Meat Science in Transition — A Personal Perspective

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I am glad to take this opportunity of expressing my deep appreciation to the American Meat Science Association and to Protein Technologies International for making it possible for me to participate in the Reciprocal Meat Conference in Nebraska. I am greatly honored to have been selected as the recipient of the International Award.

Crystalline Meat Pigment

As part of my research for the Ph.D. degree at Cambridge, I was asked by my supervisor, Prof. David Keilin, FRS, to attempt to grow large crystals of myoglobin for John Kendrew (later Nobel Laureate). He required crystals of sufficient thickness to withstand the prolonged exposure to X-rays necessary for accurate diffraction photographs of the protein's structure. Horse hearts were a convenient source of myoglobin. Seeking horse hearts at the local knackery for the same purpose at this time (1950-51), was an American, James Watson. Humanity has benefited enormously from the fact that he did not succeed in producing crystals of the dimensions required (Watson, 1968), for he turned his attention to elucidating the structure of deoxyribosenucleic acid in collaboration with Francis Crick. On the other hand, the fact that I pursued the problem further (Lawrie, 1951), has clearly had a less exciting outcome — but at least it led to my interest in the relationship between the biochemical differentiation of muscular tissue and the quality of the meat it becomes post-mortem; and thereby to involvement with problems of meat research in many countries during 45 years.

The Significance of Muscle Colour

Because the intracellular pigment of muscle, myoglobin, had been confused with the haemoglobin of residual blood, its identity as a separate molecular species was not proved conclusively until 1932, when it was first crystallized by Theorell. The position had been complicated, however, by the demonstration of another pigment in muscle by McMunn in the 1880's, which he named myohaematin. His findings were strongly rejected by the dominant chemists of the day and were forgotten until reinvestigated by Keilin in 1925, who showed that myohaematin represented a group of related compounds which he named cytochromes *a*, *b* and *c*, according to the position of the absorption bands in their spectrum. Later he demonstrated the admixture of an additional component, a_3, which was the enzyme needed to link the uptake of oxygen to the other cytochromes; and thereby to the oxidation of substrates in the cell. The fact that cytochromes were found only in cells which operated aerobically was thus significant.

As early as 1667, Nicholas Stensen, in observing the relative redness of muscles in different animals, surmised that the colour might have some functional significance; and Hill (1933) had deduced, from the relative powers of myoglobin and haemoglobin to absorb oxygen at different tensions, that myoglobin might act as a short-term store of oxygen in the tissues.

Against this background, a further aspect of my Ph.D. studies was an attempt to elucidate the role of myoglobin and the cytochromes in muscle. Moreover, because of Lipmann's (1941) demonstration that the breakdown of 'energy-rich' phosphate (hydrolysis of the terminal phosphate of adenosine triphosphate, ATP) was the source of energy for muscular contraction, the relationship of these pigments to the resynthesis of ATP, by post-mortem glycolysis of glycogen or from stored creatine phosphate (CP), also seemed to merit investigation.

It transpired that the concentrations of myoglobin and of the cytochrome enzymes in muscle, and the capacity to resynthesize ATP, were covariant (Lawrie, 1952, 1953). Exceptions to this relationship tended to confirm its validity (Table 1). Thus the fact that the heart had a relatively low concentration of myoglobin, despite an exceptionally high cytochrome oxidase activity, could be explained by its lavish, blood-borne supply of oxygen, and by its frequent and continuous contrac-

Table 1. Comparative Increases* in the Capacity for Aerobic ~P Synthesis, Cytochrome Oxidase Activity and Myoglobin Concentration on psoas Muscles from Immature and Adult Horses.

Age	*Δ~P/Δt(Air) Δ~P/Δt(N_2)*	*Cytochrome Oxidase (Q_{O_2})*	*Myoglobin (% wet wt)*
0 - 2 yrs. (Immature)	43.8	37.9	42.8
2 - 12 yrs. (adult)	1.0	0.6	2.1

* the increases are expressed as percentages per year of the average adult values for these three parameters

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tions, whereby the need for an additional store of oxygen, as oxymyoglobin, was less than that of skeletal muscles. Again, the concentration of myoglobin in the muscles of the Blue whale (0.8%), although markedly greater than that in beef, seemed at variance with its low content of cytochrome enzymes; but this could be rationalized by the need for an oxygen store in diving. I was particularly impressed by the finding that the myoglobin concentration in the *l.dorsi* of thoroughbred racing horses was almost twice as great as that in the corresponding muscle of the draught horse (Lawrie, 1950), especially as concentrations of myoglobin in the other muscles did not differ markedly between the two types of horse. It was evident that the flexing action of the back in racing had established a requirement for more oxygen-derived power (and thus of myoglobin) than the level progression of the draught horse. As my supervisor remarked, differences of such an order do not require statistical analysis to be convincing.

