EARLY DETECTION OF MEAT QUALITY CHARACTERISTICS: THE DANISH SITUATION

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Summary

Denmark has always concentrated on quality in meat production. The country has high production costs and cannot compete on quantity alone. Due to the unique, highly integrated structure of the Danish industry, consensus exists as to which quality characteristics are the most important ones. Consequently, quality goals have been identified, and collaborative actions have been implemented leading to the development of a number of measuring systems for the early detection of important quality characteristics. Also, quality aspects which do not have direct economic consequences for the producer are considered.

The paper describes recent attempts to introduce new detection technologies in Danish abattoirs.

Water holding capacity and marbling fat may be estimated in pork (longissimus dorsi) by means of the MQM equipment on the day after slaughter with satisfactory reliability. On the other hand, attempts to determine marbling fat for beef with this technology were not successful, probably due to the stochastic nature of the marbling in beef longissimus. However, near infrared reflection spectroscopy turns out to be very promising in determining intramuscular fat, collagen content and pigmentation in beef.

Near infrared reflection spectroscopy is also utilized in determining the protein content in slaughter pigs and individual muscles. This is of particular interest for meat intended for processing into products such as bacon and cooked ham, etc. It is found that protein content can be predicted from the spectra with twice the standard deviation of a reference laboratory method such as Kjeldahl.

Meat colour may be assayed from the pigment content in muscular tissue by reflection spectroscopy within the visible range. For pork, this is an unsatisfactory procedure, as "structural contributions" sometimes dominate. Veal calves and young bulls do not show this interfering characteristic, and colour may be reliably predicted from pigment content.

Finally, a short account of the Danish boar taint analysis system is discussed.

Introduction

Denmark has a long tradition of concentrating on quality rather than quantity in its meat producing industries. Of the nearly 17 million pigs slaughtered annually, 80% are exported and of the 800,000 cattle slaughtered, approximately 50% are exported. In value, this amounts to 10% of the total Danish export. Although the numbers seem high ,they only account for a small percent of the world's total meat export. This means that Denmark has a volume too small to be able to compete on quantity alone. Furthermore, high production costs compared to most other meat exporting nations emphasizes the need for producing quality.

Denmark's strength lies in the degree of integration within the industry. Most pig producers are members of co-operative slaughterhouses and these, in turn, can have processing facilities of their own. Thus, in contrast to most other countries factory economy does have consequences for Danish producers, although this is often indirect.

There is close collaboration between research institutions with respect to breeding and disease prevention, and the Danish Meat Research Institute (owned and financed by the industry) which ensures that the latest developments in meat science, meat processing and plant design are available to the whole Danish industry. Finally, a national network of advisers ensures that the latest knowledge in breeding, feeding and management reaches producers directly.

This integration means that quality goals are national and that quality aspects, which do not have direct economic consequences for producers can, if necessary, be taken into account. In this context it should be mentioned that quality goals are set by the Quality Committee, which consists of representatives of breeders, abattoirs, processors and marketing people.

Early detection

In order to meet customer demands for quality of meat and meat products, it is of utmost importance to have knowledge concerning a number of measurable quantities early in the slaughtering process. Ideally, the result of a physico-chemical measurement should be available immediately. This is not always possible for a number of reasons, although examples to the contrary are becoming more frequent.

However, it is seldom required to have the result instantaneously. Time lags up to several hours may be justified without impairing a sorting situation or a change in process flow. Such long times will normally be the result if a sampling and off-line measurement is necessary.

In this review some recent approaches to detecting a variety of meat quality characteristics are discussed. Most of these are very fast and capable of delivering results quickly and with a high frequency. They were originally conceived for use in the pig slaughtering and processing industry, but in some cases they can be used on beef as well with only minor modifications.

What is meant by quality?

The definition of quality in this context is a very diffuse one and different people have widely differing opinions. However, for the present purpose the quality of the lean meat in the carcass is the important issue; besides, all customers prefer high lean meat percentages in the carcasses or cuts they buy.

