New Sensors and Techniques for Meat Quality Measurements

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Introduction

Extensive efforts are currently devoted to developing techniques for evaluating the quality of pork and beef meat in abattoirs. There is a strong desire for these techniques to become the new generation of grading equipment, some would say it's a strong need. Increasing national and international competition, and increased customer demands are the driving forces behind the current technological push. The purpose of this paper is to present the status of some of the cutting edge technology that is currently being investigated for meeting the meat quality measurement demands. The paper focuses mainly on the techniques utilized and on the applications currently investigated, with less focus placed on the results.

Laboratory Methods for Meat Quality Evaluation

To a large extent, meat quality is being defined from the scientific ability to measure it. As a natural consequence of this, the laboratory tests have usually been regarded as the truth in the determination of the meat quality. For pork, the quality matter is usually connected with the PSE/DFD status and therefore closely related to color/paleness and water holding capacity. For beef, the quality problems are more concerned with tenderness and marbling. The laboratory methods are therefore highly focused on determining these characteristics in meat. The approach regarding the development of on-line techniques, is usually to reproduce the laboratory measurements with a faster technique that is applicable directly on the slaughter line.

Color Measurements

Color measurements are more important for the visual impression of the meat than as an actual quality parameter. Color measurements are influenced by 1) the actual color, paleness, and myoglobin in the meat, and 2) the optical properties and light scattering effects on the meat surface. Color is usually measured in the Cielab L*a*b* scale where L* denotes the brightness, a* the red-blue color, and b* the green-yellow color. Other standards (e.g. XYZ and YIU) exist, but L*a*b* tend to be the most commonly used for color representation, often measured with a Minolta Cromameter. For more on color measurements, see Swatland (1994), Wyszecki and W.S. Styles (1982), and Publication CIE No 15.2.

Water Holding Capacity

Water holding capacity (WHC) has been approached by several techniques with varying success. Initially, filter paper methods (with or without press) were used for determining water bound physically in muscle fibers. However, the filter paper methods have been criticized for having a poor relation to the fluid drip observed in the retail stores. Drip loss methods usually measure the fluid lost from a 2.5 cm longissimus dorsi sample as percentage of the weight of the sample during a 48-hr period, as proposed by Honikel. A recent approach taken by the Danish Meat Research Inst. (DMRI) uses a plastic cup with a removable container. The advantage of this method is less manual labor and the possibility of measuring at several time intervals (e.g. 12 hr, 24 hr, and 48 hr). However, the correlation to Honikel's drip method has been low. Transportation loss and centrifugation have also been investigated as ways to study water holding capacity.

Marbling

Marbling has always been a major quality characteristic in beef. Due to the increase in leanness of pork carcasses in recent years, attention to the degree of marbling in pork has increased significantly. NPPC has published a five-scale marbling standard to be followed in breeding and for quality sorting in plants. The NPPC scores range from "devoid or practically devoid" to "moderately abundant or greater" (NPPC 1991). A more objective reference method is the chemical extraction of lipid with (e.g. ether). Extraction methods differ from visual scoring in that a vol-

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ume is being evaluated, whereas the marbling judgment inspects the surface only.

Subjective and Sensory Evaluation

As mentioned briefly above, subjective evaluations of the appearance of raw meat are used according to proposed standards. The meat quality evaluation from NPPC presents five-scale standards on color, firmness/wetness, and marbling. Similar standards exist from USDA and from meat research institutes around the world. Sensory evaluation of cooked meat by panels is becoming an independent science, with specific research and consulting groups. The task of representing end quality as seen by the consumer in a reproducable and interpretable way is important in today's meat research. For more on sensory science, see Cross (1986).

Tenderness

Standardized mechanical measurements evaluating the physical properties of meat have been widely used for tenderness of meat. Processes like penetration, compression, and shear have been analyzed, but the Warner-Bratzler shear force has gained wide acceptance as a standard mechanical indicator of tenderness (Swatland 1995). The meat is typically cooked to a internal temperature of 65.0 °C.