These findings on the different biochemical nature of so-called 'red' and 'white' muscles led to further investigations on the factors involved in determining them, viz. species, breed, sex, age, exercise and training, plane of nutrition and anatomical location. All could be explained on the basis of the relative need for oxygen-derived power, as moderated by the speed of contraction appropriate for the action of each muscle, and thus the need for a store of glycogen. In general, and in confirmation of the work of other investigators, red muscles were found to rely on a continuous supply of oxygen during prolonged contractile activity; whereas white muscles, operating in short bursts, had greater concentrations of glycogen to service the anaerobic resynthesis of ATP, albeit inefficiently compared with respiration. Clearly the concentration of the glycogen reserves in muscle determine the amount of lactic acid which can be produced during post-mortem glycolysis and thus the ultimate pH attained by the muscle as meat (Table 2).

Table 2. Some Relative Differences Between 'White' and 'Red' Muscles.

Parameter	*'White'*	*'Red'*
Myoglobin concentration	low	high
Respiratory enzymes	scarce	plentiful
Capacity for aerobic ~P synthesis	low	high
Creatine phosphate reserve	high	low
Glycolytic enzymes	plentiful	scarce
Glycogen reserve	high	low
Rate post-mortem pH fall	fast	slow
Ultimate pH	low	high
Control of actomyosin ATP-ase(SR)	high	low
Capacity for protein synthesis in vivo	high	low
Capacity for proteolysis post-mortem	high	low
Calpain/calpastatin ratio	high	low
3-methylhistidine in myosin	high	low
Fibre diameter (average)	broad	narrow

Both the rate and extent of post-mortem glycolysis, and the rates and extent of post-mortem proteolysis, are major determinants of meat tenderness. Red and white muscles differ in these parameters. Thus, it has long been appreciated that the rate of post-mortem glycolysis is greater in white muscles (Needham, 1926). In valid comparisons between muscles within a carcass, those with less myoglobin exhibit a faster rate of post-mortem lactic acid production (Lawrie, 1952, 1966); and for a given muscle (e.g. *longissimus dorsi*) under controlled conditions (e.g. under nitrogen at 37°C) the rate of post-mortem glycolysis is generally greater in porcine muscles (white) than in those of the ox or horse (red) (Lawrie, 1966). It must be noted, however, that such intrinsic differences in the rates of post-mortem pH fall may be confounded by the location of the muscles since the metabolism of those which are more superficial, and thus more exposed to the post-mortem cooling environment, will be slowed more effectively than that of muscles of deeper location in the carcass, in which the high in-vivo temperature will persist for longer.

In their now classical work on "cold shortening," Locker & Hagyard (1963) showed that when beef muscles were cooled below 10° to 15°C, whilst they were still in the early prerigor state (pH ca.6.0-6.4), they shortened and were relatively tough as meat. Locker and Hagyard could not elicit cold-shortening in the flesh of rabbit, in which the majority of the musculature is white (although J.R. Bendall caused the effect in the red *soleus* muscle of this species). Subsequently Bendall (1975) demonstrated that in the pig those muscles which have more myoglobin are more liable to cold shorten than those which are relatively colourless. In endeavouring to account for cold shortening, it was shown that the sarcotubular system in early prerigor muscle (Cassens & Newbold, 1967) and the mitochondria (Buegge & Marsh, 1975) were stimulated to release calcium ions by the cold, whereby the contractile ATP-ase of actomyosin was activated and post-mortem glycolysis accelerated. The greater development of the sarcotubular system in white muscles (Lawrie, 1952: Fawcett & Revel, 1961) and the greater prevalence of mitochondria in red muscles, makes the former better able to counteract the flux of calcium ions induced by cold shortening conditions.

