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PII: S0308-8146(97)00009-5

Food Chemistry, Vol. 59, No. 4, pp. 491–497, 1997

0308-8146/97 $17.00+0.00

An introduction to the OECD programme: meat quality and the quality of animal production

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(Received 15 March 1996; revised version received 18 September 1996; accepted 18 September 1996)

A survey is given of direct and indirect quality characteristics of meat. The latter are associated with the animal production systems. It is stated that integration and quantification of these criteria, evaluation of interactions between them and consideration of the social acceptance of the associated production methods is a major challenge for the modern animal scientist. The development of these concepts since 1980 within the workshops of the consecutive Organisation for Economic Co-operation and Development (OECD) research programmes is described. As a model for a more integrated approach, personal efforts of the author related to the nutritional engineering of beef fat composition, the role of meat proteases and lipases in flavour development of fermented meat and the effects of breeding and use of growth-promoting substances on meat sensory quality are summarized. © 1997 Elsevier Science Ltd

INTRODUCTION

In industralized countries animal production has evolved into highly specialized systems for producing specific food (raw) materials: beef, pork, milk, eggs, poultry etc. The systems obey market principles (pork, poultry and eggs) or are sustained by financial supporting mechanisms (EU; milk and beef). They have led to a definite condition of surplus production, resulting in production-limiting measures and in a different approach to 'quality'. Until recently, quantitative aspects of animal production such as amounts of meat or (fat-corrected) milk produced per unit input of feed, energy, labour, etc., were considered as most important. Recently, however, both consumers and scientists have realized that such an approach is a very unilateral evaluation of a very complex system and has generated several problems.

Examples are the widespread use of substances promoting growth at the tissue level, illegal in some countries; sensory and processing 'quality' defects of pork, beef and poultry associated with selection for muscular breeds; concentration of animal wastes and human health risks (BSE!) in intensive production systems; concern for 'animal welfare' with the use of newer reproduction and genetic technologies and many other problems, including the working conditions and social status of people active in slaughtering and meat processing. It has become clear that evaluation of animal production systems has to involve an integrated approach and quantification of two sets of criteria (Demeyer, 1994):

1. Direct or rational criteria, perceptible and (?) measurable on the product.
2. Indirect or irrational (?) criteria, associated with production methods and rarely perceptible or measurable on the product.

Quantification of these criteria, evaluation of interactions between them and consideration of the social acceptance of the associated production methods is a major challenge for the modern animal scientist.

THE OECD RESEARCH PROGRAMME

The integrated quality concept, proposed in the introduction, was gradually developed, first within the 'Co-operative research project on food production and preservation' founded in 1980 by the Organisation for Economic Co-operation and Development (OECD). Between 1980 and 1990, the 'animal theme' of the project focused on the use of lignocellulose, the most abundant biological material in the world, as stated during the first two workshops, held in 1980 at Uppsala, Sweden and Amersfoort, The Netherlands. In 1990, the project was succeeded by the OECD research programme on 'Management of biological resources', directed, since January 1994, by Muriel Dunier.

The programme involves most OECD countries as members, the decision to be a member being voluntary and annual payment to the project being determined by each country's gross material product. The main activities

of the programme involve the granting of fellowships and the organization of workshops. The workshops organized within the research theme 'The use of animal biotechnology to improve animal health status and meat quality' have taken place in Melle (November 1990), Nottingham (April 1991), Helsinki (June 1992), Zeist (November 1992), Theix (May 1993), Kepple Island (August 1993), Celle (June 1994) and Tromsö (August 1994). More details on the history of the OECD project are given in their Proceedings (see e.g. Demeyer & Raichon, 1991; Raichon *et al.*, 1993). During the first workshop, a whole array of subjects related to the theme was covered and it was decided to focus attention of the theme on the impact of biotechnology on consumer acceptance of meat. The Nottingham, Helsinki and Theix workshops indeed dealt with the relation of genetics and muscle metabolism to pork and beef quality, including consumer acceptance. It was realized, however, that other important aspects of the complex animal production systems should not be ignored.

