# Factors affecting flavour in beef

## A literature review, with recommendations for the British beef industry on how flavour can be controlled

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## Introduction

Reviews in many countries have generally concluded that consumers view tenderness as the most important aspect of meat eating quality in all species. Juiciness and flavour are generally considered as being of secondary importance. However, there is increasing evidence to suggest that flavour is becoming more important, perhaps because of more demanding consumers or possibly because tenderness variation has been reduced by controlling the factors known to be involved, for example carcase chilling rate and conditioning time. Indeed, a recent study at Bristol University showed that overall liking was more highly correlated with flavour than tenderness in beef animals which were uniformly tender (Campo *et al*, 2004). In a Norwegian study of meat quality in 15 species, Rodbotten *et al.* (2004) concluded that odour and flavour were the most important attributes after colour contributing to the overall appreciation of meat and the variation between species. Beef was shown to have distinct sensory characteristics, quite different from pork or lamb.

Conclusions regarding which are the most important aspects of eating quality are likely to be different between meat scientists and cookery writers such as Delia Smith, Hugh Fearnley-Whittingstall and Nigel Slater, who maintain that flavour is undoubtedly the most important aspect of eating quality. Writers like these conclude that modern livestock production gives too much emphasis to leanness and tenderness and not enough to flavour. However, it is becoming clear that, as with tenderness, flavour in beef can be controlled and improved even in lean carcasses by paying attention to critical points in the chain, as has been successfully achieved for tenderness. Thus knowledge of how flavour develops and is affected through the supply chain should be able to be applied widely in the meat industry.

Previous reviews on beef flavour have concentrated on effects exerted in a particular part of the supply chain e.g. on the farm (the effects of diet or genetics) or during processing. This review comprehensively examines all the stages of beef production with the aim of suggesting where in the supply chain future efforts to improve beef flavour should be concentrated.

**What causes meat flavour**

The flavour of meat develops during cooking through the effects of heat on the many compounds present. Most important for basic meat flavour are water soluble compounds such as sugars, sugar phosphates, sugar nucleotides, free amino acids and peptides. Reactions between these are also important. Sugars and amino groups react together in reactions called Maillard reactions. Cysteine, an amino acid containing sulphur, and ribose, a sugar, are two important compounds and in general, many of the compounds which produce meaty aromas and flavours contain sulphur (Mottram, 1998).

Fat, and the fatty acids which constitute it, are also important in flavour development. They are responsible for the characteristic species flavour of the meat and they act as a solvent in which other flavour compounds are contained. Diets probably have their greatest effect on flavour via changes in fatty acid composition. It is well recognised that oxidation of fat under prolonged storage produces an undesirable odour and flavour termed rancidity. This is also part of the 'warmed over flavour' which occurs in reheated foods containing unsaturated fat. More recently it has been recognised that thermal degradation and oxidation of fatty acids produces a range of compounds which contribute positively to meat flavour. It is estimated that about half the volatile compounds produced during cooking are lipid-derived although

most of these have very high odour thresholds and may not be important. However some, particularly aldehydes, alcohols and ketones, have low odour thresholds and are important for flavour formation (Elmore *et al*, 1999).

Lipid-degradation products participate in reactions with Maillard reaction products to produce a further range of flavour compounds. They also inhibit the formation of some products of Maillard reactions, for example the heterocyclic compounds such as pyrazines formed at high temperatures. Production of oxidation products from fat is increased as the unsaturation of the fatty acid increases and the free radicals generated during oxidation catalyse the oxidation of less unsaturated fatty acids. Because phospholipids are the most unsaturated lipid class they have a more important role than triacylglycerols in meat flavour development (Mottram and Edwards, 1983).

Over 1000 compounds have been identified as important for flavour development, with more being reported for beef than other meats. Given the importance of so many different compounds in eliciting a wide range of flavours in meat, it is not surprising that many factors and events in meat production and processing, which affect the composition of meat, also change the eventual flavour produced.

**Measurement of flavour and its variability**

Flavour can be defined as a complex group of sensations comprising olfactory (odour), taste and other chemical sensations such as spice heat (Lawless and Heymann ,1998). These are perceived differently by people and are impossible to measure instrumentally. Assessment is therefore done by a panel of ideally 8 to 12 people who are trained to identify the flavour or

other taste characteristic and the scale (intensity) of it. In most animal science studies the meat samples, often loin steaks, are cooked in a standard manner eg. grilling to a predetermined internal temperature eg. 70$^{o}$C. Samples are then presented to the panellists in a structured way so as to fairly evaluate the effects of e.g. production and processing factors. At Bristol University we use 1 – 8 intensity scales for evaluating the main attributes including beef flavour and abnormal flavour. Often a flavour profile is also constructed using line scales of say 0 to 100. In the flavour profile, words to describe nuances of odour or flavour are used such as rancid, metallic, bitter, sweet, etc. Guidelines for training panellists conducting sensory tests and evaluating the results have been published (e.g. Cross *et al*, 1978). Despite these, there are wide differences between research groups in different countries in methodology, especially number of panellists, cooking temperatures and number of points on the scoring scale. These differences should not alter major conclusions such as the ranking of treatments.

Chemical measurements of flavour volatile compounds have been described by several workers (e.g. Mottram, 1998; Elmore *et al*, 1999). These help us to understand how odours and flavours develop but chemical analysis is not considered a substitute for trained taste panel analysis at present.

The variability in taste panel scores for beef flavour (the characteristic flavour of beef) and abnormal flavour (flavours not associated with beef) is quite high, comparable to tenderness and juiciness as judged by the coefficients of variation (standard deviation as % of mean value) for taste panel scores in a recent study at Bristol (Table 1). There were 138 steers in the study representing 2 breeds (Aberdeen Angus cross and Holstein-Friesian), 3 ages (14, 19 or 24 months) and 2 diets (grass silage and a barley-soya concentrate with some steers also

fed fresh grass at 19 months). Loin steaks were grilled to 74°C internal temperature and evaluated by a trained taste panel using 0 – 100 line scales. Results in Table 1 were for all the cattle. The panellists concentrated their scores in the lower ends of the scales, giving a relatively low score to beef flavour and lower still to abnormal flavour. Histograms of the scores are shown in Figure 1. These show that the range of scores was less for beef flavour and abnormal flavour than for toughness and juiciness.

Table 1. Mean values and variability of taste panel scores (0 – 100) for grilled loin steaks in 138 steers

| Variable | n | Mean | Standard Deviation | Coefficient of Variation | Range |
|---|---|---|---|---|---|
| Toughness | 138 | 39.408 | 9.060 | 22.99 | 45.500 |
| Juiciness | 138 | 34.748 | 8.484 | 24.42 | 44.000 |
| Beef | 138 | 27.453 | 5.106 | 18.60 | 23.300 |
| Abnormal | 138 | 14.745 | 4.363 | 29.59 | 23.800 |

**Production effects on beef flavour**

Factors during animal production which could affect beef flavour are age, breed, gender, fatness, diet and production system.

Age

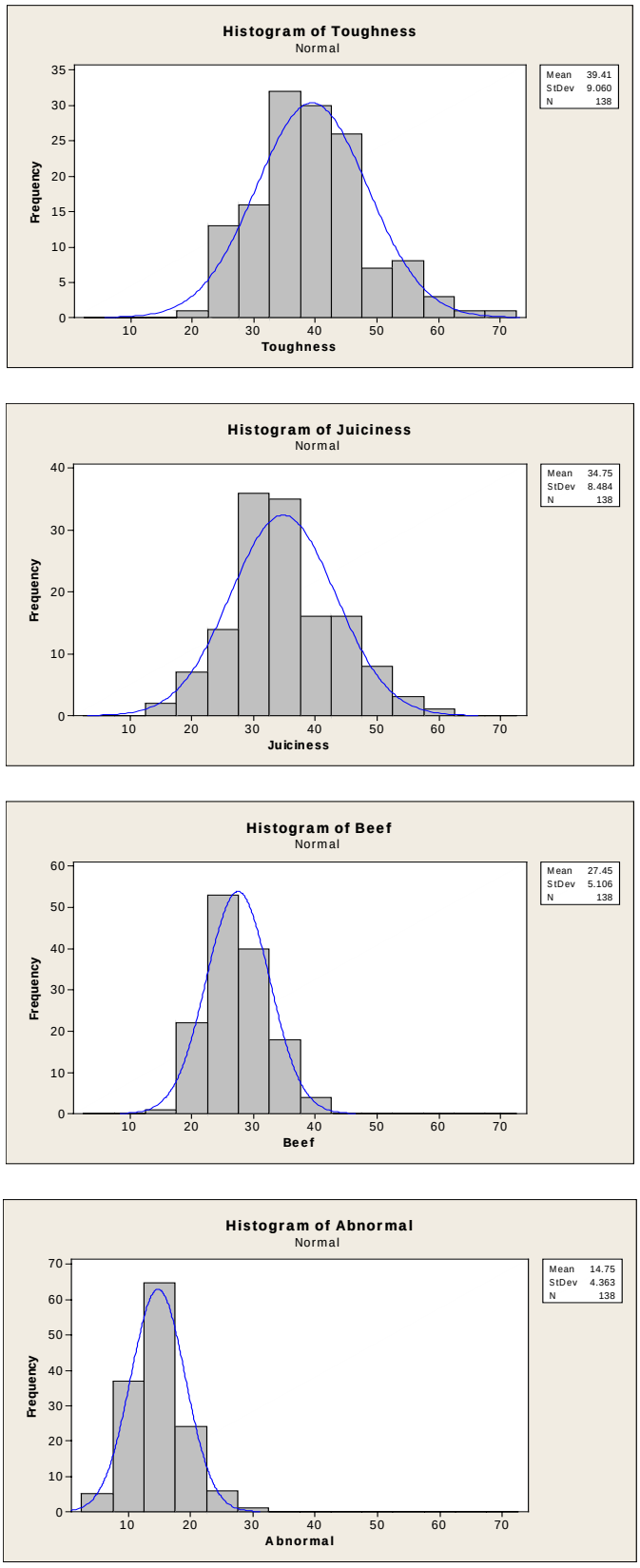
There are clear differences in the flavour of veal and beef. Rodbotten et al (2004) compared meat from 17 animal groups including 15 species. Samples were heated in a waterbath to 72°C then evaluated by an 11-person trained taste panel on a 15 cm continuous scale. The values were transformed to a 1 – 9 scale increasing in intensity. Flavour descriptive terms