Reflecting their greater dependence on respiration for energy, red muscles tend to have a smaller glycogen store and a more limited *extent* of post-mortem glycolysis (and thus a higher ultimate pH) than white muscles under comparable circumstances (Lawrie, 1955) although as a contributory factor, it is also evident that the nature of the glycogen in certain red muscles causes it to be resistant to breakdown post-mortem (Lawrie, Manners & Wright, 1959).

The rate and extent of post-mortem proteolysis (ageing) is greater in white muscles than in red (Dransfield, 1980-81). This reflects the facts that the ratio of the enzyme calpain II to its inhibitor, calpastatin, is higher in white muscles and that the susceptibility to breakdown of both the myofibrillar and connective tissue proteins of white muscles is greater than that in red (Monin & Ouali, 1991).

The distinctive biochemical features of white and red muscles suggest that different strategies should be adopted in electrical stimulation and cooling, during hot deboning operations, in order to elicit those tenderness levels which are optimal for each.

Post-Mortem Glycolysis, Stress and Meat Preservation

Experiments carried out at the Low Temperature Research Station, Cambridge, had shown that the glycogen reserves of rabbit muscle were depleted by inanition or by struggling immediately pre-mortem — and that the latter, if inhibited by the muscle relaxant myanesin, conserved glycogen reserves and would thus delay the onset of rigor mortis (Bate-Smith & Bendall, 1947, 1949), which is due to the depletion of the ATP level. Although evidence of the effect of these factors on pig muscle had been reported by Callow (1937, 1939), their influence on the muscles of cattle was largely unknown, and this was of concern in relation to the post-World War II international trade in frozen beef between Australia and New Zealand and Europe. Freezing is an effective procedure for the long-term preservation of meat; but frozen meat suffers from an obvious disadvantage in that, on thawing, it exudes a considerable quantity of fluid (drip). In the hope of ameliorating this problem, a collaborative programme was established between the Dept. of Scientific and Industrial Research of UK (which was responsible for operating the Low Temperature Research Station at Cambridge) and the CSIRO of Australia, at their laboratory on the premises of the Queensland Meat Industry Board's Brisbane abattoir, Cannon Hill. Accordingly, I spent the period 1953-56 carrying out investigations on frozen beef, having the benefit of control over the origin, feeding, slaughter and sampling of cattle of known history.

In the laboratory it is possible to freeze muscles before the onset of rigor mortis. Such muscles, on thawing, contract violently, lose two-thirds of their initial weight as drip and become tough — the phenomenon of thaw rigor (Chambers & Hale, 1932). Thaw rigor had also been observed with whale meat in the Antarctic (Sharp & Marsh, 1953), the low basal metabolism of this species making pre-rigor freezing possible even with portions of commercial size. The Australian experiments showed, however, that even when beef quarters were exposed to blast freezing whilst in the warm, pre-rigor condition, they could not be cooled sufficiently swiftly to freeze them before rigor mortis ensued, and thaw rigor thus did not occur.

It was found possible, however, to reduce the amount of drip by pre-slaughter injection of relaxing doses of magnesium sulphate, which slowed the rate of post-mortem glycolysis (the administration of calcium salts had the converse effect) (Table 3). In an alternative approach to drip control, various drugs, such as neopyrithiamin and insulin, were injected pre-slaughter, whereby glycogen reserves were severely depleted, causing a high ultimate pH and thereby very little drip on thawing (Howard & Lawrie, 1956, 1957).

Unexpectedly, in view of the prevalence of dark-cutting beef in various countries — cattle resisted the depletion of glycogen reserves when exposed to exhausting exercise or inanition, circumstances which cause an elevated ultimate pH in laboratory animals. Yet the muscles of certain steers which had been well-fed and rested yielded dark-cutting beef. Such animals were observed, however, to be of an excitable temperament, often trembling when standing and thereby lowering the equilibrium level of glycogen in their muscles (Howard & Lawrie, 1956). Clearly inherent excitability must be a major factor in producing stress in meat animals - in addition to exhausting exercise, starvation and inclement weather. One could epitomize the position: If you can chase a steer, it probably won't produce dark-cutting beef; but if it chases you, it probably will produce the condition!