In Zeist, a discussion on biotechnology and animal welfare was held and in Nottingham the Cambridge physiologist Derek Lindsay emphasized the importance of vaccin technology in tropical animal production systems, leading to the Kepple Island workshop. Frank Ellendorf and Eddy Decuypere, the poultry scientists of the Celle Institute and Leuven University, respectively, initiated and organized the 'poultry workshop' held in Celle, June 1994. An intervention by the Norwegian representative on the project's governing board was the starting point for the aquaculture workshop, organized within the 3d International Marine Biotechnology Conference held in Tromsö.

Beginning in 1995, the programme was renewed, incorporating 'Quality of Animal Production' as one of the four research themes. Since the start of the new programme, three workshops and/or expert meetings, involving an active input of the theme co-ordinator, were held in Kulmbach (February 1995), Melle (April 1995) and Wellington (February 1996). In September 1995, a follow-up on the Kepple Island workshop was organised in Japan. Again, very different (quality) aspects of animal production were highlighted. In Kulmbach, methods for colour measurement of meat and meat products were discussed. The meeting was the last of a series of three Kulmbach meetings dealing with measurement of sensory quality of meat, and reported in subsequent ICoMST meetings (Barton-Gade *et al.*, 1993; Chrystall *et al.*, 1994; Cassens *et al.*, 1995).

The growing concern of meat consumers related to the impact of animal production on environment led to the 'methane' workshop in Melle, where soil scientists and animal scientists were confronted in evaluating the relative importance of both ecosystems in methane emission. Dairy biotechnology, neglected until then, was addressed in the Wellington workshop. A confrontation of the specific characteristics of Mediterranean meat products with the OECD recommended methods, developed earlier at the Kulmbach meetings, forms the basis for the present workshop. This specific subject, however, should not limit possible initiatives of participants to address the much wider problem area covered by the programme. Such efforts are bound to be difficult, as they often require integration of multidisciplinary approaches. Some possible effects of animal characteristics and animal production methods on direct meat quality, as studied in the author's laboratory, will be briefly discussed as a limited illustration of such an approach.

ANIMAL PRODUCTION AND MEAT QUALITY

Nutritional engineering of beef fat

It is widely accepted and laid down in the official nutritional guidelines of many countries that both food energy intake as fat and the proportion of saturated fatty acids in dietary fat should be lowered. The consumer has translated these guidelines into an aversion and even fright of fat: 'healthy' is the most important criterion determining the consumer's attitude to food, 'fat' is not healthy and 'meat', especially pork, is considered as an important source of (saturated) fat in the diet (Spitters, 1994). Although beef is not a major contributor to (saturated) fat intake (Demeyer *et al.*, 1995), the proportion of poly-unsaturated fatty acids (PUFAs) in beef fat is very low.

To maintain and improve beef consumption it seems, therefore, worthwhile to increase PUFA content of beef. A main target can be intramuscular fat, as that cannot be physically removed before consumption. Intramuscular fat is less than 1%, however, in very lean animals obtained by selection, limited feeding and/or early slaughtering and contains PUFA proportions comparable to pork because of the relatively high proportion of membrane polar lipids (Table 1). The reason for this finding may be related to the heterogeneous nature of intramuscular fat, consisting of triacylglycerols present in intramuscular adipocytes, and polar lipids, mainly consisting of the phospholipids present in the membrane structures of both adipocytes and muscle fibres.

It is indeed known that both ruminants and monogastric animals specifically direct PUFAs towards the synthesis of phospholipids (Vernon & Flint, 1988). As lower fat contents reflect the presence of fewer and smaller adipocytes containing less triacylglycerols, the accompanying increase in the proportion of phospholipids in total lipid may result in an increased PUFA content of total lipids. In ruminants, PUFA supply for tissue polar lipid PL synthesis may be limited by rumen biohydrogenation of feed PUFA's, the major process determining body lipid composition in ruminant animals.