were generated by the panellists themselves based on the wide range of species in the study. The results (Table 2) show that in comparison with beef, veal has lower overall flavour intensity, a higher acidic taste and lower gamey and cloying notes. The 17 groups were analysed using principal components which showed that beef was in a different part of the 'meat universe' from veal. Veal was associated with pork, turkey and chicken, and beef with horse, goat and whale. For beef animals in the normal commercial range the effects of age on flavour are much less marked than between beef and veal. Nevertheless there is a trend for beef flavour to intensify as age increases between 12 and 30 months.

Table 2. Mean values for flavours of beef and veal (1 – 9 scale) (Rodbotten *et al*, 2004)

| | Beef | Veal |
|---|---|---|
| Flavour intensity | 6.9 | 5.1 |
| Sweet | 3.6 | 3.2 |
| Acidic | 3.0 | 4.9 |
| Metallic | 3.6 | 2.8 |
| Livery | 3.3 | 1.2 |
| Gamey | 4.1 | 1.3 |
| Cloying | 3.5 | 1.8 |
| Bitter | 3.8 | 2.7 |

Figure 1. Distribution of taste panel scores (0-100) for grilled loin steaks in 138 steers.



Breed

Considerable speculation surrounds the role of breed in determining eating quality. There have been some comprehensive studies on the effect of breed, particularly the germ plasm evaluation programme conducted by the USDA at the Meat Animal Research Centre (MARC), Nebraska, USA. In one study, cattle of 14 breed types were evaluated (Koch *et al*., 1976). These were comprised of Hereford or Angus cows mated to Hereford, Angus, Jersey, South Devon, Limousin, Charolais and Simmental sires. Steers were reared from 240 days of age for 217 days on average on a corn silage and concentrate diet. For the eating quality studies, rib steaks aged for 3-4 days were oven broiled at 177ºC to an internal temperature of 65ºC. A 6-person taste panel evaluated tenderness, juiciness and beef flavour on 1-9 scales. Based on the results in Table 3, the authors concluded that differences in palatability traits between breeds were small. There were statistically significant although numerically small differences for tenderness and juiciness, with Jersey and South Devon breeds producing the highest scores. These were ascribed to greater maturity in the early-maturing Jersey and South Devon breeds. Marbling score was significantly higher in Jerseys, reflecting their dairy breed type. Interestingly Moore and Bass (1978) in New Zealand found the highest scores for tenderness and flavour in Jerseys among 10 breed groups. There were no differences in beef flavour between the breed groups (Table 3).

Other authors have observed that breed effects on eating quality, including flavour, are small and where they exist they are related to fatness differences, the fatter animals tending to have higher intensity scores (Laborde *et al*. 2001; Chambaz *et al*. 2003). This reflects the small but positive effects of fatness on eating quality which will be described in a subsequent section.

Table 3. Taste panel desirability scores (1-9 scale) for rib steaks from 7 sire breeds mated to Hereford and Angus cows. Scores adjusted to a starting age of 240d and 217d on feed (Koch *et al* 1976).

| | Hereford | Angus | Jersey | South Devon | Limousin | Charolais | Simmental |
|---|---|---|---|---|---|---|---|
| Tenderness | 7.3 | 7.4 | 7.5 | 7.5 | 7.0 | 7.4 | 6.9 |
| Juiciness | 7.0 | 7.1 | 7.3 | 7.2 | 7.1 | 7.1 | 7.1 |
| Flavour | 7.5 | 7.5 | 7.6 | 7.5 | 7.5 | 7.6 | 7.5 |

There have been few studies of eating quality in traditional or rare breeds in comparison with modern breeds. It is widely believed that eating quality, perhaps especially flavour will be superior in these breeds. Traditional breeds are likely to be older at slaughter and possibly fatter, reflecting their smaller body size, and these factors might affect flavour. In one study, however (Vatansever *et al*. 2000) no differences in flavour attributes were found between Welsh Black, a traditional Welsh cattle breed and Holstein-Fresian steers.

The finding by Vatansever *et al*. (2000) that the level of eating quality, including flavour, is high in dairy cattle breeds is consistent with the results in Table 3 for the Jersey. Thonney *et al*. (1991) compared rib eye steaks from Holstein and Simmental-Angus breeds. The taste panel scores for tenderness and flavour were significantly higher in the Holstein, as was overall acceptability. In this study, marbling score was similar in the 2 breed groups, but at the same carcass fat level, marbling fat is higher in dairy than beef breeds, possibility contributing further to higher eating quality.

The main conclusion on breed is that differences are of minor significance for flavour.

Gender

Gender is an important factor affecting eating quality in pigs, with some entire males (boars) eliciting high scores for offensive odours and flavours of cooked pork and bacon. These odours and flavours are collectively termed "boar taint". Boar taint is due to high concentrations of androstenone, a breakdown product of testosterone and skatole produced in the hind gut. The effect of gender on odour and flavour in cattle is less clear, with some studies showing no differences in beef intensity or flavour desirability between bulls and steers (Field, 1971; Cross *et al*. 1984). However, other studies show lower intensity of beef flavour and particularly higher abnormal flavour in bulls (Crouse *et al.,* 1983; Arthaud *et al*., 1977). Gorriaz *et al*. (2002) found significantly greater beef flavour in bulls than heifers and a higher livery odour and flavour. Differences between steers and heifers appear small although there are few reported studies.

A study conducted by Bristol University for MLC (Bristol University, 2000) examined 160 dairy cross bulls and steers of different ages (12, 14 and 16 months). A group of suckler bulls and a group of dairy cross bulls which had grown rapidly from 14 to 16 months were also included. The following muscles/cuts were examined following ageing for 14 days at 1ºC:

*Longissimus lumborum*. Sirloin steaks. Grilled.

*Gluteus medius*. Rump steaks. Grilled

*Semimembranosus*. Topside. Roasted.

*Gluteobiceps.* Silverside. Roasted.

Results for the 14-month steers, 14-months bulls, 16-month bulls, and bulls grown rapidly between 14 and 16 months are shown in Table 4. and show that the flavour liking score was lower in all cuts from the 16month bulls than the other groups. In most cases this was due to higher abnormal flavour and less commonly to a lower beef flavour score. The groups of bulls grown rapidly to 16 months were intermediate between the 16-month bulls and the steers. The 14-month bulls and steers were not different in flavour characteristics. In bulls and steers aged 12-months, abnormal flavour was higher and flavour liking lower in sirloin steaks and silverside roasts from the bulls.

Table 4. Flavour characteristics of different beef cuts in bulls and steers (Bristol University, 2000).

| | 14-month steers | 14-months bulls | 16-month bulls | Rapid bulls |
|---|---|---|---|---|
| Grilled sirloin (*Longissimus)* | | | | |
| Beef flavour | 2.8 | 2.9 | 2.7 | 2.9 |
| Abn. flavour | $3.7^{ab}$ | $3.9^{bc}$ | $4.2^{c}$ | $3.4^{a}$ |
| Flavour Liking | $3.2^{b}$ | $3.2^{b}$ | $2.8^{a}$ | $3.2^{b}$ |
| Grilled rump (*Gluteus medius)* | | | | |
| Beef flavour | 3.1 | 3.0 | 2.8 | 3.0 |
| Abn. flavour | 3.5 | 3.4 | 3.7 | 3.5 |
| Flavour Liking | 3.3b | 3.4b | 3.0a | 3.2ab |
| Roast topside (*Semimembranosus*) | | | | |
| Beef flavour | 2.9 | 2.9 | 2.7 | 2.7 |
| Abn. flavour | $3.3^{a}$ | $3.4^{a}$ | $3.7^{b}$ | $3.5^{ab}$ |
| Flavour Liking | $3.2^{b}$ | $3.4^{b}$ | $2.9^{a}$ | $3.2^{b}$ |
| Roast silverside (*Gluteobiceps*) | | | | |
| Beef flavour | $3.0^{bc}$ | $3.2^{c}$ | $2.8^{ab}$ | $2.8^{a}$ |
| Abn. flavour | $3.3^{a}$ | $3.2^{a}$ | $3.9^{b}$ | $3.5^{a}$ |
| Flavour Liking | $3.5^{b}$ | $3.8^{c}$ | $3.1^{a}$ | $3.3^{ab}$ |

Means with different superscripts are significantly different ($P<0.05$)

In the bulls examined at Bristol and illustrated in Table 4, there were few examples of dark, firm, dry (DFD) beef, which has a high pH. When present, this causes high abnormal flavour associated with a high water and low sugar content of muscle (see Section on Pre-slaughter stress).

