RELATIONSHIPS BETWEEN THE COMPOSITION AND QUALITY OF MEAT

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Summary

Many studies have shown direct effects of carcass composition on meat quality. As the ratio of fat to lean falls, handling and eating aspects of quality tend to decline. In most cases, the effects are small and should not change the direction of lean improvement programmes which accept the strong consumer desire to purchase leaner meat. However, we should increasingly be using production and processing options which improve quality at low fatness, e.g., ad lib feeding, use of certain well muscled breeds (cattle), elimination of halothane gene (pigs), certain diet ingredients, slower cooling, longer conditioning times, and so on.

Some of the production options chosen for producing leaner carcasses have lowered eating quality by more than would be expected from the reduction in fat. Examples are pigs homozygous for the halothane gene and beta-adrenergic agonists. These associated effects on meat quality make the links between composition and quality appear stronger than they actually are.

In certain pig stocks, it is clear that the emphasis should now shift from increasing lean meat yield to improving meat quality.

Introduction

The possible existence of important negative correlations between the lean content of the carcass and the quality of meat is of concern to us all in the animal production industry. Most of us now accept that consumers wish to buy meat containing low levels of fat, and the meat industries of several countries now have major lean improvement programmes in place. However, it is the enjoyment of meat when eaten which will cause consumers to continue purchasing meat at high levels and many studies show that eating quality tends to fall as leaness increases. The balance between composition and quality should therefore be kept under review as the nature of the meat on sale to consumer changes.

In examining recent information on the relationships between carcass composition and meat quality, this paper considers whether some of the quality deteriorations allegedly attributed to increasing lean or reducing fat are actually caused by other factors.

Definitions of meat quality: Which aspects of composition affect quality?

In this paper, meat quality is defined in terms of those characteristics which can be changed by production and processing factors. They fall under the heading 'sensory' and 'functional' aspects described by Foster and Macrae (1992) as being the second priority for consumers when they buy food (the first is for safety, i.e., freedom from harmful ingredients such as food poisoning organisms or drug residues). The most important sensory and functional characteristics, which will form the definition of meat quality in this paper, are shown in Table 1.

Most research studies agree that changes in fatness are more significant for quality variation than changes in leanness. Of the fat deposits, the fat within muscle -- the marbling fat -- is the most critical for eating quality and possible roles for marbling fat are described in Table 2.

Table 1. Components of meat quality in beef, lamb and pork.

Eating quality	The lean meat should be tender and juicy with sufficient flavour to confer a 'good taste.' The levels of abnormal flavours should be low.
Colour	The lean meat should be neither pale nor dark. Fat tissue should be white.
Handling characteristics	The tissues should be firm and adhere well together during butchery and preparation for cooking. High levels of drip are undesirable.

Table 2. The possible roles for marbling fat in controlling the eating quality of meat.

	Role of marbling fat
Tenderness	Dilution of resistant myofibrillar proteins by softer fat reduces shear force. Fat between muscle fibre bundles produces a less rigid structure. Muscle fibre bundles more easily separated during mastication when perimysium contains more fat. Fat produces a smoother 'mouth feel' (especially for processed meats). Fat reduces water loss during cooking.
Juiciness	Fat promotes saliva flow in the mouth and aids in mastication. Juiciness and tenderness are correlated.
Flavour	Flavours result from chemical reactions involving lipids.

From Wood (1991).

Handling characteristics, such as cohesiveness between tissues, are also strongly correlated with the proportion of carcass fat which possibly best describes the stage of development of the tissues. At low levels of fat, the lack of attachment between muscle groups is clearly seen and at high levels of fat, the firmness ('setting') of the meat is greatest.

Associations between composition and quality

Eating quality

The effects of fat on eating quality are more easily demonstrated in processed products such as hamburgers when the range of fat levels is wide than in fresh meat within a narrower range. In ground beef patties, Kregel *et al.* (1986) and Hunt *et al.* (1990) clearly showed reductions in taste panel scores for tenderness and juiciness as fat content was reduced below about 20% lipid. In ground pork patties, Reitmeier and Prusa (1987) found extremely low scores at 4% lipid (juiciness scored 2 on a 0-17 intensity scale). Several comments have been made by retailers and manufacturers during the last few years admitting to the difficulty of retaining taste characteristics in low fat products such as hamburgers and sausages.