In order to detect a shortage of PUFA supply for phospholipid synthesis in ruminants vs non-ruminants, the fatty acid composition of phospholipids, forming the main fraction of the so called PL should be

Table 1. Fatty acid composition (% w/w) of beef adipose tissue[a] (mean values ± S.D.), compared to pork lard

	Subcutaneous	Intermuscular	Perirenal	Intramuscular	Pork lard[b]
Myristic (14:0)	2.6 ± 0.7	2.5 ± 0.7	2.2 ± 0.6	1.6 ± 0.6	1.5
Palmitic (16:0)	27.4 ± 2.3	26.0 ± 2.6	23.7 ± 2.8	23.8 ± 2.4	26.0
Palmitoleic (16:1)	4.0 ± 1.0	2.9 ± 0.5	1.4 ± 0.5	3.2 ± 0.6	3.3
Stearic (18:0)	12.8 ± 2.3	18.1 ± 2.9	30.8 ± 4.2	15.2 ± 2.0	13.6
Oleic (18:1)	44.8 ± 2.0	42.2 ± 2.3	34.0 ± 3.1	36.6 ± 2.2	43.9
Linoleic (18:2)	2.2 ± 0.4	2.3 ± 0.4	2.4 ± 0.5	8.0 ± 1.5	9.5
Linolenic (18:3)	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.3	1.4 ± 0.4	0.4
Arachidonic (20:4)	0.0	0.0	0.0	1.6 ± 0.4	
Other	5.5 ± 2.4	5.3 ± 2.7	4.7 ± 2.0	5.0 ± 2.0	< 1
Total FA (mg/g)	721.3 ± 92.2	682.1 ± 71.6	777.6 ± 82.6	8.1 ± 3.3	

[a]The fatty acids listed represent 88.5 ± 0.6% and 94.2 ± 0.3% of the total fatty acids for beef and pork respectively, because of the presence of several branched chain and odd chain fatty acids, mainly of (rumen) microbial origin. Results from analysis on 27 cows (double-muscled Belgian Blue-White breed), 790 ± 52 kg LW and 44 ± 7 months old and slaughtered between 7 July and 1 September 1992 at our institute. Samples were obtained 24 h after slaughtering and cooling from the 8th rib cut of subcutaneous fat (above *Latissimus dorsi*), intermuscular fat (close to the *M. Serratus dorsalis*) and intramuscular fat (*Longissimus thoracis*). Kidney fat is also removed. Samples are vacuum packed and kept at −80°C for maximum three months (Martens, 1993).
[b]From Engeseth *et al.* (1992).

compared. Table 2 illustrates such comparison, again involving diets without added fat and showing that PUFA contents of ruminant and pork intramuscular PL are quite similar.

However, it is becoming clear that intramuscular fat contents well above 1% and maybe up to 5% may be necessary for optimal palatability. It may also be desirable for beef fat to contain more PUFAs, both for nutritional and sensory purposes (Gandemer *et al.*, this workshop). Engineering of beef fat composition is best done through inhibition of the rumen biohydrogenation of PUFAs. Rumen biohydrogenation can be adequately prevented by coating of unsaturated oils with formaldehyde-reated protein. Use of this 'protected' lipid is not allowed or indicated, however, because of the presence of formaldehyde. Protection of PUFAs through their transformation to calcium soaps is too much dependent on pH to be of practical value (Van Nevel & Demeyer, 1996). A promising nutritional approach may be a more specific use of feed additives, already found in ruminant nutrition, such as ionophores, for inhibition of rumen lipolysis, a prerequisite for biohydrogenation (Van Nevel & Demeyer, 1995) (Table 3). Use of dietary antibiotics may thus affect both nutritional and sensory properties of beef.

Muscle enzymes and flavour of fermented meats

The production of fermented sausages involves comminution of muscle and fat tissue with salt, nitrate and/or nitrite and spices, including eventually sugar, starter cultures and other additives such as non-meat proteins. After stuffing the mixture into a casing, the resulting sausage is left to ferment and dry, often in two consecutive and separate stages, making up the ripening period and lasting between three weeks and six months. The presence of salt, the lowering of water activity (a_w) and the exclusion of O_2 serves to select for salt-tolerant lactic acid bacteria, producing lactic acid from carbohydrates added and/or present. This lowers pH to final values between 4.5 and 5.5, inducing denaturation of salt-solubilised protein to a gel structure that can be sliced.

