59	4·34	4·54	4·03	4·53	4·73	4·08	4·20	4·33	3·64	4·64	4·08	3·97	0·224	NS	***	NS
Chewiness¶	3·49	3·27	3·20	3·67	3·21	2·77	3·88	3·40	2·75	3·43	2·87	2·82	3·53	3·28	2·95	0·130	NS	***	NS
Acceptability††	3·37	3·62	3·49	3·19	3·55	3·82	3·20	3·60	3·79	3·54	3·79	3·48	3·27	3·46	3·58	0·134	NS	***	*

* $P<0{\cdot}05$, ** $P<0{\cdot}01$, *** $P<0{\cdot}001$.

† Scale 1–8; 1 extremely tough, 8 extremely tender.

‡ Scale 1–6; 1 very poor, 6 very good.

§ Scale 1–6; 1 very poor, 6 very good.

‖ Scale 1–8; 1 extremely dry, 8 extremely juicy.

¶ Scale 1–6; 1 not chewy, 6 extremely chewy.

†† Scale 1–6; 1 not acceptable, 6 extremely acceptable.

Table 2. Carcass weight and tenderness of the *longissimus dorsi* muscle in steers with different preslaughter growth patterns (data from Moloney *et al.* 2000*b*)

	Growth pattern†					Statistical significance of difference
	Continuous	Low–high	High–low	Pulse	SED	
Preslaughter growth rate (kg/d)	0·76	1·15	0·52	0·73		
Carcass weight (kg)	300	300	296	296	4·5	NS
Fat score	3·36	3·31	3·39	3·60	0·218	NS
WBSF (kg): 2 d‡	5·96	7·42	6·22	6·97	0·907	NS
7 d	4·13	5·54	4·43	4·69	0·558	NS
14 d	3·88	4·63	4·33	3·82	0·490	NS
Tenderness§: 2 d‡	3·65	3·62	4·47	3·93	0·469	NS
7 d	5·59	5·05	5·36	5·10	0·414	NS
14 d	6·09	4·80	5·26	5·27	0·376	*

WBSF, Warner Bratzler shear force.

* $P<0\cdot05$.

† Final 8 weeks for continuous (fed to achieve a preslaughter growth rate of 0·72 kg/d continuously for 17 weeks), low–high (fed to achieve a preslaughter growth rate of 0·36 kg/d for first 8 weeks and 1·08 kg/d for final 8 weeks), high–low (fed to achieve a preslaughter growth rate of 1·08 kg/d for first 8 weeks and 0·36 kg/d for final 8 weeks); final 3 weeks for pulse (fed to achieve a preslaughter growth rate of 0·36 kg/d for first 2 weeks, 0·72 kg/d during weeks 4 to 14, and 1·08 kg/d for the final 2 weeks).

‡ Period of ageing.

§ Sensory assessment of tenderness; scale 1–8; 1 extremely tough, 8 extremely tender.

tenderness thus rejecting the hypothesis that preslaughter growth rate *per se* increases tenderness. Feeding concentrate diets to cattle before slaughter has improved meat tenderness in some studies (Coleman *et al.* 1995; Van Koevering *et al.* 1995). This effect may be associated with turnover of insoluble collagen and greater solubility of newly-synthesized collagen, but may also be an indirect response to increased surface and intramuscular fat, and a decreased rate of carcass chilling compared with carcasses from unsupplemented animals. Additionally, where cattle are grown at different rates (high-concentrate rations *v.* high-grass rations) to a common degree of fatness, differences in tenderness may also reflect the greater maturity of the slow-growing animals.

In summary, animal management factors appear to have a smaller impact on beef tenderness than post-mortem carcass management. To ensure meat tenderness at the point of purchase by the consumer, all points of the beef production chain should be optimised. The industry is moving in this direction by developing a systems approach that is analogous to the ‘hazard analysis at critical control points’ approach used in food-safety assurance. This ‘palatability assurance at critical control points’ approach facilitates the incorporation at every stage of the production chain, from genetic selection to final meat preparation and cooking, of new technologies that can help to optimise eating quality and reduce variability in beef.