Most studies on fresh meat have been conducted with steaks, chops or roasts from the loin region and the muscle sampled is *m. longissimus*. Concentrations of marbling fat (ether-extractable lipid) in *m. longissimus* typically range for 0.5 to 2.5% for pigs and 1 to 7% for cattle, higher figures being reported in the U.S. literature. Recently, attempts have been made to define threshold levels for marbling fat below which eating quality deteriorates and above which no noticeable improvement occurs.

In beef, U.S. studies have concluded that about 3% lipid, equivalent to the 'slight' visual marbling score is the threshold value for eating quality (Campion *et al.*, 1975; Smith *et al.*, 1984; Dikeman, 1987). However, this level is higher than that seen in many European studies in which high scores for eating quality have still been found. In the Danish study of Liboriussen *et al.* (1977), for example, eight breed groups of 12-month old bulls had on average 1.7% lipid with a range of 1.4 to 2.0%. Tenderness, juiciness and flavour scores were approximately 8.0 on the 1 to 10 hedonic scales. In a large study of British and French cattle of mixed sex, Fisher *et al.* (1983) found that at 20% dissected fat in the side (about average for British cattle now), ether-extractable lipid was 2.1% in *m. longissimus*. In a more recent study of young bulls, values of 1% were seen (Fisher *et al.*, 1992b) and it was concluded that factors other than marbling fat were influencing eat quality.

Some results from the National Consumer Retail Beef study in the United States suggest that consumers may well adapt to the 'taste' of low-fat meat in the same way that has been demonstrated for dairy products (Mela, 1990). Consumers in Philadelphia, used to relatively fat meat, gave low satisfaction ratings to highly trimmed cuts whereas consumers in San Francisco, where average fat levels are lower, preferred the trimmed cuts from leaner carcasses (Savell *et al.*, 1989). Perhaps new studies would identify a lower threshold value than the 3% lipid identified previously.

In pork studies conducted in the 1960s and 1970s in the United States and Europe, conflicting conclusions as to the importance of fat in eating quality were drawn (Batcher and Dawson, 1960; Hiner *et al.*, 1965). The clear negative association between production efficiency and costs on the one hand, and carcass fat content on the other, caused European producers to search for production technologies for reducing fat (genetics, nutrition, sex type). The small differences in eating quality in favour of higher backfat or marbling fat levels were judged not to be important in the face of the strong pressure for leaner carcasses (Rhodes, 1970). Cuts were usually presented with skin (crackling) attached, leaving little scope for trimming as in U.S. practice.

More recent studies in Denmark and the United States found stronger relationships between marbling fat concentration and eating quality scores. In the Danish work (Bejerholm and Barton-Gade, 1986), a threshold value of 2.0% total lipid (approximately 1.7% ether-extractable lipid) was identified for optimal tenderness. In the U.S work (De Vol *et al.*, 1988), the threshold level was 2.5 to

3.0% total lipid (2.1 to 2.5% ether-extractable lipid). In contrast to these papers demonstrating positive effects of marbling fat, a Swedish study (Goransson *et al.*, 1992) found no difference between pork steaks having 0.8, 1.2, 1.8, 2.2 and 2.6% total lipid.

Since the early 1970 studies, the concentration of marbling fat has steadily fallen as pig carcasses have become leaner and, at present, is about 0.8% ether-extractable lipid in U.K. pigs (Meat and Livestock Commission, 1989). In other European countries, values are also significantly lower than the 1.7% plus ether-extractable lipid identified as a threshold for eating quality by Bejerholm and Barton-Gade (1986) and De Vol *et al.* (1988). In a study of 'lean' and 'fat' U.K. carcasses (8 and 16 mm P_2 fat thickness), eating quality scores were higher in the fatter carcasses, the mean values for ether-extractable lipid being 0.55 to 0.96 respectively (Table 3). There were significant positive correlations between marbling fat and taste panel scores for tenderness, juiciness and overall acceptability, but the highest of these (juiciness, 0.31) was not strong enough to suggest an important controlling role for marbling fat in eating quality variation. Subsequent work has also found high levels for eating quality in pork steaks having 0.8% ether-extractable lipid (Meat and Livestock Commission, 1989).