Table 2. Fatty acid composition (% w/w) of intramuscular polar lipids

Reference	SFA[a]	MUFA[a]	PUFA[a]	% PL in TL[b]	% Total lipid (TL)
Beef					
Marmer *et al.* (1985)	36.9	32.1	27.1	26.8	1.7
Larick & Turner (1989)					
Grain	39.9	31.4	21.5	10.2	3.2
Grain + grass	38.1	22.0	32.8	11.2	3.1
Blunk *et al.* (1992)	32.0	32.0	28.1	—	—
Demeyer *et al.* (1994)	35.7	25.1	37.3	27.3	1.1
Pork					
Gandemer *et al.* (1992)	34.5	18.2	38.7	21.8	2.7
Engeseth *et al.* (1992)	27.5	20.1	29.9[c]	—	3.5
Kramer *et al.* (1993)	25.96	27.81	30.93	—	—

[a]SFA: myristic (14:0) + palmitic (16:0) + stearic (18:0) acids-MUFA: oleic (18:1) acid-PUFA: linoleic (18:2) + linolenic (18:3) + arachidonic (20:4) acids.
[b]% polar lipids in total lipid.
[c]Does not include arachidonic acid (20:4).

Table 3. Effect of ionophores on *in vitro* lipolysis and hydrogenation of soybean oil[a,c] (Van Nevel & Demeyer, 1995)

Ionophore added (20 ppm)	FA liberated		Hydrogenation of FFA (%)
	From TG (mg)[b]	FFA accumulated (mg)[b]	
Salinomycine	53.7[d] ± 8.2	48.6[d] ± 8.9	56.4 ± 3.5
Lasalocid	51.7[d] ± 8.0	52.2[d] ± 7.2	46.8 ± 6.4
Monensin	52.4[d] ± 12.3	59.0[d] ± 4.9	43.1 ± 18.5
None	68.3 ± 7.3	69.1 ± 5.3	55.8 ± 9.0

[a]80 mg of soybean oil and 0.5 g of concentrates were incubated with 10 ml of rumen fluid and 40 ml of Burroughs solution, containing 10 mg of N as NH_4HCO_3, during 6 h under CO_2. The final concentration of the ionophores in the incubation was 20 ppm
[b]Triglycerides (TG) and free fatty acids (FFA) were separated by thin layer chromatography and their fatty acid composition determined by gas–chromatography.
[c]Mean values ± S.D.; number of observations: blank (25) and ionophores (3–4).
[d]Significantly different from control ($P < 0.1$).

The adequate (fast) reduction of pH and the lowered a_w ensure both product stability and safety. Characteristics of Mediterranean products derive mainly from drying, whereas for Northern products acidulation and smoking are major determinants. During ripening, a multitude of simultaneous reactions and changes determine the production of a series of volatile compounds crucial for a basic flavour apart from that determined by spices. Such compounds are derived to a large extent from protein and lipid metabolism. The data presented in Table 4 suggest that proteolysis may be a very important determining factor in flavour development, providing the necessary substrates for flavour compound-producing bacteria (Demeyer, 1992; Van Cleemput *et al.*, 1995).

Proteolysis during dry sausage ripening is predominantly determined by muscle cathepsin D-like enzymes, activated because of the drop in pH (Demeyer, 1992; Verplaetse *et al.*, 1992). Also, it was shown that muscle protease activity differs between meat species (Demeyer *et al.*, 1992). Table 5 summarizes quantitative data from experiments using both antibiotics and pepstatin, a specific cathepsin D inhibitor, in a model system. The results suggest that bacterial and muscle endopeptidase activity are of roughly the same quantitative importance.

These findings shed more light on the animal factors determining sausage flavour (Fournaud, 1976) and provide insight into possible effects of the use of growth promotors on flavour development in fermented meats: beta-adrenergic agonists have been shown to affect both the activities of cathepsins and the level of their cystatin-like inhibitors (Koohmaraie *et al.*, 1991). Also, proteolytic changes affected by the use of growth promotors may interfere with texture development in heated meat products (Demeyer & Samejima, 1991).