Flavour

Flavour is an important component of the eating quality of all foods, including meat. The meaty flavours of cooked meat result from reactions between carbohydrates and proteins and between their breakdown products (Mottram, 1992). The products of heat-induced oxidation of fatty acids, particularly polyunsaturated fatty acids (PUFA), such as aliphatic aldehydes, ketones and alcohols, may have intrinsic flavours and they may also react further with Maillard products to give other compounds that contribute to flavour (Elmore *et al.* 1997). Attributes of meat such as flavour and aroma, which are part of the eating sensation, do not lend themselves easily to objective measurement, and either trained ‘taste’ panels or a panel of ‘typical’ consumers are most frequently used to assess flavour. In these procedures meat is prepared under standardised cooking conditions, and the members of the panel are asked to score (often on an eight-point scale) the sensations of interest. The sensations assessed may be described differently in different studies. For example, in some studies (French *et al.* 2000*b*), panellists are asked to score flavour from very poor to very good. In many American studies panellists assess flavour intensity, off-flavour intensity or flavour desirability (Miller, 1994).

A body of information exists on the effects of beef production practices on flavour, measured in this way. Grain source had little effect (Miller *et al.* 1996), while source of ensiled forage generally also had little or no effect on beef flavour (Berry *et al.* 1988; Moloney *et al.* 1999). In many American studies panellists rated the flavour of grass-fed beef inferior to that of grain-fed beef (Griebenow *et al.* 1997). Since flavour desirability and flavour intensity increase with fat content (Owens & Gardner, 1999), these findings may reflect differences in fatness in animals produced on both rations. In contrast, panellists in the Republic of Ireland (French *et al.* 2000*b*; Table 1) and in Canada (McCaughey & Cliplef, 1996) found no difference in the flavour of grass-fed and grain-fed beef. This finding may reflect a higher antioxidant concentration, with consequent protection against lipid oxidation and the production of ‘off-flavours’ (see p. 224) in the grass used in these studies. It may also reflect differences in the previous experience of the panellists. Thus, when grass-fed British and grain-fed Spanish lamb were offered to both British and Spanish panellists, both agreed that the British lamb had more intense lamb flavour, but whereas the British panellists gave a higher ‘flavour liking’ score to British lamb, the

Spanish panellists preferred the flavour of the grain-fed Spanish lamb (Sanudo *et al.* 1998). In the literature summary of Owens & Gardner (1999) age, perhaps through increasing carcass fatness, was positively associated with flavour desirability. In contrast, daily gain, possibly reflecting a faster rate of lean tissue gain, was negatively related to flavour desirability. Although flavour intensity increased with increasing *longissimus* lipid content, greater maturity of lean tissue reduced flavour intensity.

The meat descriptive attribute method, as described earlier, provides an indication of flavour differences between treatments, but changes in specific flavour attributes have also been assessed (Miller, 1994). Identified flavours in beef are listed in Table 3. Undesirable (to American panellists) flavours, such as ‘milky’ and ‘grassy’, associated with forage-fed beef have been attributed to an increase in the concentration of linolenic acid in neutral and polar lipids. Myristic, palmitic and margaric acids have been related to ‘cowy’ and ‘painty’ flavours of beef (Camfield *et al.* 1997). Larick & Turner (1990) showed that as the concentration of linolenic acid in muscle phospholipids declined and that of linoleic acid increased, flavours identified as ‘sweet’ and ‘gamey’ declined, whereas ‘sour’, ‘blood-like’ and ‘cooked beef fat’ increased. During post-mortem ageing, desirable flavours (‘beefy’, ‘brothy’, ‘browned-caramel’ and ‘sweet’) typically decrease, while ‘bitter’ and ‘sour’ flavours increase (Spanier *et al.* 1997). In addition to altering the flavour of fresh beef, unsaturated fatty acids are susceptible to rancidity during ageing or with exposure to O_2. Beef from grass-fed cattle developed off-flavours more quickly and reached higher concentrations of thiobarbituric acid-reactive substances during ageing than beef from grain-fed cattle in the studies of Reagan *et al.* (1981) and Xiong *et al.* (1996). ‘Fishy’ flavours are often detected in beef from grass-fed cattle after several months of storage, even if the beef is frozen during storage (Moore & Harbord, 1977). Vatansever *et al.* (1999) reported that panellists rated beef from cattle fed rations that contained fish oil, linseed oil or palm oil concentrates similarly for beef flavour, abnormal flavour and overall liking. However, when panellists were trained to distinguish beef flavour intensity, ‘fatty’ or ‘greasy’, ‘blood’, ‘livery’, ‘metallic’, ‘bitter’, ‘sweet’, ‘rancid’, ‘fishy’, ‘acidic’, ‘cardboard’, ‘vegetable’ and hedonic overall liking, beef from steers fed fish-oil concentrate was rated more ‘rancid’ and more ‘fishy’ than beef from the other rations (Enser *et al.* 1997). However, overall scores were low, and overall liking was similar for control and fish-oil-fed animals, although steaks from linseed-fed animals were preferred. These observations indicate that conclusions as to beef flavour are also influenced by the methodology employed in its assessment. Dietary supplements of antioxidants generally retard lipid oxidation and the accumulation of thiobarbituric acid-reactive substances (Kerry *et al.* 2000), and thereby may delay appearance of objectionable flavours, particularly for beef with higher concentrations of PUFA.