Table 3. Eating quality of loin chops in 58kg pig carcasses differing in fat thickness.

	P2 fat thickness (mm)		
	8	*16*	
Consumer panel [a]			
Extremely or very tender	35	37	**
Extremely or very juicy	16	23	***
Extremely or very flavourful	35	35	N S
Taste panel [b]			
Tenderness	1.0	1.1	N S
Juiciness	1.1	1.3	**
Flavour	1.5	1.7	N S
Overall acceptability	0.7	1.0	N S
Marbling fat (%)[c]	0.55	0.96	***

[a] Tests conducted by Meat and Livestock Commission involving 500 families. Values are percentage of chops in the categories shown. Kempster *et al.* (1986).

[b] 12-member Bristol taste panel used the following scores differing in intensity: tenderness, flavour and overall acceptability -7 to +7. Juiciness 0 to 4. Wood *et al.* (1986)

[c] Diethyl-ether extraction of cores of m.longissimus from the last rib position. Wood *et al.* (1986).

Interest in the Duroc breed is mainly connected with its higher natural concentration of marbling fat and the effect of this on eating quality. In a large scale study (Meat and Livestock Commission,1989), taste panel scores for tenderness and juiciness increased steadily as the percentage of Duroc genes in an initially 'white' population increased from 0 to 75 and the concentration of marbling fat from 0.7 to 1.27%.

There is now, therefore, a recognition that eating quality will tend to be reduced in pigs of the Large White and Landrace type as P_2 fat thickness levels fall below about 10mm and marbling fat below about 0.8%. Changes to production and processing regimes which increase eating quality independently of fatness may help to offset the lack of fat, but breeding companies should be wary of making further reductions below these levels.

Handling characteristics

At low levels of fat in the carcass, the fat and muscle tissues do not adhere together so strongly and the carcass lacks firmness. The effects of composition on these 'handling characteristics' are most obvious in pigs (Table 4). Although traditional butchers preparing meat for sale (as in these tests) are likely to be more critical of these aspects than consumers, an independent viewing panel at Bristol gave optimum scores for 'overall visual attractiveness' to loins with an intermediate level of fatness (11mm P_2 fat thickness). Loins below, as well as above this level, were judged less attractive. These carcasses were those described in Table 3 and the butchers conducting the handling tests considered that the leanest carcass (8mm P_2) would have the lowest eating quality.

Table 4. Butchers' assessments of meat quality in 58kg pig carcasses differing in fat thickness (at P2 position, mm).

	Leg			***Loin***		
	8	***12***	***16***	***8***	***12***	***16***
Drip loss (%)	1.8	1.7	1.9	4.8	3.8	3.0
Butchers' assessment[a]						
Much too fat	0	4	16	0	4	39
Much too lean	22	3	1	15	1	0
Fat very firm	3	7	14	3	9	24
Fat very soft	11	4	1	10	2	1
Setting firm or satisfactory	37	64	76	39	72	83
Setting floppy	63	36	23	60	28	17
Separation none	3	13	32	4	16	35
Separation excessive	37	12	7	46	18	11

[a] A panel of 45 butchers assessed 100 carcasses in each fat thickness group. The values are the number of joints in the category shown. From Kempster *et al.* (1986).

Production options for reducing fat: The effects on quality

Genetics

Cattle

Several studies have shown that cattle breeds differing in composition at the same weight have slightly different levels of eating quality, favouring those with the fatter carcasses and higher levels of marbling fat (e.g., Campion *et al.*, 1975). Dairy breeds, such as Friesian and Jersey, have higher concentrations of marbling fat at the same carcass fat content than beef breeds, such as Hereford or Angus (Fisher *et al.*, 1983), and tend to have higher eating quality scores (Moore and Bass, 1978).

In double-muscled cattle, such as the Belgian Blue breed, higher tenderness is possibly caused by a higher ratio of myofibrillar protein to connective tissue (Boccard, 1978). The Piemontese breed also produces relatively tender meat in association with results suggesting reduced connective tissue ('background') toughness (Fisher *et al.*, 1992a).