The Australian programme had also provided further evidence of important differences between the muscles of the carcass. Thus, when frozen and thawed, the *l.dorsi* muscle always yielded more drip than the *psoas*, at any pH (Bouton, Howard & Lawrie, 1957); and pre-slaughter stress clearly affected some muscles more than others. For example, the ultimate pH was elevated more frequently in *psoas* than in *l.dorsi* (Howard & Lawrie, 1956, 1957).

As has been reported more recently, within a given muscle the stress caused in animals by mixing groups from different localities depletes glycogen more from white fibres than from red; whereas pre-slaughter adrenaline injection affects red fibres more severely than white (Lacourt & Tarrant, 1985).

The undesirable effects of a high ultimate pH, caused by metabolic stress, on the quality of fresh meat (e.g. the dark-cutting condition), could be used to advantage, however, with freeze-dried meat. In an investigation funded by the U.S. Department of Agriculture after I had returned to Cambridge in 1956, it was shown that the induction of a high ultimate pH (by pre-slaughter subcutaneous injection of adrenaline) markedly improved the texture, tenderness and hydratability of both freeze-dried beef and pork over these features in non-injected controls (Penny, Voyle & Lawrie, 1963, 1964). It was also evident that different muscles reacted to freeze-drying, and to its combination with elevated pH, according to their intrinsic biochemical nature, this being reflected in their subsequent eating quality.

Table 3. Typical Effects of Serum Magnesium and Calcium on Onset of Rigor Mortis In I. Dorsi and psoas Muscles of Steers.

Condition	*Blood serum*		*Time to onset of rigor mortis*	
	Mg	*Ca*	*l. dorsi*	*psoas*
	(mg/100ml)		*(min/37°C under N_2)*	
Control	2	10	220	130
Hypermagnesaemia	21	9	310	300
Hypercalcaemia	2	42	120	45
Hypocalcaemia	4	1	210	180

Table 4. Comparative Composition of Various Muscles from Normal(C) and Doppelender(D) Heifers.

Muscle	*Moisture (%)*		*Intramuscular Fat (%)*		*Nitrogen (% fat-free)*		*Hydroxy-proline (μg g⁻¹)*	
	C	D	C	D	C	D	C	D
rsi	76.5	75.6	0.56	0.27	3.54	3.70	520	350
ps femoris	76.8	76.9	0.61	0.29	3.46	3.58	760	470
orius	78.0	77.4	0.58	0.25	3.33	3.41	870	460
aspinatus	78.0	77.5	0.78	0.39	3.29	3.45	1080	450

Factors Responsible for Muscle Differentiation

When back in England, I continued my interest in muscle differentiation. A series of analytical investigations on meat of accurately known history provided further evidence that species, breed, sex, age and anatomical location systemically affected the composition of muscles. Of particular interest was the finding that, although the muscles of "doppelender" heifers contained more total protein than those of normal siblings, the percentage of connective tissue protein was markedly lower in the former (Lawrie, Pomeroy & Williams, 1964) (Table 4). It was also shown that the composition of the *l.dorsi* muscle of the pig differed more within the members of a litter than between litters from the same parents, indicating that the influence of the individual predominated over that of the mother (Lawrie & Gatherum, 1964). The technique of gel electrophoresis demonstrated that muscles also differed in the nature of their sarcoplasmic, myofibrillar and connective tissue proteins, whereby the meat of different species and the muscles within a given species could be identified. The technique also revealed those proteins which were most susceptible to denaturation in processing and in stressed animals (Parsons et al, 1969; Mattey et al, 1970; Roberts & Lawrie, 1974).

I must mention one disconcerting result. Two sibling Friesian heifers at Sutton Bonington, being thus of closely related genotype, were fed the same diet and subsequently slaughtered at the same weight. The carcass of one was rejected by the butcher as being too tough for his customers, and chemical analysis revealed that its muscles contained six times as much collagen as those of the half-sister. The occurrence of an apparently random difference of this order was a sobering reminder that our ignorance about the nature of meat is not insignificant! It is evident that, notwithstanding the factors known to affect the composition of meat, there must be other influences yet to be identified.