The quality characteristics of the lean are somewhat dependent on the end-use of the product. For fresh meats an attractive appearance and a good eating quality are probably the most important, i.e., a good water holding capacity (WHC) and normal pH value (neither PSE nor DFD), a good colour without bruises and blood splashing and a certain amount of marbling fat. For meat intended for processed products, the protein and pigment contents are important and marbling should ideally be low. Any product irrespective of end use should of course be hygienically impeccable and untainted.

Eating quality

The important characteristics promising, but not guaranteeing, good eating quality are a good WHC with normal pH values, adequate marbling, appropriate maturing and for beef a low collagen content. Amongst the measurable characteristics, good reference methods exist for marbling (NMKL, 1974) and collagen content (ISO, 1978), whereas little consensus exists on which method is the better one for assaying WHC. In the work reported here, salt soluble protein, as determined by the Biuret method was chosen, as this gives a good indication of the extent of protein denaturation after slaughter as well as the visual impression of colour and structure (Barton-Gade 1981).

Previous experience obtained at the Danish Meat Research Institute on manual and automated classification of pig carcasses utilizing monochromatic light (950 nm) insertion probes have been further pursued to yield systems that in addition to measuring fat and meat depths also estimate WHC and intramuscular fat (IMF), i.e., marbling. In their final version the equipments based on such probes are known as MQM equipment (Meat Quality Marbling; Barton-Gade and Olsen, 1984; Borggaard *et al.*, 1989).

Until about a year ago MQM technology (see Figure 1) was used at Danish abattoirs to sort out pork with *guaranteed good eating quality*, which was defined as meat with WHC-values 0.15 AU (absorbance units in the colourimetric determination of salt soluble proteins) and IMF 1.4 %.

Sorting took place typically the day after slaughter, immediately before the carcasses were cut. Part of the concept was a maturing period of the meat of at least 72 hours between slaughter and sale by ensuring that cuts did not leave the abattoir until two days after slaughter. Only meat from selected classes according to the classification result were subjected to the sorting process.

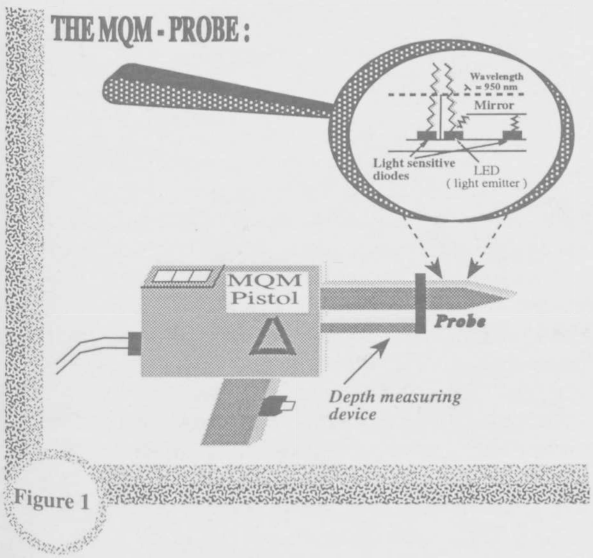

Figure 1. Principle of the MQM-equipment.

The meat was marketed in Denmark only under a brand name, mostly as cuts from loin and ham, at a price approximately 15 % above normal. In spite of thorough advertising, the sorted cuts were only marketed for about a year, as the brand never caught the consumer's interest.

The manually operated sorting equipment had a capacity of approximately 300 determinations per hour with one operator. As regards sorting reliability, R2 between reference measurement and probe value was 0.86 with a RSD = 0.015 AU for WHC (longissimus dorsi). The range in Danish pork is approximately 0.07 to 0.21 AU with a mean value of 0.18 AU. For IMF the corresponding values were R2 = 0.80 with a RSD = 0.2 % IMF. The range here is approximately from 0.7 to 4.5 % IMF, with an average value of 1.3 % (longissimus dorsi).

Similar probes were tested on beef longissimus with limited success, probably because of the stochastic occurrence of marbling in beef. However, very promising results were obtained by using fibreoptical insertion probes in the near infrared (800-1600 nm) wavelength range, see below. Preliminary results indicate good correlations also for collagen content and pigment content (Table 1 and Figure 2).

Table 1. Preliminary results obtained using near infrared fibreoptical insertion probes on beef *longissimus*[a].