Spadaro et al. (1998) present a method for modeling the mechanical characteristics of beef. By a simulation of the human chew cycle, the stiffness and energy dissipated during the chew process were estimated from the modeled viscoelastic properties of meat. The results are encouraging with high correlation to sensory analysis. The method has the advantage of measuring raw meat, in contrast to the Warner-Bratzler method.

pH Probes

Measurement of pH both early post mortem and post rigor mortis have proven to be an important analytical measurement. Although pH change in the muscle as it develops into meat is not fully understood and explained, the pH decline post mortem is interpretable from muscle metabolism. pH measurements have been used in slaughter plants for determining PSE and DFD in pork. Kaufman (1986) reports the combination of light reflectance and post rigor pH were optimal in describing the drip loss. The pH-STAR probe is a pistol for determining the pH in plants. This system is manufactured by SFK Technology, and can be connected to a computer for on-line use.

Spectroscopy

Spectroscopy describes the wide field of spectrophotometric data collections. Many of the techniques have been well known for years, but are being more widely used industrially and analytically due to more advanced and accurate spectroscopic collection techniques with the use of computers. In addition, more intelligent data analysis of the typically large data sets is a key factor in the progress being made in spectroscopy.

Generally, spectroscopic data collection techniques can be separated into three main steps: excitation, sorting, and detection. Excitation (or illumination) denotes the input of energy into the sample. The light source and frequency is different for the various techniques: ultraviolet (UV) techniques use the wavelength range from 200-400 nm (e.g. with a Deuterium illumination source), the visual range is covered by the spectrum from 400-700 nm, the near infrared area ranges from 700-2500 nm, the area from 2500-5000 nm is often referred to as the mid infrared area and the area above 5000 nm is called as the far infrared range. Sorting refers to the reaction in the medium to the illumination. Typically the energy is absorbed by the sample, transmitted through the sample, and reflected from the sample surface. Detection is the collection of the desired data from the sample sorting of energy, as in measuring reflection from the surface.

A brief introduction to three spectroscopic techniques: near infrared reflectance, fluorescence, and vision techniques follows.

Near Infrared Reflectance

Near infrared reflectance (NIR) is probably the most used spectroscopic technique worldwide. The technique has been employed for analytical use for at least 70 years, and has been commercially available since 1940 (McClure, 1994). The technique has been widely applied in food quality investigation (e.g. seed analysis, milk, soybeans, tomatoes and sausages) to estimate protein and water contents, (Ellekjaer, 1994).

The light used for the excitation in NIR ranges from 700-2500 nm. The energy is partly absorbed, partly transmitted through the sample, and partly reflected from the sample as part of the sorting procedure. The reflection from the surface is sampled with a spectrophotometer, typically using a filter-based instrument, a diode array instrument, or by grating dispersion.

One of the advantages of the NIR technique is the penetration into the media. Usually, a depth of 2-4 mm is measured in a fat or meat object depending in the intensity of the illumination. Furthermore, the technique is non-invasive and allows further analysis of the sample. However, since some sample techniques in meat require the use of probes, the measurement can be invasive. Many sources give a genuine and good introduction to the NIR technique, (e.g. McClure, 1995).

Application: DMRI NIR Probe

DMRI developed a NIR system based on a halogen lamp, a filter based spectrophotometer sensitive between 900-1800 nm, a fiber optical cable, and an insertion probe. Dr. John Forrest of Purdue University and DMRI conducted an experiment in 1996 at the Danish animal testing plant in Foulum. NIR spectra were measured on pork at intervals of 30 seconds in five minutes at 35-40 minutes post mortem. Observations of the spectroscopic development in different wavelength regions revealed a relationship to drip loss with correlation of up to 0.7 (Forrest 1997).

A similar system was prototyped by SFK Technology. Here a combined Halogen and Deuterium lamp, a fiber optic cable, a spectrophotometer sensitive in the wavelength range 300-900 nm, and an insertion probe were used. The system is applied 24 hours post mortem with single measurements performed in approximately 2 seconds, enabling true on-line use. The system was tested on pork at Hormell in 1997 and the results are currently being evaluated.