Meat Identification in Food Analysis

Studies of the biochemical differentiation of muscular tissue highlighted the problem of how to distinguish them as meat post-mortem; and the more general question of how to quantify the proportion of the total proteins in food products which was contributed by those of meat. Electrophoretic and immunological techniques fail to identify proteins quantitatively when the product concerned, for example, has been heated in commercial sterilizing processes. For legislative purposes, in the interests both of consumers and producers, there is clearly a need for an unequivocal index of meat which would survive processing treatments.

It is generally accepted that the most characteristic and invariant component of meat is its content of the contractile proteins, myosin and actin. Johnson et al (1967) had demonstrated that an unusual amino acid, 3-methylhistidine, was a constituent of the actin and myosin of adult muscles. Were its concentration to be constant in muscles, and were it absent from the non-meat proteins which were likely to be incorporated in meat products as extenders or substitutes, it would be a unique index of meat; and, on investigating this possibility, we found that the 3-methylhistidine titre of commercially sterilized mixtures of beef and soya was directly proportional to the beef content (Hibbert & Lawrie, 1972). Moreover, the amino acid was virtually absent from all the vegetable proteins examined. Although the 3-methylhistidine titre proved to have a similar value between species, and between muscles within a species, the concentration of the amino acid was markedly higher in the muscles of whales and in those of mature pigs. This was found to be because, in these species, some was present as balenine — a dipeptide compound similar in structure to the better known carnosine and anserine, which act as buffers in muscle. It was thus necessary to use *protein-bound* 3-methylhistidine as the basis of the index (Rangeley & Lawrie, 1976). The methodology was further modified by converting the amino acids to fluordinitrobenzene derivatives, by their separation using high pressure liquid chromatography (Jones et al, 1982) and by expressing the 3-methylhistidine titre on a connective tissue-free basis (since collagen does not contain this amino acid and the amount of collagen varies between muscles (Poulter & Lawrie, 1980). Independent investigators confirmed the validity of the 3-methylhistidine titre as a quantitative, robust index of meat from the skeletal muscles of the usual animal species (Jones et al, 1982); but a limitation to the use of the index was revealed when it was found that the cheek meat of bovines had a distinctly low titre (Jones et al, 1985). This was shown to be due to the relatively low content of 3-methylhistidine in the myosin of bovine *masseter/malaris* muscles (White & Lawrie, 1985) and seems to be a feature of ruminant cheek meat. In both cattle and sheep, this muscle consists entirely of "red" fibres, no doubt reflecting the slow, continuous action of chewing of the ruminant; whereas these muscles in the pig have a titre of 3-methylhistidine similar to that of the skeletal muscles

Table 5. 3-Methylhistidine in Bovine Myosin and Actin (mg g^{-1} nitrogen).

Muscle	*Myosin*	*Actin*
l.dorsi	2.38	23.0
semimembranosus	2.37	23.2
masseter/malaris	0.52	20.8

in this species and to those of the skeletal muscles of cattle and sheep (Johnson et al, 1986). Since the 3-methylhistidine content of the *actins* of both red and white muscles was subsequently shown to be the same, however (Johnson & Lawrie, 1988), it is now clear that actin-bound 3-methylhistidine should be the robust index used in assessing the meat content of foods when their exact nature and processing history are unknown to the analyst (Table 5).

The programme of research on 3-methylhistidine further impressed me with the importance of the biochemical differentiation of muscle in accounting for variation in the eating quality of meat. Even in respect of proximate composition, however, it has become evident that intrinsic differences between muscles are important. Thus it has now been demonstrated that the fat-free nitrogen content of meat, which is used by analysts to assess the quality of products offered for sale to the public, varies systematically between commercial joints of pork and beef (Anal. Methods Committee, 1991, 1993), and that an appropriately different factor should be used when the identity of the joint from which the meat originates is known. Moreover, changes in the type of cattle and pigs which now form the bulk of the animals providing the meat supply in UK have altered the overall nitrogen factors from the value they had 30 years ago when I first became involved in considering the question.

