RECENT METHODS FOR PREDICTING QUALITY OF WHOLE MEAT

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ABSTRACT

The world of meat faces a permanent need of new methods for meat quality evaluation. Researchers want improved techniques to deepen their understanding of meat features. Expectations of consumers for meat quality grow constantly, which induces the necessity of quality control at the levels of slaughtering, meat cutting, and distribution. This article is focused on techniques intended to predict technological and sensory qualities from measurements carried out on fresh intact meat. pH has been measured since a long time, but its on-line determination still progresses through automation. In the laboratory, NMR provides new insights on WHC mechanisms. Image processing has considerably improved the assessment of meat appearance. Developments of techniques for prediction of toughness are in progress, either directly, through ultrasonic analysis or NIR reflectance, or indirectly, through determination of connective tissue content by fluorecence probes. Control of authenticity benefits from the last developments of molecular biology and analytical chemistry. However, implementation of methods for meat quality evaluation has been very limited in the industry. The reasons of that situation are analyzed. Among the techniques recently described, the most promising for large-scale meat quality evaluation are considered to be ultrasonic analysis, image processing and NIR spectroscopy.

INTRODUCTION

Obviously, the concept of food quality varies dramatically according to the economic development level of the human groups. The few people whose meat supply still depends on hunting do not have the same regards towards a piece of meat as the overfed inhabitants of the most developed countries. Nevertheless, it seems reasonable to think that meat consumers have been concerned always and everywhere with the safety and the sensory quality of food, in particular meat. But recently, say in the present century, new expectations have been born and are still growing. In industrial societies, purchasers of any product are expecting an optimal quality/price relation and constancy in quality. This is true for the manufacturers who buy raw material for further processing as well as for the end consumers who purchase consumer goods. This has led to increasing demands, particularly in the last three decades, for :

- technological quality, due to the strong industrialization of meat processing
- guarantees of safety and eating quality, from consumers having an extensive choice of food commodities
- authenticity, a concept which includes many aspects such as adulteration, improper description of the products, origin designation...

Thus the agents of the fresh meat production chain are facing a still increasing need of techniques for meat quality evaluation. In parallel, meat research has developed in tremendous proportions. In every domain of meat science, researchers need access to new techniques in order to go deeper and faster in the comprehension of the mechanisms underlying meat quality.

The present article will focus on techniques intended to predict technological and sensory qualities, and applicable to fresh intact meat, for use in the industry as well as in research laboratories. A unique characteristic of the meat industry segments working with carcasses or meat cuts is that they deal with a very unconstant matter, divided in numerous pieces of reduced individual size and value. Generally individual evaluation is needed for each piece, which evidently determines the acceptable rate and cost of measurements.

PH

pH is probably the quality attribute most commonly measured in fresh meat, as it affects technological ability, keeping ability and most sensory traits. In France, ultimate pH measurement has been used in pig selection since 1981, and it is routinely performed on most hams entering processing plants. Traditionnally, pH is measured using a voltmeter equipped with a glass electrode. Recent progress has consisted in a dramatic reduction of time needed for measurement and in automation. Response-time of the most recent electrodes is less than 2 seconds, allowing on-line measurements at a rate of 1000 per hour. Automation

of on-line pH measurements has been realized, with a potential rate of 1300 carcasses or 2000 hams per hour (Reichert, 1996).

Early prediction of ultimate pH would be of interest to sort DFD beef carcasses from the end of the slaughterline. Recently, techniques relying on local electrical stimulation for 1 to 3 min followed by pH measurement were developed (Braathen, 1993; Hald et al., 1993). So far, it seems that none of these techniques were put into practice, although they could be rather easily carried out on beef slaughter lines working at a rate of 50-60 carcasses per hour, and possibly could be automated. Perhaps, the decrease in DFD meat frequency resulting from improvements of slaughter conditions has reduced the interest of slaughterers for pH prediction.