	Min.	*Max.*	*Mean*	*SD*	*RSD*	R^2
IMF (%)	0.80	10.50	5.49	3.10	0.66	0.93
Pigment (iron) ppm	0.0	28.6	18.1	6.6	1.3	0.97
Collagen (%)	0.30	0.87	0.52	0.17	0.053	0.91

[a] Data from 10 carcasses are included. They were chosen to reflect a large variation in IMF and age.

Colour

The colour of fresh meat is normally dominated by the pigment content, i.e., the sum of the myoglobin content and the residual haemoglobin, either in their native forms, or after exposure to air as oxygenated species. However, other factors also influence meat colour, sometimes to such an extent that the visual appearance of meat has very little correlation to pigment content. This is, for example, the situation in extreme cases of either PSE or DFD. In the former event the meat is much lighter, or paler, than pigment content dictates, in the latter considerably darker. The reasons to these findings have been discussed in detail previously and will therefore not be dealt with here (MacDougall, 1970; Birth *et al.*, 1978).

Other, less known phenomena also influence meat colour, but not to the same extent as PSE and DFD. Such influences are often termed "structural contributions", e.g., where low ultimate pH affects changes in myofilament spacing as negative charge repulsion decreases toward the iso-electric point of about 5.4 leading to a paler colour (Bendall and Swatland, 1988).

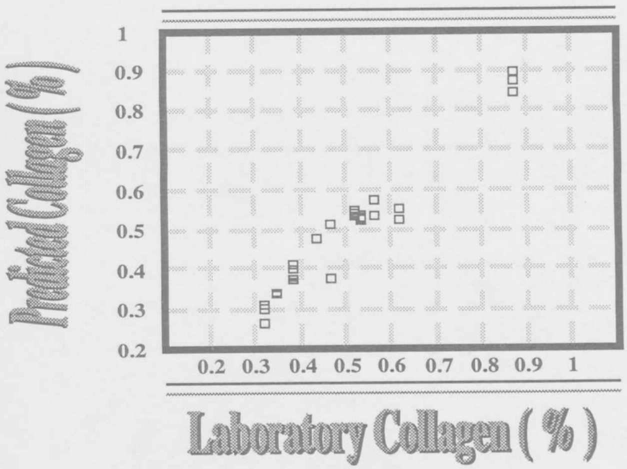

Figure 2. Collagen content as determined by near infrared spectroscopy; predicted values vs. laboratory results (see also Table 1).

Both PSE/DFD and *structural influences* develop with time after slaughter, whereas the pigment content remains unaltered. With this in mind it was decided in Denmark a few years back to develop a rapid on-line measuring system for meat colour based on the pigment content, as this was the only property measurable shortly after killing. It was hoped that pigment content as determined on the warm carcass would provide a good estimate of the visual perception of meat in the final cut, as the PSE/DFD frequency in Danish pork is fairly low.

A measuring system based on reflection of polychromatic visible light was constructed (Andersen *et al.*, 1989). Light is introduced to the muscular tissue by means of fibre optics embedded in a stainless steel insertion probe. The reflected light is subsequently detected on a diode-array detector and treated mathematically to present the final result as a pigment concentration (Figure 3.). Actually, it proved beneficial to express the result in parts per million (ppm) of iron content (Andersen and Andersen, 1989), as the latter is a faster and more accurate assay for pigment content than is the normally used Hornsey procedure (Hornsey, 1956).

Several features are included in the apparatus: procedures safeguarding correct light calibration (dark and white references) and also ensuring that the calibration remains correct over a working day by automatically recording the dark current between all measurements and correcting whenever necessary. Furthermore, a function is included warning the operator when the optical window is more than approximately 20 % covered with marbling fat, and prompting him or her to repeat the measurement in a slightly different position.