In conclusion, it appears that beef flavour intensity may be reduced and abnormal flavour intensity increased in bulls compared with steers and heifers.

Carcass and meat fat content

Speculation continues to surround the role of fat in beef eating quality, particularly the role of marbling fat. The extent of marbling is the key criterion determining the USDA Quality grade for beef, giving the impression that marbling fat directly determines eating quality. However, a common conclusion from the published literature is that the level of marbling, although positively correlated with tenderness, juiciness and flavour scores, explains only a small proportion of their overall variation, possibly 10 - 15% (Dikeman, 1987).

Despite low correlations between marbling fat level and eating quality traits in several reports, some studies appear to support an important role for marbling fat. For example, the results in Table 5 taken from the study of Smith *et al*. (1984) show that tenderness, juiciness and flavour desirability scores increased as marbling score increased from "practically devoid" to "moderately abundant". Improvement in flavour was similar to that in tenderness. Values for ether-extractable lipid in Table 5 were determined by Savell *et al*. (1986) in a separate study. Correlations showed that about 30% of the variation in beef flavour and 27% of variation in tenderness was accounted for by marbling fat level. An important feature of the work of Smith *et al*. (1984) was that there were approximately equal numbers of carcasses

in each marbling score group, even in the extreme groups. In commercial reality however, carcasses are likely to be in a much narrower range. For example, in a Canadian study of commercial cattle where loin joints were grouped in the "slight" to "modest" marbling score range, correlations between marbling score and eating quality were around 0.1 for beef flavour. This conclusion is closer to the concensus of the published work.

Table 5. Taste panel scores (1-8 scales) for sirloin steaks from "A-maturity" carcasses with different USDA marbling scores (Smith *et al*, 1984).

| Marbling score | Flavour | Juiciness | Tenderness | Lipid (%)[1] |
|---|---|---|---|---|
| Mod.-abundant | 6.27[a] | 5.52[a] | 6.60[a] | 10.42 |
| Sl.-abundant | 6.05[ab] | 5.44[a] | 6.41[a] | 8.56 |
| Moderate | 6.01[b] | 5.31[a] | 6.32[a] | 7.34 |
| Modest | 5.76[c] | 4.97[b] | 6.30[a] | 5.97 |
| Small | 5.75[c] | 4.92[bc] | 6.01[b] | 4.99 |
| Slight | 5.60[c] | 4.80[bc] | 5.88[b] | 3.43 |
| Traces | 5.36[d] | 4.58[d] | 5.37[c] | 2.48 |
| Pract. devoid | 4.88[e] | 4.73[cd] | 4.90[d] | 1.77 |

[1]Ether-extractable lipid in *longissimus* (%) (Savell *et al*. 1986)

Means in a column with different superscripts are significantly different ($P<0.05$)

European cattle are considerably leaner than the US cattle shown in Table 5. In a Danish study in young bulls, the average solvent-extractable fat level in loin muscle was 1.6%, corresponding to a "practically devoid" level of marbling fat according to Savell *et al*. (1986). However, the tenderness and flavour of loin steaks was apparently at a high level. In research studies at Bristol University, marbling fat concentrations of 2-4% of *longissimus* muscle weight are commonly seen (Choi *et al*. 2000).

Table 6. Effects of fat content of ground beef patties on eating quality (1-20 scale). (Kregel *et al*. 1986).

| | Fat (%) | | |
|---|---|---|---|
| | 9.5 | 21.0 | 28.5 |
| Tenderness | 9.6[a] | 11.8[b] | 13.1[c] |
| Juiciness | 7.2[a] | 10.5[b] | 11.3[c] |
| Beef flavour | 9.9[a] | 9.3[a] | 9.0[a] |

Means with different superscripts are significantly different ($P<0.05$)

For tenderness and juiciness, correlations with fat concentrations have been observed in ground beef products where fat levels are higher than in fresh muscle cuts. The data in Table 6 are from a study by Kregel *et al*. (1986). Beef patties with different fat percentages were produced from chuck joints and subcutaneous fat from US Choice grade carcasses. They were oven-broiled at 180ºC to an internal temperature of 71 or 77ºC and evaluated by a 9-member trained taste panel using a 20cm scale. As percentage fat increased from 9.5 to 28.5%, tenderness and juiciness scores sequentially increased. However, there was no significant effect of fat level on beef flavour intensity, scores tending to decline as fat levels increased. This lack of effect of fat level on flavour in ground beef patties was also seen by Berry and Leddy (1984).

Although there are conflicting results we conclude that fat level has a definite role in flavour development.

Diet

Melton (1990) in a review, concluded that diet was the major factor influencing flavour in meat animals including beef cattle. Various constituents in tissues are influenced by diet to affect flavour but the most important are the fatty acids (Melton, 1990;Larick and Turner, 1990).

In an experiment to investigate the effects of diet on beef meat quality, Scollan *et al.* (2001) fed 32 steers on a grass silage:concentrate diet (60:40), the concentrate containing different oil sources. Total dietary oil content was 6% of which 3% was from Megalac (relatively saturated), Linseed (high in 18:3), Fish oil (high in 20:5 and 22:6) or a 50:50 Linseed:Fish oil combination. Vitamin E was included in the concentrates at 345mg/kg as an antioxidant. After 120 days feeding, the cattle were slaughtered and samples removed from the carcasses at 48h post-slaughter. The loin joint from one side was conditioned at 1ºC for 11 days, after which steaks were overwrapped in $O_2$-permeable film and displayed for up to 16d in simulated retail conditions for colour and lipid oxidation (shelf life) measurements. Steaks for sensory analysis were also displayed for 5 days, then frozen at –20ºC. After thawing, these were grilled to a final internal temperature of 74ºC before analysis by the trained taste panel consisting of 10 assessors. They used 1-8 category scales to evaluate the main characteristics of eating quality (tenderness, juiciness, beef flavour, abnormal flavour) and also specific flavour notes using 0-100 line scales. The terms used to describe beef flavours were decided in training sessions on loin steaks from the study. Analysis of flavour volatiles produced during cooking was carried out using gas chromatography-mass spectrometry following autoclaving at 140ºC and collection of the volatiles on Tenax (Elmore *et al*. 1999).

The results of the research are in Table 7. There were significant effects of the dietary oil sources on fatty acid composition, in both neutral lipid and phospholipid. Linseed increased the concentration of 18:3, doubling it in phospholipid. This in turn led to an increase in 20:5 (EPA) through providing more substrate for the desaturase and elongase enzymes. Fish oil led to large increases in 20:5 (EPA) and 22:6 (DHA) in phospholipid. These changes in fatty acid composition affected shelf life parameters (Vatansever *et al*. 2000), the fish oil samples showing increased lipid oxidation and colour deterioration during simulated retail display.

Results in Table 7 show that the high PUFA diets caused increases in lipid-derived volatiles detected by head space analysis after cooking. These included the unsaturated aldehydes shown in the Table. As a group, the unsaturated aldehydes were quantitatively the most dominant class of volatiles, although the most significant within them were 2-and 3-methylbutanal, derived from amino acids. Complete analysis of the volatiles by Elmore *et al*. (1999) showed that non-lipid derived volatiles were not different between the treatments (e.g. pyrazines). However, compounds formed from reactions between lipid-derived products and products of the Maillard reaction were increased on the Linseed and Fish oil diets. These included alkyl-3-thiazolines.

Elmore *et al*. (1999) showed that many products of lipid oxidation increased on the high n-3 PUFA diets were not directly derived from n-3 PUFA but from less unsaturated fatty acids such as 18:1 n-9 (oleic) and 18:2 n-6 (linoleic). They concluded that free radicals generated during oxidation of the most unsaturated fatty acids initiate oxidation of less unsaturated fatty acids in a chain reaction.

Table 7. Fatty acid composition (%) of *longissimus* neutral lipid and phospholipid, aroma volatiles and taste panel scores in steers fed different diets.