Changes in muscle energetics are easily monitored by ^{31}P NMR (Nuclear Magnetic resonance) which measures phosphorylated compounds such as ATP, creatine phosphate, sugar-phosphates and inorganic phosphate (Pi). The pH can be evaluated from the position of the Pi resonance. NMR presents several advantages over chemical techniques. It can be used in vitro on muscle samples, but also non-invasively in vivo on small and medium-sized meat animals (Monin and Renou, 1989). It avoids the variability inherent to repeated sampling. ^{31}P NMR makes it possible to investigate pH heterogeneity within muscle tissue. A broadening or splitting of the Pi resonance may occur in post mortem or excised muscle. It was attributed to the existence of cellular micro-compartments with different internal pH values (Renou et al., 1986). Post mortem metabolism and pH changes were studied using ^{31}P NMR in muscles from various meat species (Lundberg et al. 1987 ; Moesgaard et al., 1995 ; see the latter for further references). In pork, Miri et al. (1992) proved the possibility of predicting the ultimate quality (normal, PSE, DFD) from excised muscle samples measured at 30 min post mortem. Thus NMR has proved to be a unique tool for study of post mortem muscle metabolism and pH changes, but its interest is limited to the laboratory area.

SENSORY QUALITY

Appearance

Appearance is one of the main traits determining purchase decision and acceptability of meat. It relies on three main factors: colour, amount of visible fat (marbling) and wetness (exudation). In the USA, marbling constitutes the basis of beef quality grading.

Meat colour depends on pigment concentration, pH, amount of intramuscular fat (IMF) and oxido-reduction status. It is traditionally assessed by photometric or spectrophotometric methods (reflectance, CIELAB or chromatic coordinates), using external (surface spectrophotometers) or internal (optic fibres) measurements. The principles underlying colour measurement and some related problems have been extensively discussed by Swatland (1995a). Portable spectrophotometers are convenient for carcass color grading in industry, as correlations of colour parameters with colour grading by experts are high (Denoyelle and Jabet, 1997). Recently, Gerrard et al. (1996) predicted fairly well sensory colour scores of beef steaks using colour image processing (R^2=0.86 between scores and image features). Image processing is suitable to follow beef discolouration during retail display (Ringkob, 1996, 1997). The advantages of image processing are evident. It is absolutely non-invasive, needing no contact between the equipment and the analyzed product. It can be used on film packaged meat without opening the package. Being applied to the whole meat joint, it can ensure that no visible defect potentially detrimental to consumer acceptability is forgotten. Clearly this technique is of immense interest in experimental work as well as in packing industry and trade. An other potential field of application is the poultry industry, where discolouration of packaged turkey steaks is a very serious problem.

Visible fat involves IMF (marbling) and intermuscular fat. Marbling is an important indicator of meat quality, which is visually estimated in some carcass grading systems. High marbling may be wanted (for beef in the USA and Japan, for instance) or unwanted (for pork in France, Fernandez et al. 1998). Marbling can be quantified by image processing in beef (Gerrard et al., 1996) as well as in pork (Scholz et al., 1995). Marbling structure can be described quite accurately (number, size and shape of fat deposits) with this technique (Gerrard et al., 1996 ; Albrecht et al., 1996), which should help to better understand the relationships between marbling traits and consumer acceptability.

Intermuscular fat is important for consumer acceptability of meat commodities containing several muscles, as lamb legs, pork and lamb chops or ham slices. High amounts of intermuscular fat are undesirable. To our knowledge, no tentative has been made to quantify specifically the intermuscular fat in carcasses or joints. Quantification can be performed rather easily in cuts using video-image analysis (Swatland, 1995a). Another potential technique is ultrasound echography, which can be applied on whole

carcasses or cuts (hams, loins, shoulders). However the automation of this technology for industrial practice gives problems (Chanet, 1997). Xray-computerized tomography as well as magnetic resonance imaging (MRI) allow precise quantification of intermuscular fat (Foster et al., 1989 ; Vangen, 1989), but their use is yet limited to laboratory studies. Recently, Barra et al. (1998) documented the possibility of obtaining 3-D images and quantifying automatically intermuscular fat from whole hams, using whole-body medical MRI equipment.