Upgrading Abattoir Offal

In both developed and developing countries, a not inconsiderable proportion of the total protein of the carcass is underutilized because it is present as unaesthetic offal. With a rapidly increasing world population, the waste of such expensively produced protein is particularly undesirable. The success of the Boyer process in the 1960's in extracting vegetable protein from indigestible matrices by alkaline solutions, and thereafter spinning it into organoleptically acceptable, textured fibres, made it appear worth attempting a similar approach with abattoir offal. Accordingly, I directed a programme on this topic over the period 1972-1987. The factors influencing the extraction of protein from ovine and bovine stomachs, lungs and blood were identified: The conditions affecting the texture of spun fibres from the extracted proteins were determined; and the benefits for structure, appearance and nutritive value of combining the different features of the proteins extracted from various sources were discovered (Young & Lawrie, 1975: Swingler & Lawrie, 1978: Gault & Lawrie, 1980). Since it was shown that offal protein could be texturized by high temperature/high pressure extrusion, after less rigorous extraction conditions than those necessary for spinning, this process was also investigated: The importance of lipid-protein interactions in controlling the texture of the extruded product became evident (Areâs & Lawrie, 1984: Mittal & Lawrie, 1986).

An ancillary aspect of these investigations on offal was an attempt to identify the individual proteins to which attributes of functional importance to the food industry could be ascribed. Thus blood plasma proteins were separated by pilot-scale column chromatography into three major fractions and their properties compared with those of egg albumen in cake-type model systems. They exhibited surprising differences (Howell & Lawrie, 1985) (Table 6).

Overall, the programme on offal recovery indicated not only how meat industry wastage could be lessened but also pointed to the potential benefits for the food industry generally which could be anticipated from exploitation of the individual proteins of recovered proteins. Future meat research workers will hopefully progress this field.

Overseas Meat Problems

In 1964, I resigned from my post with the ARC at Cambridge and accepted an appointment to organize teaching and research in food science at the University of Nottingham. The campus of the Faculty of Agricultural and Food Science at Sutton Bonington has a high proportion of students from overseas. The post at Nottingham thus provided an excellent opportunity to study meat problems in conjunction with personnel from developing countries. For example, these studies included investigations of the behaviour of intermediate moisture meat in Nigeria (Obanu et al, 1976) and of the effects of electrical stimulation on carcasses under conditions of high ambient temperature in the Sudan (Babiker & Lawrie, 1983); of the use of the flour from pulses as inexpensive extenders of sausage meat in India (Verma et al, 1984): of the suitability of the native criollo goat (in Mexico) and of rabbits (in Sri Lanka) as potential sources of quality meat; and of the optimum conditions for the production of salted dried mutton in Brazil (Zapata et al, 1990). Apart from such research, consultancy work on meat science programmes in Central and South America, Africa and Asia was involved.

Table 6. Gel Strength* of Blood Plasma Fractions(P), Egg Albumin(E) and Mixtures of These, After Heating for 15 Min at 85°C in 45% Sucrose Solution.

Fraction	*6%P*	*3%P + 3%E*	*6%E*
I (fibrinogen, α_2, ß and α globulins)	323	377	120
II (α globulins)	0	237	110
III (serum albumin)	22	253	116

* load in g required to depress gel surface by 6mm

Disseminating the Discipline of Meat Science

As the years went by, I became acquainted with meat research workers in many countries whilst attending conferences (especially the meetings of European Meat Research Workers as they were called until recently). I was responsible for organizing the 4th meeting in Cambridge in 1958, and during consultancy and lecturing assignments abroad. It seemed evident that there was a need for a publication to disseminate interdisciplinary and international knowledge on all factors which influence the properties of meat. Such would enable meat research workers in one field to appreciate the findings of those in other areas of research via a common forum presented in one language (English). It would obviate the difficulty of access to the variety of journals which had hitherto been used for publication. Moreover, hopefully, appreciation of the problems of other disciplines would foster cross-fertilization. Accordingly, and following enquiries from various colleagues in 1976, I suggested to Applied Science (now Elsevier) that an international journal *Meat Science* should be established, having an editorial board of members representing countries with a strong interest in meat research. The first issue appeared at the beginning of 1977. To date, about 1000 papers have been published. These originated from 40 different countries. Both the volume of papers submitted and the number of countries submitting them continue to increase.