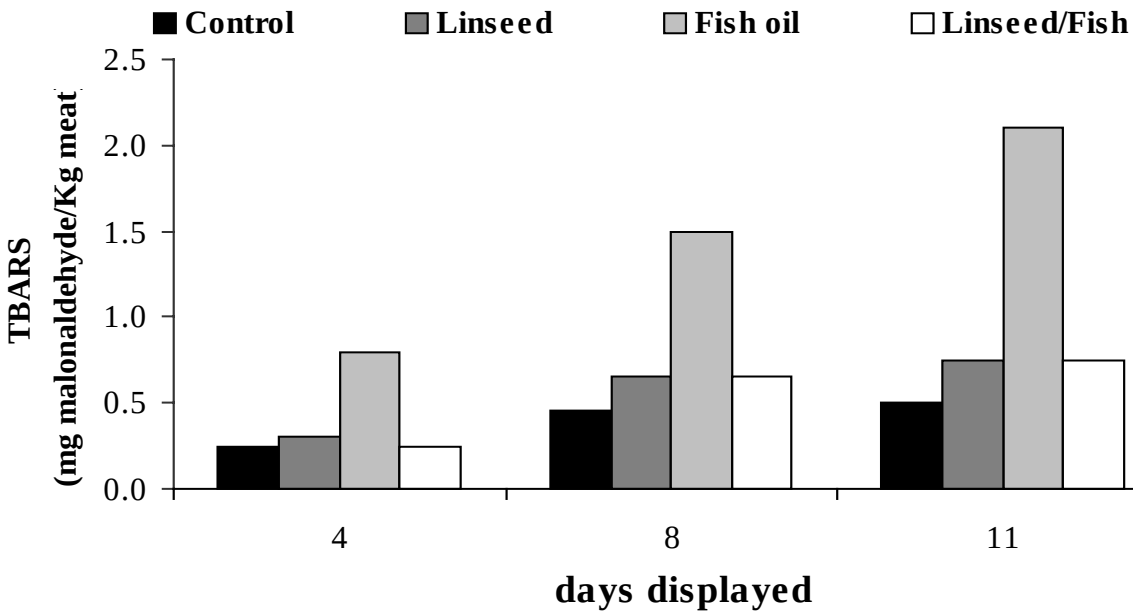
| | Megalac | Linseed | Fish oil | Linseed/ Fish oil | Sig. of diet |
|---|---|---|---|---|---|
| Neutral lipid[1] | | | | | |
| 18:0 stearic | 15.8 | 14.2 | 13.2 | 12.9 | *** |
| 18:l *n*-9 oleic | 36.0 | 35.7 | 30.1 | 33.2 | ** |
| 18:1 trans | 1.9 | 3.8 | 4.4 | 4.9 | *** |
| 18:2 *n*-6 linoleic | 0.93 | 0.79 | 0.57 | 0.72 | *** |
| 18:3 *n*-3 ∝-linolenic | 0.36 | 0.59 | 0.38 | 0.41 | *** |
| Phospholipid [1] | | | | | |
| 18:0 stearic | 10.5 | 10.4 | 9.7 | 9.6 | * |
| 18:1 *n*-9 oleic | 23.4 | 21.6 | 17.4 | 20.7 | ** |
| 18:2 *n*-6 linoleic | 11.4 | 10.1 | 8.4 | 9.2 | * |
| 18:3 *n*-3 ∝-linolenic | 2.1 | 4.3 | 2.4 | 3.5 | *** |
| 20:4 *n*-6 arachidonic | 5.1 | 4.5 | 3.0 | 3.9 | *** |
| 20:5 *n*-3 EPA | 2.3 | 3.5 | 4.9 | 3.6 | *** |
| 22:6 *n*-3 DHA | 0.55 | 0.63 | 1.08 | 1.22 | *** |
| Aroma volatiles[2] | | | | | |
| Heptenal | - | 14 | 8 | 11 | NS |
| Octenal | 3 | 10 | 7 | 11 | * |
| Nonenal | 21 | 69 | 44 | 78 | * |
| Decenal | 41 | 99 | 58 | 108 | * |
| Taste panel scores[3] (1-8) | | | | | |
| Beef flavour | 3.8 | 3.8 | 3.5 | 3.8 | NS |
| Abnormal flavour | 2.8 | 2.9 | 3.2 | 2.9 | NS |
| Flavour liking | 4.4 | 4.5 | 4.2 | 4.7 | NS |
| Overall liking | 4.4 | 4.5 | 3.9 | 4.6 | *** |
| Flavour descriptors (0-100) | | | | | |
| Fatty/greasy | 15.7 | 17.6 | 19.3 | 17.9 | NS |
| Bloody | 13.2 | 10.5 | 13.0 | 10.0 | NS |
| Livery | 14.2 | 13.1 | 16.7 | 15.6 | NS |
| Rancid | 1.7 | 0.6 | 2.3 | 1.1 | * |
| Fishy | 5.0 | 4.4 | 8.9 | 4.4 | *** |

[1] Scollan *et al* (2001) [2] Elmore *et al* (1999) [3] Vatansever *et al* (2000)

The effects of the diets on flavour of beef sirloin steaks as determined by the taste panel are also shown in Table 7. The overall effects determined using 1-8 intensity scales show only small differences, although there is a tendency to lower beef flavour and higher abnormal flavour in the Fish oil group. The panel also scored flavour liking slightly lower in the Fish oil group and overall liking significantly lower. Although the differences were relatively small, the detailed descriptive terms also indicated that the Fish oil diet produced undesirable flavours, e.g. rancid and fishy. In contrast the Linseed and Linseed/Fish oil diets produced acceptable flavours in comparison with the control Megalac group.

Although the flavour differences between treatments were not numerically large, they consistently point to poorer flavour in the Fish oil group, associated with higher lipid oxidation. The clearest demonstration of this was the lipid oxidation results (Figure 2) which showed that the Fish oil samples had TBARS values of about 1.5 in sirloin steaks after 8 days of retail display. This is a level of oxidation that would be detected as rancid by taste panelists and possibly by consumers (Younathan and Watts, 1959). The fatty acid results in Table 7 do not provide a clear explanation for this effect since they reveal only small differences between treatments in n-3 PUFA concentrations. For example, DHA was similar in Fish oil and Linseed/Fish. However, the percentage of total n-3 PUFA, including fatty acids not shown in Table 7 was much higher in the Fish oil samples, 14.6% versus 11% in Linseed/Fish. A further observation was that the vitamin E concentration in minced forequarter muscles was significantly lower in the Fish oil group, being 6.9, 6.5, 5.7 and 6.4mg/kg in Megalac, Linseed, Fish oil and Linseed/Fish oil respectively. These results show that vitamin E was utilized *in vivo* to combat lipid oxidation in muscles of the Fish oil group.

Figure 2. Lipid oxidation in sirloin steaks from cattle given different dietary oil sources (Vatensever *et al*., 2000)




Several studies with cattle have examined the differences in flavour between those fed on a grass or forage diet and those fed on a grain-based (Concentrate) diet. In many countries it is recognized that grass/forage-feeding has the potential to reduce costs and the image of "extensively" rather than "intensively" produced meat is more attractive to consumers. In many papers published in the USA however, the conclusion is that grass feeding produces less desirable-flavoured beef (Harrison *et al*., 1978;Schroeder *et al*., 1980;Mederios *et al*., 1987;Berry *et al*., 1988 ;Larick and Turner, 1990). Typical results, those of Schroeder *et al*. (1990) are in Table 8. Steers were grazed on pastures consisting of native range, forage sorghum and crested wheatgrass for 4 months. Some were then slaughtered (treatments 2, 3 and 4) and some were then fed for 104 days in a feedlot on a flaked corn and corn silage diet (treatments 1 and 5). After slaughter, carcasses were aged for 5d. Steaks from the 9-12 rib section were used for shelf life studies after trimming to 0.6cm external fat. They were wrapped in oxygen-permeable film and displayed at 3ºC in retail display conditions. Off-

odours were determined at 5d of display. Steaks for sensory testing were frozen at –20ºC before analysis. They were then broiled on an open-top electric broiler unit to 71ºC internal temperature and evaluated by an 8-member trained sensory panel using 1-8 point hedonic (liking) scales.

Table 8. Effect of different forage and concentrate feeding treatments on meat and eating quality in steers (Schroeder *et al*. 1980).

| | Concentrate | Pasture groups | | | Concentrate |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Hot carcass weight | 313.4[b] | 182.6[a] | 182.1[a] | 181.9[a] | 306.3[b] |
| Lipid percent in *longissimus* | 3.3[b] | 2.6[ab] | 2.7[ab] | 1.0[a] | 4.5[b] |
| Meat odour (5d)[1] | 4.0[c] | 2.5[a] | 3.3[b] | 2.3[a] | 4.0[c] |
| Lean colour (5d)[2] | 5.0[c] | 1.4[a] | 3.2[b] | 1.3[a] | 5.2[c] |
| Juiciness | 5.5[bc] | 5.1[ab] | 5.0[ab] | 4.9[a] | 5.7[c] |
| Beef flavour | 5.7[b] | 4.8[a] | 4.4[a] | 4.3[a] | 5.6[b] |
| Tenderness | 5.3[b] | 4.2[a] | 3.4[a] | 3.4[a] | 5.6[b] |

[1]4=no detectable odour 1=extremely detectable. [2]7=no discolouration, 1=>90% surface discolouration

Means with different superscripts are significantly different (P<0.05)

Results in Table 8 show that the concentrate-fed groups had higher juiciness, tenderness and flavour. These steaks discoloured less during retail display and less odour was detectable at 5d of display. A finding which is very typical of US studies of this type was that the carcass weights of the pasture-fed groups were lower, as was marbling fat as determined by the lipid

content of *longissimus*. Another important factor is that forage feeding in US studies usually means grazing of extensive unimproved ranges at low stocking densities.The nutrient value of these forages would be lower than typical British grasslands.