Fluid exudation is particularly detrimental to commercial appearance of prepackaged meat, firstly pork but also beef and veal. Water holding capacity of fresh meat is assessed with methods which basically have not changed since decades (filter paper press method, Grau and Hamm, 1952 ; centrifugation : Wierbicki et al., 1957 ; absorption of water by a paper strip, Goutefongea, 1971 ; drip : Penny, 1977). Progress in methodology has been marginal even though accuracy has been noticeably improved through a number of studies (e.g. Kauffman et al., 1986 ; Irie et al., 1996). Water holding capacity of meat depends primarily on the extent of the post mortem myofibrillar shrinkage and the correlative changes in the extracellular water compartments (Offer and Knight, 1988). These changes have been studied by microscopy and X-ray diffraction (Irving et al., 1990). An other way which has been relatively little investigated is NMR relaxation measurement of water protons, which gives information about dynamics of water. The general features of proton relaxation in muscle are characterized by longitudinal relaxation time (T_1) and transverse relaxation time (T_2). In rigor muscle, a multicomponent T_2-relaxation behaviour is observed, which has been related to water distribution (Fjelkner-Modig and Tornberg, 1986 ; Tornberg and Larsson, 1986 ; Tornberg et al., 1993). These autors considered that three water compartments could be identified. The longest T_2 was regarded as corresponding to "free" or "expelled" water (no more than 1 % of total water). The major fraction of water (about 80 %) had the shortest T_2 and was considered as mainly held by the myofibrils. Tornberg et al. (1993) showed the possibility to estimate the water compartment outside the fibre bundles from NMR measurements. Magnetic resonance imaging (MRI) provides maps of relaxation times in the tissue on a supramolecular scale. Foucat et al. (1995) mapped T_2 and water diffusion coefficients along (D_z) and across (D_x) the muscle fibres of rabbit muscle. They concluded that structural changes such as the variation in the spacing of the actin-myosin lattice are well described by the post mortem evolution of T_2, D_z and D_x, and diffusion anisotropy (D_z/D_x). Obviously, ^{1}H NMR is a powerful technique to investigate the mechanisms of water dynamics and water holding in the muscle tissue. NMR relaxation measurements are currently used for control of some foods (grain, oils, wines...) but not yet in the meat industry, although it could offer a valuable tool for qualitative appraisal of meat features. A combination of T^1 and T^2 measured two hours after slaughter differentiated PSE from normal meat without fail (Borowiak et al., 1986). Significant relationships were found between relaxation parameters and meat characteristics such as ultimate pH, water holding capacity and cooking loss (Renou et et al., 1985 ; Fjelkner-Modig and Tornberg, 1986 ; Tornberg et al., 1993). The relatively long duration of the measurements (in the order of minutes) implies that the latter are made on large pieces of meat, which in turn is stopped by the high cost of equipment. Development of "out of magnet" methodology is promising to overcome this obstacle (Grosescu, personal communication).

Eating quality

Toughness

Toughness of meat depends on the connective tissue, the state of the myofibrillar structure and the structural interactions between fibres and extracellular matrix (Dransfield, 1997). Numerous tentatives have been made to estimate toughness directly through mechanical measurements, or indirectly through its relations with meat components.

Direct measurements

A number of techniques have been proposed to measure meat toughness using mechanical measurements. However, according to Tornberg (1996), there has been no real progress in this field since the thirties, when Bratzler (1932) conceived the well-known Warner-Bratzler shear device. As pointed out by Tornberg, the Warner-Bratzler technique is the instrumental technique that usually yields the best correlation with sensory panel scores for meat toughness. Moreover mechanical tests are destructive and time-consuming. A technical jump was recently made by Hildrum et al. (1994), who showed that sensory hardness and tenderness can be predicted by NIR spectroscopy (reflection mode). This technique is rapid and non-destructive when applied on meat cuts. Byrne et al. (1997) confirmed the good potential of NIR spectroscopy for predicting toughness. They predicted Warner-Bratzler shear force at 14 days from reflectance spectra obtained on the first day after slaughter (r=0.79 for 39 heifers

of similar age, size and grade). However weaker relationships were achieved for sensory tenderness and texture. They concluded that further work is required before NIR can be established as a reliable meat quality indicator. Park et al. (1994c) tentatively measured beef tenderness, juiciness and flavour using ultrasonic spectral analysis. Accuracy of their prediction models was not adequate for use as a tool in practice, but they considered that this approach had potential for non-destructive sensory attribute measurements. One advantage of ultrasonic methods is that they can be applied on whole carcasses.