To form the basis of a course in meat science for home and overseas students, it seemed appropriate to set out, in a book, the logical sequence of events from conception to consumption of meat in the format I had found useful during the 15 years I had spent in meat research in Cambridge and Brisbane. The first edition of *Meat Science* was published in 1966. It has since been translated into German, Italian, Japanese, Russian, Spanish and Portuguese: and a 5th English edition was published in 1991. An Arabic edition is currently planned. I thus believe it has had some influence in making the concepts of the subject available internationally.

Whither Meat Science?

On an occasion such as this, it seems appropriate to speculate a little on future developments in meat science. It is evident that the biochemical differentiation of muscular tissue reflects the existence of a substantial reservoir of quality intensities, both within a given meat species and between species, and fundamental studies of polymers in biological systems are revealing how this reservoir might be exploited in the interests of the consumer.

Sophisticated computer technology is now making it possible to identify the precise location and architecture of the molecular groupings in proteins and lipids which are responsible for texture and flavour-producing characteristics; and to construct proteins, having desired organoleptic attributes or enzymic activity, by assembly from selected amino acids. The essential stereochemical configuration for various enzymic activities is being established by studying the subtle relations between low concentrations of water and functional locations on the protein. This is proving possible by freezing enzyme systems in different activity modes at rates so fast (e.g. 40,000 C° per sec) that no ice crystals form and there is thus no distortion. Again, non-functional amino acid sequences in enzyme proteins can be removed to enhance the intrinsic activity of the molecules. Such developments in fundamental protein chemistry could have profound significance for meat science.

With the techniques for transgenic manipulation now available, improvements in meat animals, by incorporating desirable features found in one breed or species into another, can be anticipated. It is thus possible to predict that problems of the meat industry — such as pale, soft, exudative (PSE) flesh — will be solved by identifying, and removing, their cause at a fundamental level. In 1990, MacLennan et al, demonstrated that an inability to prevent excessive release of calcium ions from the sarcoplasmic reticulum of muscle (believed to be the immediate prerequisite for malignant hyperthermia and PSE), was associated with a particular gene (the ryanodine receptor). In the following year, Fujii et al, (1991) identified the specific defect responsible—namely, the substitution of thymidine for cytosine at location 1843 on the cDNA, whereby cysteine was coded for at position 615 on the ryanodine protein instead of arginine, with consequent stereochemical changes adverse for the protein's proper functioning. A relatively simple technique has now been devised to detect this genetic defect in porcine tissues under practical conditions in the meat industry (Houde & Pommier, 1993).

Again, a significant improvement in the hygienic control of meat and meat products can be anticipated as a result of the genetic manipulation of the bacteria which are responsible for spoilage or food poisoning. The gene which causes the marine organism *vibrio fischeri* to be luminous can be incorporated into the DNA complement of various bacteria commonly found in meat, whereby their numbers and viability can be visualised. As few as 10 cells can be detected within two hours and the acceptability or otherwise of batches of meat and meat products assessed swiftly instead of requiring a delay of some days (Stewart & Williams, 1992). It is now also possible to detect viable pathogens swiftly even in the presence of large numbers of other bacteria, by incorporating an ice-nucleation gene into the pathogen of interest. This codes for a protein whose configuration provides a template for ice crystal formation: the latter can be accurately detected using an indicator dye (Wolber & Green, 1990).

When I first visited the USA in 1960, my attention was drawn to a book entitled *Biochemical Individuality* (Williams, 1956), in which the author demonstrated the substantial anatomical and physiological differences which are found between apparently normal, healthy human adults. He postulated that, in respect of the complex entirety of metabolic features which characterize the human body, no two individuals could be identical; and recent work on deoxyribosenucleic acid has confirmed this postulate and revealed the genetic basis by which the uniqueness of the individual is determined. An important aspect of this diversity is the more or less subtly different pattern of receptors which each individual possesses to assess the quality of meat. Thus, disagreements between individuals on the latter are likely to be at least partly due to genuine differences in the sensations each perceives. The spectrum of values for each quality attribute is likely to be much more extensive than we currently appreciate. A time may be envisaged when genes, constructed to specify the sequences

needed for desired intensities of each quality attribute, will be available for incorporation into the genome of meat animals. I would submit that the possibility, thereby, for increasingly complete satisfaction of the individual meat consumer's ideal requirements must be a major inspiration for meat scientists in determining research programmes within the areas of their own particular expertise. Today's seemingly impossible objectives soon become tomorrow's norms.

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