Algorithms based on multivariate statistics (Kowalski *et al.*, 1986) and neural networks (Borggaard and Thodberg, 1992) were developed for *longissimus dorsi*, *semimembranosus* and *biceps femoris* and rather good correlations are found

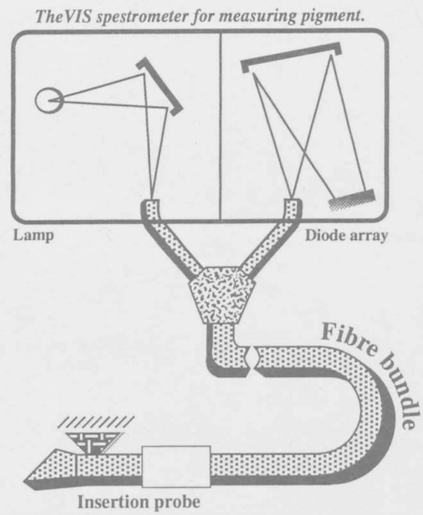

Figure 3. Principle of the fibreoptical pigment meter.

between estimated and actual pigment contents, i.e., R2-values typically of the order 0.9 with RSD's of approximately 0.4 ppm iron (range 4-9 ppm for *longissimus dorsi*). The capacity of the equipment when operated manually is approximately 120 determinations per hour with three probe insertions. In automated mode much higher capacities were anticipated.

However, in spite of the fact that accuracy, precision, speed of operation, cost etc are all within acceptable limits, the system was never implemented on-line in Danish pig abattoirs. It eventually became clear that pigment content is not a satisfactory estimator of the visual colour perception of meat in Danish pigs. Even when the WHC is *normal*, i.e., not PSE or DFD, pigment content sometimes is poorly correlated to visual colour. The reason to this is not fully understood, but it probably has to do with the aforementioned *structural contributions*. Moreover, as slaughter weights increased in Danish slaughter pigs, so did the pigment content, thus decreasing the need for outsorting of carcasses with low values.

As a consequence further development of the manual prototypes into on-line equipments was stopped. They are now used for research work and in the ongoing Danish breeding programme, as they actually are rather good predictors of pigment content and thereby avoid the large numbers of laboratory analyses to be carried out.

Concerning cattle, on the other hand, the future for on-line colour assessment appears more bright. In a recent series of experiments, data from 400 carcasses comprising veal calves, young bulls and cows were obtained with the fibreoptical pigment measuring prototype. Spectra were recorded from sirloin and full rib loin, and the reference data determined as total iron content. As always, spectra and reference data were compared and used for setting up prediction models.

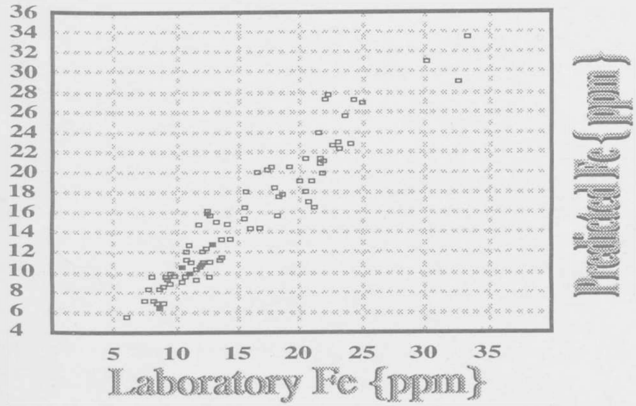

Figure 4. Pigment content in beef *longissimus* as determined by visual spectroscopy. Predicted values vs. laboratory results. R2 = 0.91; RSD = 1.96 ppm.

The equipment and model were subsequently tested on an independent test set consisting of 84 carcasses with rather convincing results. Pigment content is predicted with correlations (R2-values) better than 0.8 to the corresponding reference values, and with RSD-values of 2 to 4 ppm iron content (range 6.2 - 32.6 ppm) (see Figure 4.). More importantly, in the cases of veal calves and young bulls, pigment content proves to be a reliable predictor of meat colour. Visual inspection of cuts sorted after pigment content with the pigment prototype shows that they are correctly ranked with respect to colour. The same is corroborated by correlations (R-values) of the order 0.9 between pigment content and Hunterlab L-values.

Furthermore, it was shown that the correlation (R-value) between pigment content in *longissimus* and *semitendinosus, triceps brachii, biceps femoris* and *semimembranosus* is generally better than 0.9 for veal calves and young bulls. For cows the correlations are poorer, of the order 0.7 to 0.9 dependent on muscle type.