Indirect assessment

The amount, type and distribution of connective tissue in meat are clearly responsible for toughness differences among cuts within a carcass. In contrast, the role of connective tissue in toughness variability among carcasses for a given cut is still a matter of debate among scientists (Purslow, 1994 ; Swatland, 1995a). The main components of connective tissue are collagen and elastin. Rapid physical methods of collagen quantitation have been proposed during the past decade. Andersen et al (1993) reported a close correlation between NIR reflectance measured owing to an optic probe and collagen content in beef. However, to our knowledge, they did not confirm the possibility of using this device for industrial evaluation of meat. Swatland (1991) estimated the meat collagen content by measuring the natural fluorescence of collagen using a fiber-optic probe. Swatland (1995a) and Swatland et al. (1995) found relationships between features of the fluorescence signal and chemically determined collagen content. Multiple correlations between fluorescence features and sensory data were in the magnitude of 0.5-0.9, depending on the type of meat. The correlations were much lower in Canada Grade A carcasses than in Danish dairy beef. This would indicate that, as expected, collagen made a more substantial contribution to toughness in cull dairy cows than in beef cattle. Recently, Swatland (1997) showed that variations in pH and myoglobin concentrations can cause noticeable errors in the detection of connective tissue fluorescence by optic probe. This difficulty might be overcome by simultaneous determination of myoglobin and pH-related scattering by extra optic probes. Wold et al. (1997) described a method for rapid determination of connective tissue by macroscopic fluorescence emission spectroscopy. The technique needs to mince a meat sample and thus it is of limited practical use for carcass grading in industry.

Study of the connective tissue has been carried out using magnetic resonance microscopy (MRM) (Barra et al., 1998). 2D-images have been obtained with a spatial resolution of 50 µm, which allows to visualize the perimysium. Further work is in progress to obtain 3-D images, which hopefully will give new insights on the spatial organization of meat structural components and its relations with meat quality.

Toughness is also affected by both the state of contraction (sarcomere length) and the degree of degradation of the myofibrillar structure due to ageing. The detailed relations between the physical/chemical state of myofibrils and toughness are still controversial (Tornberg, 1996), nevertheless attempts have been made to predict the rate of meat tenderization, considering that the more aged the more tender the meat. In the laboratory, sarcomere length is usually measured from a suspension of myofibrils using laser beam diffraction. Swatland (1995b) investigated the suitability of NIR birefringence measurements for sarcomere length assessment in pork. He observed that birefringence is proportional to the overlap of thin and thick filaments until alignment is disrupted by severe shortening (sarcomere length _ 1.5 µm). Clearly, these results are encouraging. However acceptable results may only be obtained from meat that has preserved the degree of sarcomeric order and fiber alignment found in live muscle, which does not always occur. NIR birefringence proved also to be suitable to predict water holding capacity and cooking loss in turkey meat (Swatland and Barbut, 1995).

The main problem encountered with meat ageing is the great variability among carcasses in the rate of tenderization, particularly in beef. In France and probably in a number of other countries, meat is generally retailed within one week after slaughter. Certainly a noticeable proportion of meat is not fully aged, and thus has not reached its potential tenderness. So, some retailors, mainly supermarket companies, require that carcasses are kept at least 2 weeks after slaughter by the slaughter plant. This results in an unjustified storage cost for the fast-tenderizing carcasses. Lepetit et al. (1996) determined the degree of beef ageing by mesuring the resistance of the muscle fibres using a compressive method. At day 2 after slaughter, they were able to predict rather well the further tenderization of meat. In their experiment, resistance at day 2 varied from 10 to 40 N/cm^2. All samples with resistance lower than 20 N/cm^2 were fully aged at day 8, while about 2/3 of the other samples were not. The method should allow to sort the beef carcasses in function of the foreseable time for full ageing, thus optimizing the quality/storage cost ratio for every carcass. Post rigor calpastatin activity accounts for a significant part of variation in beef toughness (Whipple et al., 1990). This may be related to the close relation observed between the rate of calpastatin decline in post-mortem muscle and the

rate of meat ageing (Zamora et al., 1996). Doumit et al. (1996) developed an ELISA assay for rapid calpastatin quantification. The aim of this work was to facilitate the studies on the involvement of calpastatin in growth and muscle tenderness. Such an assay could be useful to screen carcasses for potential tenderization.

Flavour

As flavour develops during cooking as a consequence of a complex set of reactions, it is difficult to predict it from analysis of raw meat. It is known, however, that IMF, peptides, glucides and volatile compounds play a prominent role in flavour development. Quantitation of IMF is possible on the slaughter line in pork carcasses using optic probes (Borggaard et al., 1989). Ultrasonic A-mode and ultrasonic frequency analysis techniques allows non-invasive determination of IMF (Park et al., 1994a, 1994b). Recently, Egelandsdal et al. (1996) used NIR reflectance and autofluorescence to assess IMF in beef. Both techniques had similar accuracy when the amount of IMF was above 2 %. For lower levels, the fluorescence technique proved to be better than NIR.