Whereas lipid metabolism is often assumed to be mainly of bacterial origin (Arboles & Juliá, 1992; Talon *et al.*, 1992), we have shown that lipolysis during sausage ripening is almost exclusively determined by meat lipase activity (Molly *et al.*, 1996). Indeed, one of the most surprising results was perhaps the finding that addition of antibiotics to a sausage mix did not lower the production of free fatty acids (FFA) (Table 6) (Molly *et al.*, 1996).

The addition of antibiotics even sometimes increased FFA production, a finding possibly related to the use of FFA as a substrate for metabolism in the absence of

Table 4. Correlation between flavour evaluation and metabolite concentration in fermented dry sausage[a] (Demeyer, 1992)

Flavour descriptor	Metabolites[b]					
	Lactate	Acetate	Aldehydes	Pept.N	α-Am.N	NH_3-N
Rancid	—	0.67	—	—	—	0.55
Smoky	0.61	—	0.74	0.73	—	—
Ammonia	—	—	—	—	0.63	0.64
Acrid	—	0.67	—	—	—	0.56
Bitter	—	0.65	—	0.63	—	—
Salt	—	—	0.63	—	—	—
Fermented	—	0.81	—	0.64	—	—
Greasy	—	0.78	−0.56	−0.71	—	—
Spicy	0.55	—	—	0.69	—	—
Sweet	—	−0.72	—	−0.57	—	—

[a]Comparison of three factories in seven taste panel sessions: $n = 21$, correlation coefficient $r > 0.55$ at $P < 0.005$; — indicates the absence of a significant correlation.
[b]Pept.N = peptide bound N; α-Am.N = free α amino N determined using the ninhydrin reaction with leucine as a standard; NH_3-N = ammonia N determined after Conway micro-diffusion. Concentrations in mmoles/100 g DM for lactate and acetate, mg 100 g DM for aldehydes and mg g crude protein for N fractions.

Table 5. Effect of additives on production of protein fragments after 21 days of dry sausage ripening (Van Cleemput *et al.*, 1995)[a]

Protein fragments	Control C	C + antibiotics	C + pepstatin	C + antibiotics + pepstatin
122 kD[b]	40	25	20	8
38 kD	22	12	9	0
29 kD	18	5	6	5
13 kD	27	11	3	0

[a]Amounts expressed as μg Bovine serum albumin equivalents/mg sausage protein as determined by SDS-PAGE.
[b]Protein molecular weights.

Table 6. Effects of addition of antibiotics, glucose and lipolytic *Micrococci* on production of free fatty acids (FFA) and carbonyl compounds in dry sausages after 21 days of ripening (Molly *et al.*, 1996)

Antibiotic	Glucose	*Micrococci*	Formed after 21 days FFA[a]	Carbonyls[b]
–[c]	+	+	82	15.7
+	+	+	97[d]	11.4[d]
+	+	–	99[d]	11.0[d]
–	–	+	87	4.1[d]
+	–	+	94	4.0[d]

[a]As μmoles of palmitic acid/g fat.
[b]As μmoles of heptanal/g fat.
[c]+ or – indicates addition or not in the repective experiments.
[d]Significant difference from data in first row (at least $P < 0.05$).

antibiotics. Addition of a lipolytic starter with or without antibiotics did not affect lipolysis, indicative of the absence of any significant release of bacterial lipases in the presence of antibiotics. In the absence of antibiotics, interpretation of these results should be done with care, however, as no test for growth or activity of the lipolytic starter was carried out. Lipolytic *Micrococcaceae* are indeed notoriously sensitive to pH decline (Leistner, 1992). A preferential release of PUFAs suggests the involvement of muscle rather than of adipose tissue enzymes (Molly *et al.*, 1996). Addition of antibiotics depressed carbonyl production, reflecting the bacterial involvement in the production of some carbonyls. These were not of lipid origin, however, but were derived from glucose metabolism as suggested by the depression of carbonyl production and the absence of an antibiotic effect in the absence of glucose. This finding also suggests that bacterial activity is not involved in carbonyl production from lipids.