In conclusion for cattle, sorting in colour classes after pigmentation is feasible for veal calves and young bulls, but less successful for cows.

Protein

The protein content of meat is mostly interesting in relation to the processing of fresh meat into finished products like bacon, cooked ham, etc. During this processing, salt and water are added to the meat in amounts dictated by the protein content of the latter, as national and international legislation give limits to the protein-water ratio in the products. From this it follows that knowledge of the protein percentage in meat is a prerequisite for an optimal processing, and hence to an optimal economy.

To complicate matters, protein contents vary from muscle to muscle in a slaughter animal and protein levels are different between individual pigs. Danish slaughter pigs, for example, depending on fibre type have protein contents in their muscles varying between 18 and 24 %. The protein content is also dependent on breed, and, to a lesser extent, slaughter weight and feeding. This large variation, which is a relatively new phenomenon, is caused by the extensive use of crossbreeds in Denmark, and it has resulted in lowered curing yields in order to comply with the above mentioned legislation.

The Danish Meat Research Institute is currently engaged in a project aiming at remedying this situation by developing equipment capable of determining protein contents in unhomogenised muscular tissue, either as an on-line technique on freshly killed slaughter animals, or alternatively on cold muscles immediately prior to curing.

In this case also, a polychromic reflectance spectroscopic technique utilizing fibre optical insertion probes was chosen (Figure 5.). However, the near infrared wavelength range appeared more suitable for protein determination.

The project has been under way for some years now, but it has been pestered by being on the forefront of current state-of-the-art technology. Until recently difficulties were encountered in finding suitably transparent optical fibres and sufficiently sensitive detectors for the wavelength range of interest (800 - 1600 nm). However, these difficulties are now diminishing, and promising results are beginning to appear.

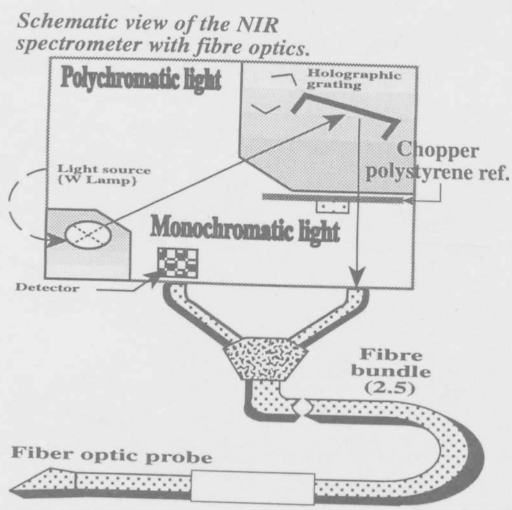

Figure 5. The principle of the near infrared measuring equipment.

In a recent experiment 386 carcasses were subjected to measurements in one position in the *semimembranosus* approximately one hour after slaughter. The spectra obtained were compared to reference results obtained by either an automated Kjeldahl or Dumas technique, which are indistinguishable in terms of precision and accuracy. The best models developed so far based on combined partial least squares - neural network data treatment yield R2=0.55 between prediction and actual concentration. It should be commented that the variation range in protein of individual types of muscle is very narrow (3%), making it extremely difficult to obtain very high correlations. The RSD-value is 0.45%, or in other terms comparable to twice the standard deviation on the reference results.

Boar taint

Amongst quality characteristics is also the absence of any off-odours. This may appear evident and it is normally considered a given property of unspoiled meat or meat products. Off-odours due to feed ingredients can be controlled via advice to farmers and feedstuff companies. However, when slaughtering uncastrated male pigs the scenario is a bit more complicated.

It is an undisputed fact that meat from a percentage of uncastrated males exhibits an unpleasant odour when heated, and this so-called boar taint has until now prevented large scale production of entire males. On the other hand, production of entire males results in a number of advantages. Uncastrated male pigs grow faster on less feed, yield a higher percentage of lean meat in the carcass and are generally healthier when compared to castrates. Consequently, the economic incentive in avoiding castration is strong, as well as the animal welfare aspect.

Danish experience gained during the last 10 years has documented that the occurrence of tainted carcasses can be kept at or below 5% (see Figure 6.) which makes production of entire males with subsequent outsorting of odorous carcasses attractive.