Table 3. Flavours detectable by trained panellists in cooked beef

Aromatics:	Cooked beefy or brothy
	Cooked beef fat
	Serumy or bloody
	Grainy or cowy
	Cardboardy
	Painty
	Fishy
	Livery or organy
	Soured (grainy)
	Medicinal
	Other
Feeling factors:	Metallic
	Astringent
	Throat irritation
	Chemical burn
Basic tastes:	Salty
	Sour
	Bitter
After tastes:	Metallic aftertaste
	Soapy aftertaste
	Other aftertaste

There appears to be a myriad of chemical compounds contributing to meat flavour. Larick *et al.* (1987) showed that lipid breakdown products such as aldehydes and ketones were more apparent in volatile compounds from beef produced on grass rather than on grains. Terpenoids derived from chlorophyll were also detected and correlated with flavour changes. Elmore *et al.* (1997, 1999) reported higher concentrations of lipid oxidation products in the aroma extracts of steaks from cattle finished on grass silage and the oil supplements described earlier (Enser *et al.* 1997). In particular, *n*-alkanals, 2-alkenals, 1-alkanals, and alkyl-furans were increased up to 4-fold. Most of these compounds were derived from the auto-oxidation of the more abundant mono- and diunsaturated fatty acids during cooking, and such auto-oxidation appeared to be promoted by increased levels of PUFA. Compounds resulting from reactions between lipid breakdown products and the products of Maillard reactions between sugars and amino groups including thiazoles and 3-thiazolines were reported for the first time in beef, and were greatly increased in animals fed PUFA supplements.

Juiciness

Despite its close relationship to overall beef desirability, juiciness has received limited research attention. For grass-fed cattle, but not grain-fed cattle, juiciness scores tended to increase during post-mortem ageing up to 10 d (Xiong *et al.* 1996). Ground beef from feedlot cattle was judged as considerably juicier than ground beef from pasture-finished cattle (Simonne *et al.* 1996), but *longissimus* steaks from concentrate- and grass-fed cattle had similar juiciness (French *et al.* 2000*a*). The compiled literature data of Owens & Gardner (1999) indicate that juiciness was negatively related to *longissimus* moisture and positively related to *longissimus* fat concentration. Mandell *et al.* (1997) noted that *longissimus* steaks with higher fat content (3·5–5 %) were more juicy than steaks that contained 2–3 % intra-muscular lipid. Although electrical stimulation of the carcass usually improves beef tenderness, it has been reported to reduce juiciness (Nour *et al.* 1994), possibly through altering glycogen or energy reserves and the rate of pH decline post-mortem. Myristic, palmitic and margaric acid concentrations of the *longissimus* were related negatively to juiciness (Camfield *et al.* 1997).

‘Healthy beef’