A number of chemical techniques have been developed to predict boar taint in male pig carcasses. Accurate detection of pork susceptible to develop boar taint at cooking is of immense economical interest, as production of entire male pigs presents numerous advantages (see review paper by Bonneau, 1998, in Session 10). Most methods rely on chemical determination of skatole and androstenone, although the exact role of each compound is still matter of debate. A spectrophotometric method for the measurement of skatole has been automated early in Denmark (Mortensen and Sorensen, 1984). Equipment has been installed in every Danish pig slaughterhouse (Andersen et al., 1993). It can deal with 180 samples per hour, but it measures only one of the involved compounds. Androstenone measurement has been much improved during the last decade, however there is still a long way to go before an industrial method is available (Bonneau, personal communication). Analysis of volatile compounds from fat offer an alternative for boar taint detection. Pyrolysis coupled with direct mass spectrometry has been proven suitable to discriminate pig backfat with low (<0.7 ppm) or high (>1.6 ppm) androstenone content (Berdagué et al., 1996). Classification using artificial neural network was 100 % accurate. However, it would be necessary to confirm the practical interest of this technique by investigating its reliability in the whole range of androstenone contents encountered in practice. Multi-gas sensors ("electronic noses") are potentially usable to assess boar taint (Bourrounet et al., 1995 ; Annor-Frempong et al., 1997). Their practical use is still limited by their extreme sensitivity towards humidity, lack of long-term stability, and memory effects which makes it necessary to wait several minutes between consecutive measurements with the current devices.

TECHNOLOGICAL ABILITY

Cured cooked meat

Curing-cooking technology is extensively used for meat preservation. Meat may be cured and cooked as whole joints (shoulders, hams) or as minced and mixed with variable proportions of fat (sausages, luncheon meat, patties, etc...). It has been known for long that pH, protein concentration and protein denaturation are prime factors of technological ability, as they determine WHC and emulsifying capacity. Therefore they strongly affect cooking loss. Evaluation of WHC has been discussed earlier. The dominant RN- gene markedly decreases pork curing-cooking yield. Moreover there is some evidence that ability to slicing by very fast modern slicers is impaired in cooked ham from RN- carrier pigs. The losses experienced in slicing and packaging ham may reach more than 50 % in extreme cases (review by Monin, 1995). Recently Lundström and Enfält (1997) developed tests to identify RN- meat. These tests rely on the rapid determination of glycolytic compounds or osmolality in meat juice. Of course they cannot be applied on every ham entering the processing plant, but they seem suitable for control by analysis of random samples from ham batches.

Dry-cured hams

The main factor known to determine processing yield of dry-cured ham is fresh ham composition. Processing yield decreases with increasing lean percentage. The lean content of hams can be estimated accurately in the industry using automated electromagnetic scanning, also referred to as TOBEC, i.e. total body electrical conductivity (Meseck et al., 1997). Determination coefficients between lean weight in the joint and conductivity features reach 0.95. Video-image analysis is also suitable to sort fresh

hams before processing (Gigli et al., 1996). Information on shape, fat content and meat quality (colour) are obtained simultaneously. Another suitable method to estimate cover fat thickness of meat joints is ultrasound echography (Chanet, 1997). However, as noted above, its automation still gives problems.

Excessive proteolysis is sometimes observed in long-aged dried hams. It results from an abnormally high cathepsin B activity in the muscle tissue (Virgili et al., 1995). The defective cured hams show a white surface film and a mushy mouthfeel. Moreover they are difficult to slice. Virgili and co-workers developed a test for identification of fresh hams prone to this defect, by rapid colorimetric determination of cathepsin B activity (Virgili et al., 1995).

AUTHENTICITY

Authenticity has probably always been a major concern of many consumers (Hargin, 1996), and it is still gaining more and more importance. Carcass grading in most countries implies knowledge of sexual type and maturity. Since 1998, French beef retailors must indicate the country of origin and the type (cow, steer, heifer, bull - meat, dairy or dual purpose) of the carcass from which the cuts displayed for sale originate. This is one positive consequence of the BSE crisis which occurred in Europe in 1996 and resulted in a marked beef consumption decrease. Abou El Karam and co-workers investigated methods to classify meat samples according to anatomical location, age, and sexual type. They obtained comparable results (i.e. 70-90 % correct classification) using image texture analysis (Basset et al., 1995) or ultrasonic measurements (Abou El Karam et al., 1997). These results were encouraging with respect to the small variation in chemical composition (dry matter, lipid, collagen) of the studied muscle samples.