Recent evidence suggests that part of the genetic effect on tenderness in beef is due to variation in the activity of the proteolytic enzyme system in muscle post-mortem. For example, Brahman (*Bos indicus*) produced tougher meat than Angus-Hereford (*Bos taurus*) steers in association with a higher activity of the inhibitor enzyme calpastatin and a lower activity of the enzyme CDP-1 (Shackleford *et al.*, 1991). Also, in 555 steers of 31 breed types, the heritability of the key calpastatin enzyme was found to be high, 0.70 (Shackleford *et al.*, 1992). However, in two studies examining the causes of genetic variation in beef tenderness, measures of marbling were almost as good predictors as those of proteolysis indicators (Seideman *et al.*, 1987; Shackleford *et al.*, 1991).

Pigs

An important reason for the negative association between leanness and meat quality in pigs is that the recessive halothane gene (ryanodine receptor gene) which causes pale soft exudative (PSE) muscle is closely linked with genes controlling lean content and conformation. That is exemplified by the Pietrain breed which has the advantage of high lean content and thick muscle, but the disadvantage of PSE and other manifestations of the porcine stress syndrome. This is a clear example of a change (deterioration) in meat quality associated with, and not due to, a change in composition.

A recent breakthrough has been the introduction of the DNA test for the halothane gene which allows breeding companies to eliminate the gene from their pig stocks altogether, or to concentrate it into only one of the parent lines. Heterozygotes are then expected to be intermediate between the parent lines for leanness and conformation, but to have a close to zero incidence of PSE. However, some evidence suggests that even in 'halothane-free' lines, muscle quality (colour and drip loss) is still negatively correlated with lean content, albeit at a lower level (Hovenier *et al.*, 1992). Interestingly, the meat quality trait showing the highest correlation with carcass lean content in this Dutch study was marbling fat concentration (r=0.44). In a U.K. comparison of 'white' (Large White x Landrace) pigs from four breeding companies, a broad association with marbling fat was also found, the pigs with the highest marbling fat concentration (0.89) having the highest score for tenderness (5.4 on a scale of 1 to 8, compared with 4.4. to 4.8 for the three other companies) (Meat and Livestock Commission, 1989).

Sex type

Cattle

Entire male cattle (bulls) are considerably leaner than castrates and have the advantage of faster growth and more efficient conversion of feed into meat. However, their meat tends toward greater toughness and a higher ultimate pH which causes a darker colour (Purchas, 1991).

It is generally believed that a major reason for higher toughness in bulls is a greater concentration of collagen in muscle, of which a higher proportion is insoluble even at high cooking temperatures. However, Purchas (1991) has noted the rather small differences between bulls and steers in connective tissue properties in most studies and concluded that an equally important factor is the tendency towards higher ultimate pH values in bulls. The relationship between ultimate pH and toughness is curvilinear, toughness being low at the extremes of the range (5.4 and 7.4) and peaking between 5.8 and 6.2, perhaps because of greater cold shortening.

Pigs

Entire male pigs are also considerably leaner, faster growing and more efficient than castrates and this explains the low level of castration now practised in the U.K. and some other countries. As with bulls, there is some evidence of lower meat quality in entires and again the effects are associated with, rather than due to, the change in composition.

The major concern over meat quality in entires is taints due to high levels of androsterone, skatole or other compounds. Results of U.K. studies have generally shown no differences in eating quality between the sex types except, perhaps, a tendency towards higher 'abnormal odour and flavour' scores in entires (e.g., Meat and Livestock Commission, 1989). These differences were found in taste panel tests, but not detected in consumer trials.

Tests conducted in other countries have sometimes also found no differences between the sex types in eating quality. However, a number have shown lower eating quality in entires especially when skatole and androsterone concentrations exceed the critical concentrations of 0.25 and 1ppm respectively (Bonneau *et al.*, 1992). It has been speculated that differences in breed, carcass weight and cooking method might explain the different conclusions of these studies.