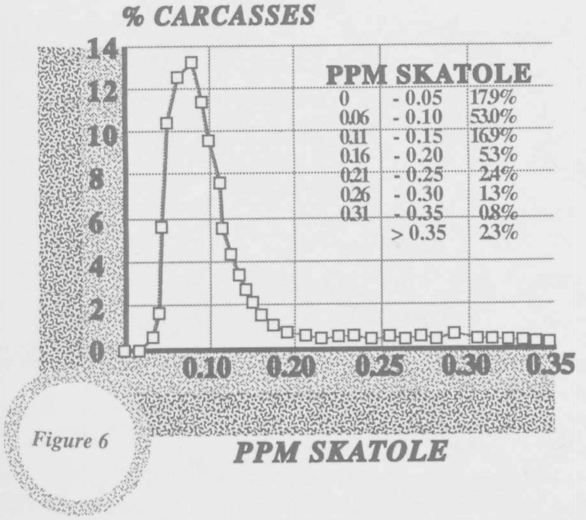

Figure 6. Distribution of skatole in Danish uncastrated male pigs. Data from approximately 100.000 pigs is included.

Boar taint is probably caused by a mixture of chemical compounds and much effort has been devoted to elucidating their individual structures. So far, at least two candidates are known, i.e. skatole (Vold, 1970; Walstra and Maarse, 1970) and androstenone (Patterson, 1968). Skatole is a metabolite of the essential amino acid tryptophan and androstenone is a metabolite of a male sex hormone.

In Denmark, most attention has been focused on skatole, as the evidence gathered on Danish slaughter pigs clearly shows abundance of this compound to be better correlated to off-odour as determined by a sensoric panel than that of androstenone. Experience gathered elsewhere seems to indicate differently, perhaps because of differences in slaughter weight, breeds, feed, tradition etc. Consequently, the Danish system for outsorting of tainted carcasses is based on skatole determination and quantification. The sorting limit, determined by multiple sensoric analyses, is 0.25 ppm skatole.

The Danish Meat Research Institute has developed a high capacity (180 determinations per hour) automated analytical procedure based on spectrophotometric determination of skatole in backfat (Mortensen and Soerensen, 1986). Samples are collected at the slaughterline about 40-60 minutes after sticking from all male carcasses and they are subsequently shipped to and analyzed in a nearby laboratory. Turn-around time from sample is taken till result is received is approximately 12 minutes, which is more than adequate for sorting after the chilling tunnel. The individual steps in the analytical procedure are shown in Figure 7.

Sampling
↓
Weighing
↓
Addition of solvent
↓
Homogenization
↓
Chilling and filtration
↓
Addition of colouring reagent
↓
Spectrophotometric measurement
↓
Calculation of skatole concentration

Figure 7. Unit operations in the automated skatole analysis equipment. Only the sampling is manual; all other operations are automated.

Such automated analytical equipment are currently being installed on all Danish pig slaughterlines. The last installation is scheduled to take place August 1993. After this time it is in principle, up to the individual farmer whether he wants to rear entire male pigs or not. (It might be of interest to add that less automated, and hence less costly versions of the skatole analysis equipment based on the same patented procedure also exist. Such a semi-automated, bench-top analogue, for example, capable of analysing 50-60 samples per hour is currently in use in Sweden (Berg, 1992)).

Conclusion

From the preceding remarks it should be clear that the Danish slaughter and meat processing industry is investing a great deal of effort and money in developing new technologies making it possible to meet requirements regarding quality issues.

It is likewise obvious that the effort is not always a successful one, either because of consumer's lack of willingness to pay more for a better quality, or because of lack of satisfactory precision or accuracy in the developed measuring devices.

However, the Danish Meat Research Institute will continue to pursue new achievements within this field of research and development, and new detection methods for early quality assessment based on video image analysis, nuclear magnetic resonance, ultrasound etc. in combination with advanced data handling techniques like multivariate calibration and neural networks are currently under investigation.

Also in the future will Danish slaughter and meat processing industry struggle to continue to produce meat and meat products of consistently high quality that fulfils the changing demands of our customers.

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