Hargin (1996) listed the authenticity problems encountered in the UK, and the corresponding available methodology, in a well-documented article. He noted that each country has specific concerns and priorities in this area. In Europe, the main authenticity issues dealing with fresh meat are origin, breed within a species, irradiation, previous freezing and ageing. Various methods have been proposed in the past for identification of frozen and thawed meat, relying on electrical properties (Salé, 1972) and enzyme activity determination (Gottesman and Hamm, 1983). Recently, Thyholt and Isaksson (1996) proved the suitability of NIR spectroscopy for identification of frozen and thawed beef. They obtained 100 % correct classification by collecting spectra between 1100 and 2500 nm from intact beef slices. Downey and Beauchêne (1997) obtained slightly less good results (95 % correct classification) by scanning in the range 650-1100 nm. The technique is applied on intact meat and takes only a few minutes. In both cases, the authors considered their study as a preliminary one and they announced that they meant to carry on with the investigation of the method. Thus we should wait for further developments of this promising technique.

Products with origin denomination generally are high-priced and bring in a higher benefit to the producers than ordinary products. So there is a need to protect such products by detecting possible cheating. These products are defined by geographical origin, know-how and in some cases by feeding diet and animal breed. For instance, the top quality Iberian dry-cured hams must be made from pigs with a minimum of 75 % Iberian blood and exclusively finished on pasture, which gives them a unique flavour of acorn (see the review paper of Lopez-Bote, 1998, in Session 1). Breed type can be assessed using DNA markers (Castellanos et al., 1997). Fattening diet can be controlled by the subcutaneous fat composition (Diaz et al., 1996) or NIR transmission spectroscopy coupled to artificial neural networks (Hervás et al., 1994). Research is currently in progress to develop techniques indicative of geographic origin. Viallon et al. (1998) were able to verify on cheese some traits of the forage fed to the dairy cows using CPG-mass spectrometry of terpenic compounds. A similar methodology allowed to determine from subcutaneous fat some specific elements of the flora grazed by cattle finished on pasture (Berdagué, personal communication). Research is in progress to assess if such a methodology is suitable for pigs. Stable isotope ratio analysis by mass spectroscopy and site-specific natural isotope fractionation by NMR are successfully used for geographic origin determination of oils, fruit juices and wines. Their interest for meat has been questioned (Hargin, 1996) but certainly they deserve investigation.

In the USA, manufacturers of fresh sausage products often purchase strictly sow meat at a premium price (Meer and Eddinger, 1997). In France, sow meat is preferred for dry sausage making. DNA-PCR tests for sex identification have become available recently (Meer and Eddinger, 1997 ; Lockley et al., 1997).

EVALUATION OF MEAT QUALITY IN LIVE ANIMALS

Methods for identification of genes detrimental to meat quality are routinely used (DNA-test for halothane sensitivity, muscle biopsy for the RN- gene). Lahucky et al. (1993) used ^{31}P-NMR combined to an efficient biopsy technique for both assessment of halothane sensitivity and prediction of meat quality in live pigs. Intramuscular fat can be measured non-invasively in live animals by ultrasonic echography (Park et al., 1994a, 1994b) or ^{1}H-NMR spectroscopy (Geers et al., 1995 ; Villé et al., 1997). ^{31}P-NMR spectroscopy allows to measure intracellular pH and energy metabolism indicators in live piglets (Monin and Renou, 1989). All these techniques are of obvious interest for genetic selection for muscle composition and meat quality. However, the results so far published using non-invasive NMR in live meat animals were obtained on piglets of less than 25 kg, which limits their practical interest. Bonny et al. (1998) have investigated the possibility of assessing the metabolic type of rabbit muscles by ^{1}H NMR in vivo. They found that predominantly slow-oxidative muscles have higher T_2 than the other ones. This finding allowed them to map the metabolic type of muscles in transversal images of the rabbit thigh. This methodology is very promising for in vivo metabolic type assessment, altough further investigation is still needed to improve its sensitivity. As the authors worked with a whole-body medical spectrometer, the technique could be applied easily to relatively large animals (100 kg pigs).

REQUIREMENTS THAT NEW METHODS SHOULD MEET

The requirements for laboratory methods are well-known : sensitivity, accuracy and robustness. Of course, to reach a given objective, cheap and fast techniques will be preferred to complicated ones. But, at least in rich countries, complexity and cost of equipment are scarcely a real obstacle to the implementation of an analytical method, when the need is really justified. The problem is totally different in the meat industry.