Fatty acids

In a recent briefing paper from The British Nutrition Foundation (1999), it was concluded that ‘meat and meat products are an integral part of the UK diet and make a valuable contribution to nutritional intakes’. The fat content of meat is less than it used to be, as a result of changes in breeding, feeding and butchery techniques. Further, lean meat is an important source of bioavailable Fe, Zn and other trace elements such as Cu and Se, along with B vitamins and vitamin D. Nevertheless, there is a perception among consumers, and often the medical profession, that beef is a high-fat food with a high proportion of saturated fatty acids (SFA) that are considered to increase the risk of CHD. Such a perception has probably contributed to the decline in beef consumption, since medical authorities worldwide recommend that energy intake from fat should not exceed 30–35 % total energy intake, that energy intake from SFA should not exceed 10 % total energy intake, and that energy intake from monounsaturated fatty acids and PUFA should be approximately 16 and 7 % total energy intake respectively. Furthermore, an increase in *n*-3 PUFA consumption such that *n*-6:*n*-3 PUFA is 4:1 has also been recommended (Gibney, 1993; Department of Health, 1994; US Department of Agriculture, 2000). Such recommendations have provided impetus to develop strategies to alter the total fat concentration and the fatty acid composition of beef fat to be more compatible with consumer requirements. Modern meat is not as fat as it was previously. Higgs (2000) has described how the combination of changes mentioned by the British Nutrition Foundation (1999) has resulted in modern lean beef with an intramuscular fat concentration of 5 % compared with 25 % in 1950–1970s. PUFA:SFA is lower in ruminant tissue than in non-ruminant tissue, due to hydrogenation of dietary unsaturated fatty acids by rumen micro-organisms. Nevertheless, SFA represent less than half the total fatty acids to beef, and of the total SFA 30 % are represented by stearic acid, which has been shown to be neutral in its effect on plasma cholesterol in human subjects (Bonanome & Grundy, 1988). These data indicate that the common reference to beef fat as very saturated is erroneous. A proportion of dietary unsaturated fatty acids bypasses the rumen intact and is absorbed and deposited in body fat (Wood & Enser, 1997). Increasing the dietary supply of PUFA, particularly *n*-3 PUFA, is one strategy to increase PUFA concentrations in ruminant tissue. An important difference between single-stomached animals and ruminants is that the long-chain *n*-3 PUFA, including eicosapentaenoic acid and docosahexaenoic acid, are not incorporated into triacylglycerols to any important extent in ruminants. They are incorporated mainly into membrane phospholipids and, therefore, are found predominantly in muscle (Enser *et al.* 1996). This factor provides the opportunity to manipulate intramuscular fatty acid composition without large increases in fatness *per se*.

There are many reports on the effects of beef cattle diets on the fatty acid composition of muscle (for example, see Rule *et al.* 1995; Wood & Enser, 1997; Demeyer & Doreau, 1999). Grass has higher PUFA, and particularly higher *n*-3 PUFA, primarily as linolenic acid, than grain-based ruminant feeds. In general, grass-fed beef has higher concentrations of PUFA, particularly in the phospholipid fraction, than grain-fed beef (Griebenow *et al.* 1997). As shown in Table 4, an increase in the proportion of grass in the diet of finishing steers decreased the SFA concentration, increased PUFA:SFA, increased the *n*-3 PUFA concentration and decreased *n*-6:*n*-3 PUFA (French *et al.* 2000*c*). The *n*-3 PUFA detected in meat from the grass-fed cattle in this study were predominantly linolenic acid. The health benefits of *n*-3 PUFA from plant and marine (i.e. eicosapentaenoic and docosahexaenoic acid) sources appear to differ. An expert workshop on this issue (de Deckere *et al.* 1998) concluded that ‘there is incomplete but growing evidence that consumption of the plant *n*-3 PUFA, alpha-linolenic acid, reduces the risk of coronary heart disease. An intake of 2 g/d or 1 % of energy as alpha-linolenic acid appears prudent. The ratio of total *n*-3 over *n*-6 PUFA (linoleic acid) is not useful for characterising foods or diets because plant and marine *n*-3 PUFA show different effects, and because a decrease in *n*-6 PUFA intake does not produce the same effects as an increase in *n*-3 PUFA intake.

Table 4. The effect of diet on intramuscular fatty acid composition of beef (data from French *et al.* 2000*c*)

Fatty acid (g/100 g fatty acids)	Silage and concentrates	Grass (g/kg DM) 0	510	770	1000	SE	Statistical significance of effect of diet
18:2	2·60	2·96	2·60	2·32	2·11	0·105	NS
18:2 (conjugated linoleic acid)	0·47^{cd}	0·37^{d}	0·54^{bc}	0·66^{b}	1·08^{a}	0·040	***
18:3	0·71^{d}	0·72^{d}	0·87^{c}	1·01^{b}	1·13^{a}	0·031	***
SFA	47·72^{a}	48·07^{a}	45·71^{b}	44·86^{b}	42·82^{c}	0·415	***
MUFA	41·83	41·48	40·90	42·31	43·07	0·249	NS
PUFA	4·14^{a}	4·93^{a}	4·53^{a}	4·71^{a}	5·35^{b}	0·29	*
n-6 Fatty acids	2·96	3·21	3·12	3·04	3·14	0·106	NS
n-3 Fatty acids	0·91^{c}	0·84^{c}	1·13^{b}	1·25^{ab}	1·36^{a}	0·042	***
n-6:*n*-3 Fatty acids	3·61^{a}	4·15^{a}	2·86^{b}	2·47^{b}	2·33^{b}	0·197	**
PUFA:SFA	0·09^{a}	0·09^{a}	0·10^{a}	0·11^{ab}	0·13^{b}	0·007	**

^{a,b,c,d} Means within rows with unlike superscript letters were significantly different ($P < 0·05$).