Recent research in Denmark has shown that stocking density and faecal contamination of pigs are major factors explaining variation in skatole concentration (Hansen *et al.*, 1992). Skatole levels in this study were, in general, much higher than those seen in U.K. work (Patterson *et al.*, 1990).

Handling characteristics, such as tissue firmness, decline in entires as in other sex types as fatness is reduced, but even at the same fat thickness, fat tissue in entires is softer because of a higher concentration of linoleic acid (C18:2) in fatty acids and a higher concentration of water (Wood *et al.*, 1989). The higher concentration of connective tissue protein possibly associated with thicker skin seems to be the main cause of this basic difference (Wood *et al.*, 1989).

Feeding/nutritional effects

Feeding level

Feeding at a higher level, i.e., close to *ad libitum*, increases fat deposition and improves tenderness and other aspects of eating quality in cattle and pigs (reviewed by Wood, 1991). Two possible explanations have been suggested for this: high feed intakes promote increased fat deposition including marbling fat; and animals which have deposited muscle rapidly are likely to have high activities of proteolytic enzymes which will tenderise meat more effectively post-mortem (Koohmaraie, 1992). It is possible that both effects operate as Warkup and Kempster (1991) concluded for pigs. However, there is so far no direct evidence that the 'lean growth' effect is directly related to increased post-mortem proteolytic breakdown of myofibrillar proteins.

Beta-adrenergic agonists and somatotropin

Beta-adrenergic agonists mimic the effects of the catecholamine hormones and cause a 'repartitioning' of absorbed nutrients away from fat towards lean disposition. However, there are some detrimental effects on meat quality associated with the production of a leaner carcass.

Two significant findings which have occurred in most studies are greater muscle toughness and an increase in muscle pH (Warriss *et al.*, 1990). There has also been a suggestion of a shift in fibre types towards more white glycolytic fibres which could partly explain both these effects. An alternative (or additional) explanation for the extra toughness is a reduction of proteolytic breakdown in muscle due to inhibition of the enzyme CDP-1 and increased activity of the inhibitor calpastatin (Kretchmar *et al.*, 1990).

Diet ingredients

Certain dietary ingredients can change eating quality particularly in the monogastric pig, but these do not usually affect carcass or meat composition. Examples are:

- oleic acid which can increase tenderness at high levels (Rhee *et al.*, 1990);
- vitamin E which, at high levels, prevents the oxidative breakdown of unsaturated fatty acids and a reduction in pork flavour (Monahan *et al.*, 1992); and
- molassed sugar beef feed which reduces skatole concentrations in backfat and can improve the overall acceptability of eating quality (Longland *et al.*, 1991).

Effects of carcass composition during processing

Processing factors such as chilling rate, electrical stimulation and the period of conditioning, are an important part of 'all round' schemes for improving meat quality (e.g., the 'Blueprint' programmes of the British Meat and Livestock Commission).

It has been suggested that the composition of the carcass modifies the effect of processing factors and specifically that thicker layers of subcutaneous and intermuscular fat will help to retain higher temperatures post-mortem to the benefit of tenderness (Dikeman, 1987). Higher muscle temperatures could prevent cold shortening through a direct effect and by causing a more rapid pH fall and could also increase the activity of proteolytic enzymes.

The effect of carcass fat on muscle temperature decline during chilling can be clearly shown but the reported effects on tenderness have not been consistent (e.g., Powell *et al.,* 1986; Koohmaraie *et al.,* 1988). Even in the early study of Smith *et al.* (1976) in lambs, the lower carcass weight of the lambs with thinner fat could have been a more important factor increasing temperature decline and cold shortening than the lower fatness itself. In a study by Lochner *et al.* (1980), an effect of chilling rate on tenderness was demonstrated in lean and fat beef carcasses, but the muscles from slow-cooled lean carcasses were still tougher than those from fat carcasses cooled slowly or quickly.

In pigs, a Danish study (Barton-Gade *et al.,* 1987) found important differences in tenderness between factories which used different chilling systems. The most important factors determining toughness overall were pH_1 and marbling fat, the most tender pork being found in the pH range 6.1 to 6.5 and above 2.0% total lipid.

It therefore cannot be concluded that the effect of fat on post-mortem temperature decline constitutes the only effect of fat on meat quality.

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