Considering the number of objective methods which have been proposed by researchers for more than sixty years for meat quality evaluation (Callow, 1936, with pH and conductivity measurements), the number of them which have been implemented in the meat industry is surprisingly low. Animal selection is probably the sphere in which the greatest number of techniques are in use, because it deals with limited numbers of animals (hundreds or thousands annually) and it can afford methods with relatively high costs. In slaughter and processing plants, the number of methods utilized for evaluation of fresh meat quality can be numbered on the fingers of one hand. Evidently, one cause of this situation is that most techniques have not met the industrial and commercial requirements.

The key words of success for any evaluation technique in the meat industry are :

- existence of a real need and an assured (not only hypothetical) benefit
- direct relation to the desired quality traits of the end product
- reasonable prediction accuracy
- realistic cost, taking into account the unitary value of the evaluated carcasses or joints
- rapidity, to comply with slaughter, cutting or packing rates of several hundreds or even thousands per hour
- potential full automation, particularly when high rates of measurements are needed
- non-invasiveness, as with the continuously increasing concern of safety, non-invasive techniques will be clearly preferred

Let us for example analyze the case of on-line evaluation of pork technological quality. It has been a matter of research for the last 30 years in many countries. The objective is to sort the carcasses or joints, either before or after chilling, in order to direct them towards the most appropriate process. Nowadays, the only technique which is applied on a large scale in the French pork industry is the measurement of ultimate pH, a few decades after it was proposed as a predictor of processing yield (Hamelin and Teffene, 1969). I am not aware if any other technique is carried out routinely on an industrial scale in any other country. Reichert (1996) wrote recently a review on possible methods for selecting pork carcasses and cuts according to quality. He concluded that it was impossible to say, after examination of the available literature, whether any of the examined techniques (i.e. pH, electrical conductivity, dielectric loss factor, impulse impedance, reflexion, fiber optic probe, colour) can provide adequate information on the ham technological quality, except pH. He attributed this to various causes, the first one being that "when using indirect measurement parameters *(for meat quality assessment)* attempts were repeatedly made, although they measure different properties, to relate **them to one another,** that is, for instance, to determine the correlation between pH and conductivity, instead of relating the measurement parameters, e.g. pH or conductivity **directly** to the sensory characteristics of the coo-

ked meat product or to the final quality, e.g. of a cooked ham". I agree with him. In most French cooked ham processing plants, pH is routinely determined to control every ham entering the plant, although other measurements, such as electrical properties or FOP measurements, would be easier to perform. That is because :

• there is a real need of controlling fresh ham quality when making a cooked ham without any water holding additive

• pH has been repeatedly shown to be the best among the known predictors of technological yield (Jacquet al., 1984) ; the accuracy of prediction is not very high (r of the order of 0.7) but in any case better than that of any other examined technique (FOP, dielectric loss factor, reflectance, WHC, subjective scoring)

• consequently, a range of pH is specified in the contracts of meat purchase, and it is needed to control that specifications are respected

• the rate of measurement (manually performed) reaches 600-800 hams per hour, making the technique rather cheap

• the technique is non-destructive and little invasive

Currently measurements are performed manually, but there is a potential for automation.

CONCLUSION

Among the numerous techniques which have been proposed for meat quality evaluation on the fresh intact product, very few meet, even potentially, the requirements of industry. While instrumentation has progressed tremendously at the laboratory level, permitting a better understanding of the mechanisms underlying meat quality, application of this knowledge to quality evaluation in the meat industry remained very limited. As Swatland et al. (1994) noted it : "introducing new technology into meat industry, at the level of slaughtering, meat cutting, and distribution, is not easy". Among the techniques which have been recently described, I think that the most promising for large-scale meat quality evaluation are :

- ultrasonic measurements, for assessing potential texture on live animals and whole carcasses, mainly because of their non-invasive character and low cost

- for meat joints and cuts, image processing and NIR spectroscopy

Image processing has proven ability to assess basic acceptablity traits, namely colour and marbling ; it is totally non-invasive and obviously, use of this technology could greatly improve control quality in meat industry. NIR spectroscopy has a large potential range of applications, from toughness prediction to frozen-thawed meat detection. However more information on its real capabilities in industrial conditions is still needed.

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