As the relative importance of muscle and adipose tissue enzymes vs bacterial (starter) enzymes in flavour development are not clear, the European Agro-Industrial Research (AIR) project on 'Optimization of endogenous and bacterial metabolism for the improvement of safety and quality of fermented meat products' was initiated in July 1994. First results of this project are summarized at this workshop (Molly *et al.*, this workshop).

Promotion of muscularity and meat quality

It is widely known that fitness for processing and sensory quality of pork vary in the opposite direction with carcass quantity (amount of meat on carcass) resulting in P(ale), S(oft) and E(xudative) meat as extreme quality defect associated with the halothane sensitivity gene, linked to maximal muscle growth. It should be mentioned, however, that accurate objective evaluation of the defect(s) and accurate quality prediction in the slaughterline seems impossible for individual carcasses (De Smet *et al.*, 1996).

Sensory meat quality defects seem to become prevalent also in double-muscled (DM) beef: Table 7 shows that the *Longissimus thoracis* of double-muscled Belgian Blue-White bulls is less tender than normal-muscled animals (Uytterhaegen *et al.*, 1994*a*).

This difference is related to the muscle and methodology of determination used. Methods and muscles emphasizing the myofibrillar contribution to texture will generate less tender DM meat, because of the limited myofibrillar fragmentation in such meat, related to the lower values for muscle protein turnover in DM animals, as reflected in a lower calpain 1/calpastatin ratio. Methods and muscles emphasizing the collagen contribution to texture will generate more tender DM meat. This is related to the lower collagen contents of DM meat (Fiems *et al.*, 1995).

It should be mentioned that, even at identical slaughter and cooling conditions, tenderness, the major palatability characteristic of beef, is subject to considerable and unpredictable variability, even within a homogeneous group of animals (Buts *et al.*, 1984). Such variability is not related to differences in collagen nature and content, responsible for inherent texture characteristics, but can largely be explained by differences in myofibrillar protein fragmentation during aging. Development of tenderness during aging of beef was indeed shown to be associated with specific proteolytic changes, but the major contractile proteins, myosin and actin are not degraded. Both neutral (calpains/calpastatin) and acid (cathepsin/cystatin) protease systems may be involved, although we have obtained evidence for a major involvement of the neutral system (Uytterhaegen *et al.*, 1994*b*). Both protease systems may be related to protein

Table 7. Meat quality of *L. thoracis* in normal- (N) and double-muscled (DM) Belgian Blue-White bulls eight days *post mortem*[a]

	N(59)[b]	DM (32)[b]	*p*-value
Shear force (Newton)	38 ± 9	60 ± 14	0.000
Sarcomere length (μm)	1.7 ± 0.1	1.8 ± 0.2	0.110
Cooking loss (%)	26 ± 3	30 ± 2	0.000
Collagen (% in DM)	2.5 ± 0.4	1.6 ± 0.2	0.000
Drip loss (%)	5.4 ± 2.6	7.2 ± 1.5	0.000

[a]Rounded values ± S.D. from Uytterhaegen *et al.* (1994).
[b]( ) = number of animals.

Table 8. Effect of rpST on post-mortal decline of pH and temperature in pork (Fabry *et al.*, 1991).

	rpST (mg d)				
	0	1.5	3	6	SE
Muscle pH 30 min pm					
Gluteus	5.92	5.74	5.84	5.76	0.31
Longissimus	5.91	5.86	5.94	5.80	0.24
Temperature (°C) 30 min pm					
Gluteus	40.1	40.6	40.3	40.8	0.9
Longissimus	40.7	41.1	40.8	41.3	0.6

turnover in the living animal and it may thus be rationalized that treatment with growth-promoting substances affecting the protease/protease inhibitor system may change tenderness development of beef. Analysis of meat at our laboratory, from animals treated with beta-agonists known to depress protein degradation, indeed showed a toughening effect of these substances (Fiems *et al.*, 1990).

Extreme muscularity is often associated with a more anaerobic nature of muscle, reflected in an accelerated post-mortem pH drop (Fiems *et al.*, 1995). Data obtained at our laboratory (Table 8) does suggest that, even with stress susceptible, very muscular pigs, the use of recombinant porcine somatotropin rpST to stimulate muscle deposition tends to accelerate post-mortal pH drop (Fabry *et al.*, 1991).

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