Bidner *et al*. (1986) compared forage and concentrate fed cattle reared to the same carcass weight. Although darker muscle colour and yellower fat were detected in the forage group, there were no differences in tenderness, juiciness or beef flavour. Melton (1990) concluded in a review that lower fatness, especially marbling fat in forage-fed cattle, associated with lower carcass weights and slower growth was an important factor in the lower sensory scores of these animals. This provides further evidence that fatness itself is an important factor in beef flavour development. In the case of underfinished grass-fed cattle, a high proportion of phospholipid in marbling fat, with its unsaturated fatty acids, could lead to rancidity as in the study of Schroeder *et al*. (1980) (Table 8).

In recent research involving University of Bristol, IGER and University of Reading we have examined the flavour characteristics of beef cattle fed an all-concentrate or an all-grass diet from 6 months to 14, 19 or 24 months.These are the steers shown in Table 1 and Figure 1. The concentrate contained 60% barley and 12.5% full fat-soyabean meal. Perennial ryegrass was used to produce the silage. There were 2 breeds, Aberdeen Angus cross and Holstein-Friesian. Differences in growth rate between the diets within breed were avoided by reducing the feed intakes of the concentrate-fed cattle so their growth rate was similar to those fed the silage. All results are given by Warren (2004) and Warren *et al*. (2005a and 2005b). Some information for the 19-month slaughter groups which weighed around 500kg at slaughter are given in Table 9. The fatty acid composition of muscle neutral lipid and phospholipid was quite different between the diets, especially the n-6 and n-3 PUFA. The concentrate diet

produced 3-fold higher concentrations of 18:2 n-6 in neutral lipid and phospholipid. The grass silage diet produced 2-fold higher concentrations of 18:3 n-3 in neutral lipid and 5-fold higher concentrations in phospholipid. The grass silage diet increased the concentration of EPA, a long chain n-3 fatty acid, to a level similar to that seen for Linseed (Table 7). The concentration of DHA was higher for grass silage than Linseed.

The results for sensory characteristics in Table 9, including flavour descriptive terms, were fairly similar between the diets and breeds. There was no evidence of "less desirable" flavours in the grass silage diet as has been reported in US studies (e.g. Table 6). On the contrary, beef flavour was significantly higher in Aberdeen Angus fed the silage diet, with a similar trend in Holstein-Friesian. Abnormal flavour was significantly lower in both grass-fed groups within breed. There was a trend for overall liking to be higher in the grass-fed groups and no evidence that rancidity was higher as shown in the US studies (Table 6). These results can possibly be explained by the high values of vitamin E in the grass-fed cattle which significantly reduced lipid oxidation measured by TBARS during retail display.

A further factor in comparisons across countries is that consumers and taste panelists will often respond positively to the flavours they expect and may react adversely to unusual flavours coming from a different production system. We found this in a comparison of British and Spanish lamb (Sanudo et al, 2000). British taste panelists preferred the flavour of British grass-fed lamb and Spanish panelists preferred the flavour of Spanish grain – fed lamb.

Table 9. Fatty acid composition of *longissimus* neutral lipid and phospholipid and taste panel scores in Aberdeen Angus cross and Holstein-Friesian steers reared on a concentrate or grass silage diet from 6 to 19 months of age (Warren, 2004).

| | Aberdeen Angus | | Holstein-Friesian | |
|---|---|---|---|---|
| | Concentrate | Silage | Concentrate | Silage |
| Neutral Lipid | | | | |
| 18:0 | 14.2[b] | 11.5[a] | 14.1[b] | 12.0[a] |
| 18:1 *n*-9 | 36.1 | 37.3 | 36.1 | 39.1 |
| 18:1 trans | 3.3[b] | 1.0[a] | 3.1[b] | 1.2[a] |
| 18:2 *n*-6 | 2.3[b] | 0.6[a] | 2.5[b] | 0.8[a] |
| 18:3 *n*-3 | 0.2[a] | 0.4[b] | 0.2[a] | 0.5[c] |
| Phospholipid | | | | |
| 18:0 | 10.8 | 10.8 | 11.2 | 11.1 |
| 18:1 *n*-9 | 16.0[a] | 26.7[b] | 13.2[a] | 24.9[b] |
| 18:2 *n*-6 | 23.0[b] | 6.2[a] | 25.3[b] | 8.3[a] |
| 18:3 *n*-3 | 0.6[a] | 3.4[b] | 0.6[a] | 3.8[b] |
| 20:4 *n*-6 | 10.4[b] | 4.5[a] | 11.4[b] | 5.2[a] |
| 20:5 *n*-3 | 0.4[a] | 2.9[b] | 0.4[a] | 3.4[c] |
| 22:6 *n*-3 | 0.08[a] | 0.75[b] | 0.09[a] | 1.14[b] |
| Lipid oxidaton[1] | 3.6[b] | 0.4[a] | 4.0[b] | 0.6[a] |
| Vitamin E[2] | 1.4[a] | 3.3[b] | 1.3[a] | 3.1[b] |
| Taste panel scores (1-100) | | | | |
| Juiciness | 30.8 | 30.0 | 32.1 | 27.9 |
| Toughness | 42.6 | 42.1 | 38.8 | 39.3 |
| Beef flavour | 25.2[a] | 30.0[b] | 21.3[a] | 25.2[a] |
| Abnormal flavour | 17.0[b] | 9.7[a] | 22.1[c] | 13.2[ab] |
| Bloody | 5.1 | 4.1 | 5.6 | 5.3 |
| Dairy | 4.7 | 5.0 | 6.2 | 4.5 |
| Fishy | 1.9 | 1.6 | 1.6 | 1.4 |
| Livery | 7.4 | 7.6 | 6.6 | 11.1 |
| Rancid | 1.9 | 1.0 | 3.2 | 2.5 |
| Overall liking | 16.3 | 21.6 | 16.3 | 18.7 |

[1]TBARS, mg malonaldehyde/kg meat [2]mg/kg meat.
Means with different superscripts are significantly different ($P<0.05$)

Elmore *et al*. (2004) have studied the flavour volatile compounds in the cattle described in Table 9. Following a grilling cooking procedure, they captured the volatile compounds at 60ºC in a waterbath on Tenax. Elmore *et al*. (2004) identified 69 compounds with concentrations >5mg/100g, 23hydrocarbons, 12 alcohols, 11 ketones, 11 aldehydes, 4 nitrogen-containing compounds, 3 sulphur-containing compounds, 2 furans, 2 esters and 1 ether. Of these, 22 compounds were affected by diet. Most of these (17) were higher on the concentrate diet. These included various aldehydes (pentenal, hexenal, heptenal, octenal and alcohols (1-octen-3-ol, cis-2-octen-1-ol), previously reported as oxidation products of 18:2 n-6. Of the compounds that were significantly higher on the grass silage diet, 2 were reported products of 18:3 (1-penten-3-ol and cis-2-penten-1-ol) and 2 have been reported by other workers as higher after grass feeding, 1-phytene and 2-phytene (Larick and Turner 1990). These compounds are formed from the phytol moiety of chlorophyll. Watanabe *et al*. (2004) have suggested that phytenes are good markers for 'pastoral flavour' and have proposed a rapid detection method. In their work, phytene levels declined to an undetectable level 5 months after the beginning of concentrate feeding (following grazing).

Grass feeding affects other constituents in the animal, among which is 3-methyl indole (skatole) (Young *et al*., 1997). This is produced by rumen fermentation and reaches high levels in fat tissues of cattle fed fresh pasture In the research described in Table 7 a group of cattle was fed fresh grass between 14 and 19 months. Their muscle tissue contained high levels of skatole and their scores for beef flavour exceeded those of the 19 month grass silage group.

There have been few studies of different grassland types although recent work between IGER and Bristol University has shown differences between red and white clover and between clovers and ryegrass with regard to lipid oxidation. We have recently compared maize silage

and grass silage and found differences in fatty acid composition (grass silage produced higher n-3 fatty acid levels in beef). These differences may follow through to differences in flavour.

In conclusion, diet is a major factor in flavour variation through its effects on the total amount of fat, the profile of fatty acids and the levels of flavour precursors such as skatole. Antioxidant status, particularly vitamin E concentration, is important, especially at low fat levels when the concentrations of polyunsaturated fatty acids are high. For British consumers, grass-fed beef having the fatty acid profile of silage-fed Aberdeen Angus cross steers described in table 9 seems ideal.

Several reports have suggested that the n-3 fatty acids are important flavour precursors, whether derived from grass or linseed. Use of linseed to increase the healthiness and flavour of concentrate-fed beef is presently being examined by several groups in Britain and elsewhere.

In most of the work reviewed, dietary effects have been investigated in the "finishing" period when fat deposition is greatest. It seems logical that effects due to fatty acid composition would have their greatest impact at this stage. Flavour compounds can presumably also be introduced earlier in growth and their impact will then depend on dilution with compounds such as fatty acids introduced later.