SFA, total saturated fatty acids; MUFA, total monounsaturated fatty acids; PUFA, total polyunsaturated fatty acids.

* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

Separate recommendations for alpha-linolenic acid, marine *n*-3 PUFA and linoleic acid are preferred.' Grass-fed beef can contribute to diets designed to achieve an increased consumption of *n*-3 PUFA.

The fatty acid composition of beef can also be manipulated by including fatty acids in the diet that are protected from rumen hydrogenation (Scott *et al.* 1971; Demeyer & Doreau, 1999). An example of the relative success of such a strategy is shown in Table 5. Inclusion of bruised whole linseed, a rich source of linolenic acid, resulted in 100 % increase in the concentration of linolenic acid in muscle, while the linseed oil–fish oil treatment increased the marine *n*-3 PUFA concentrations (Scollan *et al.* 2000). Further research is in progress to improve the transfer of dietary PUFA to muscle. Current data, therefore, indicate that beef can be produced that has a lower fat concentration (< 5 %), has a decreased amount of atherogenic SFA, has increased total PUFA concentration and improved concentrations of *n*-3 and *n*-6 PUFA and *n*-3:*n*-6 PUFA than was possible in the past. That modern lean beef can play a role in a healthy diet was demonstrated recently when lean red meat and lean white meat were compared as components of a cholesterol-lowering diet for human subjects (Davidson *et al.* 1999). Both diets produced similar reductions in LDL-cholesterol and elevations in HDL-cholesterol levels, which were maintained throughout 36 weeks of treatment.

Conjugated linoleic acid

Conjugated linoleic acid (CLA) refers to a mixture of positional and geometric isomers of linoleic acid (18:2*n*-6) in which the double bonds are conjugated instead of existing in the typical methylene-interrupted configuration. Nine different isomers of CLA have been reported as occurring naturally in food. Of these isomers, the *cis*-9, *trans*-11 form is believed to be the most common natural form of CLA with biological activity, but biological activity has been proposed for other isomers, especially the *trans*-10, *cis*-12-isomer. Although not widely accepted, 'rumenic acid' has been proposed as a 'common name' for the major CLA isomer found in natural products. Conjugated linoleic acid has been shown to be an anti-carcinogen, and to have anti-atherogenic, immunomodulating, growth-promoting, lean body mass-enhancing and anti-diabetic properties (Pariza, 1997; Parodi, 1999; Bessa *et al.* 2000). It is found in highest concentrations in fat from ruminant animals, where it is produced in the rumen as the first intermediate in the biohydrogenation of dietary linoleic acid by the enzyme, linoleic acid isomerase from the bacteria *Butyrivibrio fibrisolvens*. In the second step of the pathway, the conjugated diene is hydrogenated to *trans*-11-octadecenoic acid (*trans*-vaccinic acid) and further hydrogenation results in stearic acid (Kepler & Tove, 1967). Since there are potential health benefits arising from CLA consumption, there is considerable research effort directed to increasing the CLA content of ruminant-derived food. Milk-fat CLA concentrations are primarily influenced by linoleic acid supply to the rumen, by inclusion of grass in the diet and by forage:concentrate in the diet (Kelly *et al.* 1998*a*,*b*; Jiang *et al.* 1996). Few data are available on strategies to increase CLA concentration in other adipose tissue depots. The effect of increasing grass consumption by beef cattle on intramuscular CLA concentration is shown in Table 4. An increase in the proportion of grass in the diet caused a linear increase in CLA concentration, while a grass silage and concentrate diet resulted in a lower CLA concentration than a grass-based diet with a similar forage:concentrate value (French *et al.* 2000*c*). Reported CLA concentrations in beef are summarised in Table 6. Concentrations in Irish and Australian beef can be two to three times higher than those in US beef. This finding presumably reflects the greater consumption of PUFA-rich pasture throughout the year by cattle in these countries. The *cis*-9-, *trans*-11-CLA isomer contributes 57–85 % of the total CLA in beef fat. In addition, there is evidence that the CLA concentration increases in foods that are cooked and/or otherwise processed.