**Muscle effects on beef flavour**

Muscles in the body differ in fat and fatty acid content, collagen content, pH characteristics, muscle fibre types and antioxidant levels. They also differ in sensory characteristics especially tenderness. Three comprehensive studies have examined flavour differences between muscles. McKeith *et al*. (1985) examined 13 muscles from 10 Angus steers. Steaks were broiled to 70ºC internal temperature and evaluated by a trained taste panel using 1-8

scales. Carmack *et al*. (1995) evaluated 8 muscles from 8 steer carcasses. Steaks were evaluated on 1-10 scales after grilling. Jeremiah *et al*. (2003) examined 33 muscles from Canadian Aberdeen Angus steers. Joints were roasted to 72ºC and evaluated by a trained taste panel using 1-9 scales.

All these studies showed that beef flavour desirability (liking) was affected by muscle. However, the range of scores, from least to most desirable flavour or least to most intense beef flavour, was much less than for tenderness evaluated on the same muscles. For example, in the study of Jeremiah *et al*. (2003) in 33 muscles using 1-9 scales, tenderness ranged from 3-7, flavour intensity from 5-6 and flavour desirability from 4-6. All the studies ranked *Psoas major* (tenderloin) highly for flavour intensity and desirability and *Semitendinosus* (silverside) had low flavour scores. For the other muscles however, the ranking differed between the studies, probably reflecting the small differences between muscles. The large study of Jeremiah *et al*. (2003) showed that several muscles scored differently for flavour intensity and flavour desirability. For example *Longissimus thoracis* (rib eye) and *Longissimus lumborum* (sirloin) had low flavour intensity but high flavour desirability scores. *Biceps femoris* (*Gluteobiceps*, silverside*)* and *Serratus ventralis* (chuck) had high flavour intensity but low flavour desirability. There was no apparent correlation between flavour score and muscle fibre type based on the histochemical study of Totland and Kryvi (1991). High flavour intensity was apparent in both the red *Psoas* and the white *Gluteobiceps*. Low flavour intensity was recorded in the white *Semitendinosus* and the red *Supraspinatus* (Carmack *et al*., 1995).

Muscles therefore differ intrinsically in flavour characteristics and their different compositions means they will probably respond differently to processing treatments.

**Pre-slaughter handling effects on beef flavour**

If cattle are put under stress in the period between the farm and abattoir, they may produce dark, firm, dry (DFD) beef. This is because muscle glycogen stores are mobilised by stress hormones, leaving a low concentration of glycogen in muscle at slaughter and a correspondingly low fall in muscle pH post mortem. Muscle pH in *m.longissimus* 48hr after slaughter (ultimate pH) is typically 5.5 in normal cattle and above 6.0 in DFD muscles. The problem of DFD beef is much more common in bulls than in steers or heifers (Purchas, 1991).

As ultimate pH increases, the desirable flavours associated with cooked beef tend to decline (Dransfield, 1981). This probably occurs because the concentrations of sugars and sugar phosphates are at very low levels in DFD beef, giving fewer substrates for Maillard reactions between sugars and amino groups. In one study involving stressed and unstressed cattle, ultimate pH ranged from 5.4 to 6.7. The correlation between flavour liking score and pH varied between 9 taste panellists from 0.17 to-0.75, but in 8 out of the 9 panellists there was a significant negative correlation (Dransfield, 1981).

The conclusion that desirable flavours are reduced at high pH values caused by pre-slaughter stress was also reached in a study in pigs by Dransfield *et al*. 1985. Stressful transport conditions produced a wide range of muscle pH values in loin muscles which were then evaluated by the taste panel. Three groups were identified, based on muscle pH i.e. <5.8, 5.8-6.1 and >6.1. The percentage of "foreign" flavours identified by the taste panel increased from 5 in the low pH group to 11 in the high pH group. Byrne *et al*. (2001) showed that the higher water content of muscle in animals with high ultimate pH was an important factor in

their reduced flavour intensity. Mottram (1998) noted that Maillard reactions are less active when the water content of beef is high.

**Processing effects on beef flavour**

Some processes applied in the abattoir could change concentrations of flavour compounds and precursors e.g. sugars, proteins and lipid breakdown products. Processes that might be expected to influence beef flavour are electrical stimulation, ageing/conditioning, marination, use of microbial decontamination treatments, packaging type and cooking. In particular, electrical stimulation and ageing/conditioning might be expected to influence flavour development.

Electrical stimulation

Electrical stimulation (ES) was developed as a way to prevent cold-induced toughening in beef and lamb (Cross, 1979). This toughening is directly linked to muscle contractions which shorten the muscle under the influence of chiller temperatures (0-2ºC), and particularly when rapid chilling is used to reduce evaporative weight loss and prevent microbial spoilage. The success of ES in tenderising beef and lamb, even in the absence of rapid chilling, shows that preventing muscles from shortening is a major factor in obtaining tender meat.

Electrical stimulation speeds up muscle pH fall and depletes muscle energy reserves. By changing concentrations of sugars and nucleotides this would be expected to influence eventual flavour. However, although there is disagreement in the literature on this, the consensus view is that the effects of ES are small. Taylor *et al*. (1981), Crouse *et al*. (1983) and Cross *et al*. (1984) showed no effects of ES on beef flavour, whereas Savell *et al*. (1979)

showed an improvement. They examined 8 cattle carcasses with one side being electrically stimulated (440v) within 1hr of slaughter. Carcass were butchered at 24hr and loin steaks removed for freezing (-34ºC) prior to sensory evaluation. Steaks were cooked (broiled) to an internal temperature of 70ºC and evaluated by the taste panel using 1-8 scales. The results (Table 10) show that ES improved tenderness by 1.3 units and flavour desirability by 0.7 units.

Table 10. Tenderness and flavour desirability (1-8 scales) of sirloin steaks from electrically stimulated carcass and non-stimulated controls (Savell *et al*, 1979).

| | **ES** | **Non-ES** | |
|---|---|---|---|
| Tenderness | 5.6 | 4.3 | P<0.001 |
| Flavour liking | 5.8 | 5.1 | P<0.002 |

Ageing/Conditioning

Prolonging the period during which meat is held at 1ºC between butchery and retail sale, termed ageing or conditioning, is an important way to increase tenderness, especially in beef. It is probably the single most important factor controlling tenderness and the literature shows that it also affects flavour.

Spanier *et al*. (1990 and 1997) showed that ageing results in increased concentrations of compounds in meat which contribute to flavour. These include sugars, peptides, free amino acids and fatty acids. In their 1997 study, muscles were aged in vacuum packs for up to 14 days and were then used to produce patties. These were evaluated by a 12-person trained

taste panel using 1-15 point scales after grilling to a medium/well done state. As conditioning time increased, levels of descriptors associated with desirable beef flavour declined (beef, brothy, sweet) and those associated with undesirable flavours (painty, cardboard, bitter) increased. These positive and negative scores were strongly correlated showing that the changes were consistent. Changes in flavour were linked particularly with amino acids and peptides produced by proteolytic breakdown of muscle fibres. Lipid oxidation products were not contributors to flavours since no oxidation had occurred in the vacuum-packed beef. Jeremiah and Gibson (2003) examined different techniques for ageing beef, from carcass (dry) ageing, bone-in and bone-less vacuum packing and ageing in modified atmosphere packs. Wholesale ribs and short loins were examined and after ageing steaks were cut and grilled to 73ºC internal temperature and then evaluated on 1-9 scales. Pooled results for all ageing treatments are in Table 11.

Jeremiah and Gibson (2003) concluded that although some "inappropriate" flavour notes increased with ageing, the overall appreciation of flavour by the taste panel improved. Of the treatments studied, bone-in vacuum packed beef produced the highest beef flavour intensity. Gorraiz *et al*. (2002) also found that beef aged in vacuum packs for 7 days increased in 'characteristic' flavour intensity through the period. This was associated with increased concentrations of hydrocarbons detected by head space analysis. Some of these were said to be lipid oxidation products although other studies show these are low in vacuum packed meat (Spanier *et al*., 1997).

Table 11. Effects of various ageing treatments on beef flavour in loin steaks (1-9 scale) Jeremiah and Gibson (2003)

| | Weeks ageing | | |
|---|---|---|---|
| | 0 | 4 | sig |
| Beef flavour intensity | 6.61 | 7.03 | * |
| Flavour desirability | 6.28 | 6.77 | * |
| Livery aroma | 0.74 | 1.11 | * |
| Livery taste | 0.46 | 0.70 | * |
| Tenderness | 5.3 | 7.2 | * |

*P<0.05

Campbell *et al*. (2001) compared vacuum packed (wet) ageing with unpacked (dry) ageing and found few significant differences in flavour. However, Warren and Kastner (1992), in a comprehensive study, showed small but consistent effects in favour of dry ageing on positive flavour descriptors given by the taste panel. In this study, 8 US Choice or better striploins were vacuum-packed or not packed and aged at 3ºC for 11 days, following butchery at 3 days. Steaks were broiled on a grill to 70ºC internal temperature. Seven panellists used 1-10 scales and produced the results shown in Table 12.

Table 12. Effects of wet and dry ageing for 11 days on flavour of loin steaks (1-10 scales) (Warren and Kastner, 1992)

| | | Aged | |
|---|---|---|---|
| | Unaged | Wet | Dry |
| Beefy | 5.71[a] | 5.64[a] | 5.98[b] |
| Bloody/Serumy | 3.51[a] | 3.91[b] | 3.19a |
| Brown/Roasted | 5.04[a] | 4.74[a] | 6.01[b] |
| Metallic | 2.31[ab] | 2.50[a] | 2.18[b] |
| Sour | 2.63[a] | 2.96[b] | 2.58[a] |
| Tenderness | 5.84[a] | 6.96[b] | 6.81[b] |
| Ageing weight loss (%) | | 0.08[a] | 13.65[b] |
| Frequency of "other flavours" (%) | | | |
| Lean | 5.0 | 30.0 | 32.5 |
| Fat | 25.0 | 32.5 | 57.8 |

Means with different superscripts are significantly different ($P<0.05$)

The results in Table 12 again confirm the large effect of ageing on tenderness, against which the effects on flavour seem relatively small. Descriptors associated positively with beef flavour, i.e. beefy and brown/roasted were higher in the dry-aged treatment and descriptors associated negatively with beef flavour, i.e. metallic and sour were lower. However, this generally desirable effect of dry ageing on flavour has to be set against the much larger weight loss occurring during ageing in air (0.08 versus 13.65%).

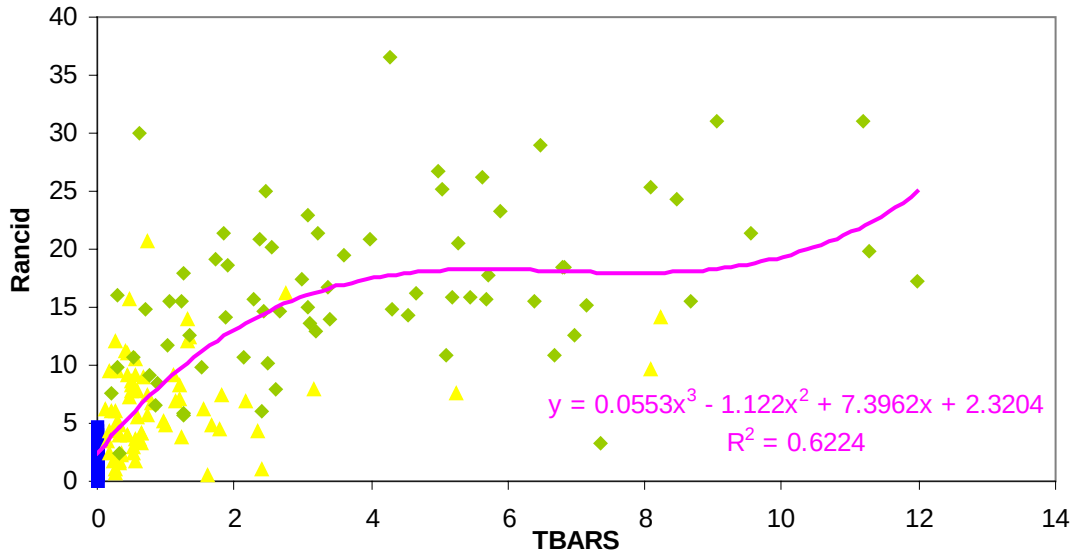
In Britain a range of meat products launched recently by Sainsburys uses dry ageing for 21 days to increase sensory quality. The conditions under which the ageing is performed is thought to be crucial in producing a well-flavoured product. Low water activity in meat

accelerates flavour formation from Maillard reactions during cooking (Mottram, 1988). It seems that an optimum balance between Maillard reaction products and lipid oxidation products has been achieved.

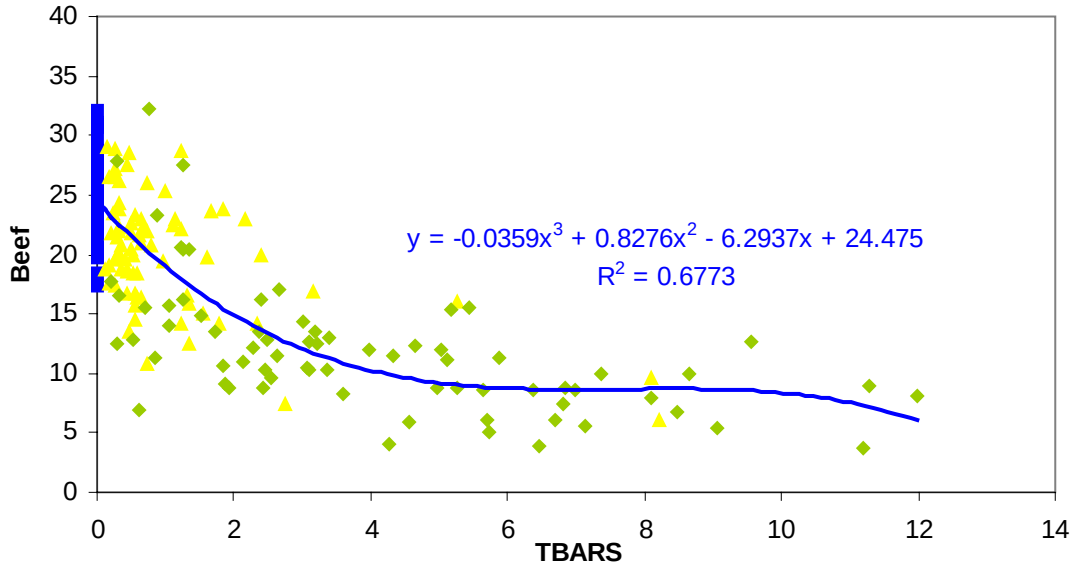
Spanier *et al*. (1997) noted that lipid oxidation products and descriptors associated with these (e.g. odour and flavour rancidity) were low after ageing in vacuum packs. On the other hand, Warren and Kastner (1992) observed that "other flavours" associated with fat increased considerably during dry ageing. This is due to the greater lipid oxidation which occurs under aerobic conditions. Extreme lipid oxidation produced very undesirable flavour responses in a study by Campo *et al*. 2004. Loin joints from 73 animals, representing several experiments in which different diets were fed, were aged in vacuum packs for 10 days, cut into steaks and then frozen. After thawing they were then displayed in modified atmosphere packs ($0_2$:$CO_2$ 75:25) for 0, 4 or 9 days at 4ºC and 700 lux to simulate retail conditions. These treatments, combining conditioning, freezing, thawing and display under aerobic conditions produced a wide variation in lipid oxidation measured as thiobarbituric acid reacting substances (TBARS). Variation was associated with the diets fed and the resulting fatty acid composition of the muscle lipid. Controls had relatively saturated fat and cattle fed protected fish oils had very unsaturated fat, which elicited a high degree of lipid oxidation. In our experience, TBARS values of above 2.0 are uncommon, but some of these samples had values >10.0. The results (Figure 3) show that rancid flavour intensity increased with high lipid oxidation and beef flavour declined. The correlation between rancid flavour score and beef flavour score was -0.79 and the TBARS value where rancid flavour overpowered beef flavour was 2.3, similar to the figure suggested by Younathan and Watts (1959) as a threshold value for consumer acceptability.

Figure 3. Relationships between rancid flavour (a) and beef flavour (b) in relation to lipid oxidation (TBARS) in packaged and displayed beef. (Campo *et al.*, 2004)

(a)




(b)



The undesirable effects on beef flavour of ageing treatments which increase exposure to oxygen were shown in a study by Torngren (2003). Loins were aged for 16 days at 2$^{o}$C in vacuum packs or in modified atmosphere packs containing 80% $O_2$: 20% $CO_2$. They were then displayed under retail conditions packed in oxygen-permeable film or in the same modified atmosphere as used during ageing. Steaks aged and displayed in the high oxygen environments showed significantly increased off-flavour and warmed over flavour and reduced beef flavour when evaluated by the trained taste panel.

Marinades

Marinade solutions, injected into beef cuts at the processing stage, have been used primarily to improve tenderness and juiciness. Calcium salts are effective, probably because they activate the calpain enzymes which break down the structure of muscle fibres during the tenderization process. However, the use of calcium chloride in early work, although greatly improving tenderness, introduced off-flavours including bitter, metallic and livery (Wheeler *et al*., 1993). Lawrence *et al*. (2003a) examined different calcium salts at different concentrations injected into sirloin strips to determine whether optimum tenderness/flavour could be obtained. They found that calcium chloride and calcium lactate reduced beef flavour intensity, partly due to an enhancement of lipid oxidation. Calcium ascorbate reduced lipid oxidation but at high concentrations (0.3M), reduced beef flavour intensity and increased abnormal flavours, presumably explained by the effect of calcium itself. In further work, Lawrence *et al*. (2003b) investigated the combined use of calcium lactate and a salt-phosphate solution to increase both tenderness and meat yield. This did not produce the marked off-flavours associated with calcium chloride, but flavour in sirloin steaks tended to be reduced by phosphate. Robbins *et al*. (2003) examined the use of a sodium chloride/sodium polyphosphate solution to increase yield, tenderness and flavour of

marinaded beef held hot in a food service situation. This "enhanced" treatment significantly increased tenderness and improved flavour in roasted clod joints, compared with controls (Table 13). The research showed that holding beef at a high temperature in a food service situation for up to 2 hours gradually reduced beef flavour intensity and increased off-flavours as lipid oxidation proceeded.