Epidemiological studies support the hypothesis that there is some factor in whole milk that has a protective effect against breast cancer and CHD (Knekt *et al.* 1996). Lower incidences of these diseases were related to greater consumption of whole milk but not to intakes of low-fat

Table 5. Fatty acid composition of *longissimus dorsi* muscle from steers fed grass silage and concentrates with different sources of oil (data from Scollan *et al.* 2000)

	Control	Linseed	Fish oil	Linseed and fish oil	SED	Statistical significance of difference
Fatty acids (mg/100 g tissue)						
12:0	3·20	3·79	3·70	4·36	0·789	NS
14:0	121	152	173	169	34·0	NS
16:0	1029	1089	1305	1171	206·0	NS
18:0	528	581	543	490	104·0	NS
18:1(*trans*)	63	147	184	173	33·2	**
18:1	1209	1471	1260	1225	279·0	NS
18:2	81	78	66	64	9·2	NS
18:3	22	43	26	30	5·6	**
20:4	23	21	14	17	1·5	***
20:5	11	16	23	15	1·9	***
22:6	2·2	2·4	4·6	4·9	0·52	***
Total fatty acids	3529	4222	4292	3973	741·0	NS

** $P<0·01$, *** $P<0·001$.

Table 6. Conjugated linoleic acid concentrations in uncooked beef

Diet	Country	Concentration (mg/g fat)	Reference
Unknown	Canada	1·2 – 3·0	Ma *et al.* (1999)
Barley (800 g/kg diet)	Canada	1·7 – 1·8	Mir *et al.* (2000)
Grass silage and concentrates	UK	3·2 – 8·0	Enser *et al.* (1999)
Maize (820 g/kg diet)	USA	3·9 – 4·9	McGuire *et al.* (1998)
Unknown	USA	2·9 – 4·3	Chin *et al.* (1992)
Unknown	USA	1·7 – 5·5	Shanta *et al.* (1994)
Grain	USA	5·1	Shanta *et al.* (1997)
Concentrate	Japan	3·4	Tsuneishi *et al.* (1999)
Grass	USA	7·4	Shanta *et al.* (1997)
Grass (?)	Australia	2·3 – 12·5	Fogerty *et al.* (1988)
Grass	Ireland	3·7 – 10·8	French *et al.* (2000*c*)
Unknown	Germany	1·2 – 12·0	Fritsche & Steinhart (1998)

milk. The authors suggested that CLA in milk fat may be the protective factor. Moreover, the incidence of breast cancer was lower in women with higher breast tissue levels of CLA (Lavillonniere *et al*. 1998). The CLA content of blood serum and breast milk can be modified by diet (Parodi, 1999). In earlier studies in Australia, breast milk from women of the Hare Krishna religious sect contained twice as much CLA as milk from Australian mothers on conventional diets (11·2 *v* 5·8 g/kg; Fogerty *et al*. 1988) This finding was attributed to the large amount of butter and ghee (a clarified butter) consumed by the Hare Krishna community. The CLA concentration in human milk can be enhanced by increasing the CLA content of the maternal diet, which suggests an opportunity to protect the female neonate from subsequent breast cancer development (Parodi, 1999).

Parodi (1994) proposed that dietary *trans*-11-18:1, the predominant *trans*-monounsaturated fatty acid in milk fat and ruminant tissue fat could be converted by desaturase enzymes to CLA in human subjects. Recently, Salminen *et al*. (1998) showed that feeding subjects a diet enriched with *trans*-fatty acids from hydrogenated vegetable oil increased blood CLA concentrations, probably reflecting the presence of *trans*-11-18:1 in the mixture of *trans*-fatty acids. A similar pathway may operate in ruminants (Corl *et al*. 1998) since *trans*-11-18:1 is an intermediate in the linoleic desaturation pathway in the rumen. While animal studies have shown benefits of dietary concentrations of CLA as low as 1–5 g/kg, the minimum effective dose to confer cancer protection in human subjects has not yet been clarified. However, this dose level is a subject of intense medical research.

Conclusion

Modern systems of cattle management can produce beef that is tender, flavoursome and healthy for consumers. Based on available information, carcass management post-slaughter has a larger effect on meat tenderness than production factors such as gender or feeding system. Optimum ‘pasture to plate’ management systems are being established to ensure beef tenderness. Flavour is an important component of beef acceptability, but assessment of flavour is subject to the previous experiences and preferences of members of a taste panel and to the methodology used. There is opportunity to exploit the diet of cattle to produce beef that has an increased CLA concentration, a lower total fat concentration and a fatty acid profile more compatible with current human dietary recommendations.

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