Table 13. Effect of a marinade containing 0.4% sodium chloride and 0.4% sodium tripolyphosphate on eating quality of beef clod roasts (0-15 scales) (Robbins *et al*., 2003)

| | Control | Treated |
|---|---|---|
| Tenderness | $9.2^{b}$ | $11.5^{a}$ |
| Beef flavour | $7.6^{b}$ | $9.0^{c}$ |
| Off-flavour | $0.8^{a}$ | $0.4^{b}$ |
| Aroma: | | |
| Beefy/brothy | 6.2 | 6.4 |
| Grainy | 1.9 | 1.8 |
| Beany/grassy | $2.0^{a}$ | $1.6^{b}$ |
| Cardboard | 0.9 | 0.9 |

Means with different superscripts are significantly different ($P<0.05$).

McGee *et al*. (2003) examined the use of a sodium chloride/sodium tripolyphosphate/sodium lactate marinade solution in inside round steaks. This treatment also improved flavour and aroma characteristics compared with controls.

Irradiation

Irradiation is not used in Britain , however it is an effective antimicrobial treatment for meat, which also initiates lipid oxidation and leads to off-odours and off-flavours such as rancid, metallic, sweet, stale and acidic (Risvik, 1986). Coleby *et al*. (1961) showed that beef was particularly sensitive to the development of irradiation off-flavours compared with other meats. These undesirable consequences of irradiation were recently confirmed by Montgomery *et al*. (2003) in ground beef patties irradiated at a level of 2kGy.

Formanek *et al*. (2003) examined the use of antioxidants to counteract these undesirable effects of irradiation. Vitamin E fed to cattle during growth and rosemary extracts used at the processing stage were effective in protecting lipids against oxidation and maintaining flavour characteristics.

Retail display conditions

Display in retail conditions quickly leads to oxidation and deterioration in colour and flavour/odour characteristics in certain beef products unless special steps are taken, e.g. changes to packaging and control over lighting and temperature. For example, Jimenez-Villarreal *et al*. (2003) showed that ground beef wrapped in an oxygen-permeable film on styrofoam trays showed colour deterioration at 1 day of display and significant appearance of off-odours at 3 days. Ground beef has an increased surface area for oxidative attack and iron and other pro-oxidants are dispersed widely.

Modified atmosphere packs containing high levels of oxygen (75 or 80%) preserve the red colour of oxymyoglobin but accelerate lipid oxygen and can lead to off-flavours. In a study by Torngren (2003) retail display in 80% $O_2$: 20% $CO_2$ increased warmed over flavour and off-flavour in comparison with an oxygen-permeable wrap. This retail display in high $O_2$

was particularly detrimental to beef flavour when combined with ageing/conditioning in the same atmosphere. Sorheim *et al* (2004) also observed that a high $O_2$ display atmosphere increased the taste panel score for rancid taste and odour.

Djenane *et al*. (2003) examined several methods to improve the shelf life of sirloin steaks including modified atmosphere packaging, surface spraying with the antioxidants rosemary oil and vitamin C and use of different lighting conditions. They showed that fluorescent light in the ultra violet range was most deleterious to lipid oxidation and the development of off-odours which appeared between 5 and 10 days of display. Use of non-ultra violet light and the antioxidant treatments reduced off-odours to the level found in steaks kept in the dark.

Cooking

As the final internal temperature of the beef steak, roast or hamburger patty increases and it progresses from a rare to a well-done state, the intensities of tenderness and juiciness decline (Parrish *et al*. 1973; Cross *et al*., 1976; Kregel *et al*. 1986). In research on pork we observed the same effects of final internal temperature on tenderness and juiciness in loin steaks and leg roasts (Wood *et al*. 1995). In our research and that of others, pork flavour intensity increased and abnormal flavour intensity decreased as final internal temperature increased across a similar temperature range. However, in beef, the concensus is that increasing final internal temperature has very little effect on flavour intensity or flavour liking (Parrish *et al*. 1973; Cross *et al.* 1976). Results of the study of Cross *et al*. (1976) are in Table 14. Loin joints from 8 carcasses were aged for 3 days. Steaks were oven-roasted to 4 internal temperatures (60, 70, 80 and 90ºC) and evaluated by a 7-member taste-panel using 1-9 scales. As internal temperature increased, tenderness and juiciness declined markedly, flavour intensity remained constant and flavour acceptability declined slightly.

Mottram (1985) showed that cooking to a high internal temperature in pork markedly increased the concentrations of heterocyclic compounds in headspace volatiles. Particularly noticeable were pyrazines with low odour thresholds, producing roasted and nutty characters. At lower temperatures, lipid oxidation products such as aldehydes and ketones predominated. We have observed (Nute, personal communication) that the surface of beef often appears moist during grilling even at high temperatures. This would be expected to limit Maillard reactions and the production of compounds such as pyrazines.

Table 14. Effects of final internal temperature during roasting on eating quality of sirloin steaks (1-9 scales). (Cross *et al* 1976)

| | Final internal temperature (ºC) | | | |
|---|---|---|---|---|
| | 60 | 70 | 80 | 90 |
| Tenderness | $5.8^{b}$ | $5.3^{c}$ | $4.6^{d}$ | $4.4^{d}$ |
| Juiciness | $6.4^{b}$ | $5.0^{c}$ | $3.3^{d}$ | $2.3^{e}$ |
| Flavour intensity | $6.0^{b}$ | $5.8^{b}$ | $5.8^{b}$ | $5.9^{b}$ |
| Flavour acceptability | $6.4^{b}$ | $6.1^{c}$ | $5.8^{cd}$ | $5.9^{d}$ |

Conclusions

Processing can therefore have important effects on the eventual flavour of beef. Ageing/conditioning and retail display conditions are important factors and excessive lipid oxidation at these stages is detrimental. Optimum treatments can be established. Use of marinades may increase in the future because of their potential to improve tenderness and flavour simultaneously. At present, however, flavour enhancement is more problematic.

**General conclusions**

The following general conclusions can be drawn based on this review:

Flavour is an increasingly important aspect of the eating quality of beef.

Flavour variation is not as large as that of tenderness but is significant and controllable.

Flavour is influenced by many factors in production and processing. The main factors are:

*Diet*, especially the source of fat and the levels of antioxidants

*Preslaughter stress*. Chronic stress causes off-flavours.

*Gender*, generally poorer flavour in bulls.

*Fat level*. High levels not necessary but low levels may induce fat oxidation.

*Conditioning*. Ageing in vacuum packs avoids fat oxidation and weight loss but benefits of dry ageing have been reported.

*Packaging*. The oxygen atmosphere in the pack is crucial for optimum colour and flavour development. High $O_2$ atmosphere promote lipid oxidation and off-flavours.

*Marinades*. Optimum tenderisation/flavour treatments are needed.

The relative size of the effects of these and the other factors considered in this review is shown in Table 15.

Table 15. Relative size of effects of production and processing factors on beef flavour

| Factors | Size of Effect |
|---|---|
| **Production** | |
| Age | * |
| Breed | * |
| Gender | * * |
| Fat content | * * |
| Diet | * * * * |
| Pre-slaughter handling | * * |
| **Processing** | |
| Electrical stimulation | * |
| Ageing/conditioning | * * * * |
| Marinades | * * |
| Irradiation | Not used |
| Retail display conditions | * * * * |
| Cooking | * * |

A common underlying factor in beef flavour variation is the level of fat oxidation in the meat. Its seems that a certain level of fat oxidation is needed for the development of flavour, especially grass-fed flavour. The unsaturated fatty acids are the substrates for this flavour development. However, excessive fat oxidation caused by some dry ageing treatments, poor temperature control or high oxygen packaging systems leads to undesirable flavours. An interrelated factor is the level of antioxidants in the diet and the meat, especially vitamin E. Undesirable flavours in some situations are related to low supplementation levels, enhanced utilization of vitamin E or a high level of PUFA in relation to vitamin E status. The balance

between Maillard reaction products and lipid oxidation products is crucial for optimum beef flavour.

From a British perspective, the effects of grass feeding are of considerable interest. Oxidation of α-linolenic (18:3) seems important for flavour development and vitamin E levels are high when fresh grass and well-preserved silage are fed. However, supplementation of vitamin E may be necessary in some situations to prevent excessive oxidation. Use of concentrates to supplement grass feeding is important on most farms to promote positive growth in the finishing period to increase tenderness. Supplementation of the concentrate with vitamin E and n-3 PUFA would retain the grass-fed nutritional benefits and reduce extensive fat oxidation.

These production possibilities should be matched with ageing/conditioning treatments and packaging modifications which do not lead to oxidized off-flavours, balancing these with meaty flavours from carbohydrates and proteins.

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