Application: DMRI Fat Quality Meter

DMRI has also developed a NIR system for fat quality inspection: the Fat Quality meter (FQM). This system consists of a halogen lamp, 8 NIR sensors between 800-1800 nanometers, and a small computer unit. All components are combined in a portable pistol, which can also be connected to a network or an external computer for data downloading. The purpose of the system is to discriminate between fat, loose, and hard fat, which can be valuable information for the sliceability as well as the visual appearance. The system has been successfully calibrated to classify the samples according to the judgment of an expert classifier, and to predict the contents of iodine. The probe is currently being tested in Japan and will soon be tested in the US. SFK Technology has just initialized development of the system, and it will be available commercially within the next year. See Irie and Swatland (1992) for a similar NIR system with the same application.

Fluorescence

Fluorescence is a spectroscopic technique used in several food quality applications as such fish bone detection, wheat flour refinement, and sugar quality measurement. The principle in the technique is to illuminate the sample with a light at a specific excitation wavelength. The excitation provides an energy contribution to the electrons in the media, and will cause them to enter a higher energy stage. When the illumination is terminated, the electrons will drop back to the original energy level. In this way they emit the energy that was obtained during the excitation, and light is emitted at a higher wavelength than the excitation wavelength. The intensity of the emitted light is measured with a spectrophotometer. Different wavelength combinations are used for the various measurements.

Application: Connective Tissue Probe

Collagen and elastin are fluorescent. This fact was utilized by Howard Swatland who developed the prototype of a connective tissue probe using fluorescence. The system consists of a UV illumination, UV sensitive sensors, a fiber optic cable, and an insertion probe with an optical window. When passing through the meat, fluorescence peaks are registered at intersections with connective tissue. Swatland (1995) showed a correlation of 0.85 between the biochemically determined collagen and the fluorescence in beef meat. Since there is a relationship between the amount of connective tissue and tenderness, Swatland was also able to show correlations ranging from 0.63 to 0.86 between the fluorescence signals and taste panel evaluation (Swatland 1995). To the knowledge of the author, the system has not been commercialized.

Vision

Cameras using charge coupled device (CCD) sensors combined with computers and digital image analysis are becoming increasingly widespread in all industrial fields including meat inspection. Several research institutes and industrial companies are working with the techniques to automate slaughter and cut lines.

Application: Purdue Color System

The color vision system developed at Purdue University by Dr. John Forrest and Dr. Mark Morgan is one example of a vision system improving the process. The system is superior to most individual panelists in grading pork samples based on color, and provides a possibility of standardizing color measurements based on the impressions of the panelists/consumers.

Application: BCC

DMRI has developed a Beef Classification Center (BCC) based upon vision technologies. The system grades the carcasses at line speeds up to 300 carcasses per hour, with color, fat color, and shape information. The fat and color information is deducted from color imaging and the shape information is obtained by horizontal laser beams illuminated on the carcass. From the curvature of the laser beams, the shape information can be extracted. The system grades the carcasses according to the European EUROP standard, and has been calibrated to manual inspectors. Currently the system is being commercialized by SFK Technology, and set up in 6 Danish beef plants.

Chemometrics

Chemometrics is a term which refers to the combination of the field of chemistry with advanced multivariate mathematics and statistics. Spectroscopic techniques generate multiple variables, often with hundreds or thousands of wavelength measurements. There has been a need for new techniques to analyze the data. So far, chemometrics has been a successful answer to these needs by combining statistics with multivariate mathematics. Techniques auch as neural networks and partial least squares regression have been used in the Danish Classification Center, the Autofom, the Purdue Color Vision system, and the Beef Classification Center. For a more general introduction to the theory behind most of these chemometrics techniques see Martens and Naes (1992). Esbensen (1994) is an excellent introduction to the practical use of the techniques.

Ultrasound

Ultrasound consists of audio waves typically ranging from 20 kHz up to 15 MHz. The technique is fast and non-invasive, and has therefore been of natural interest in medical and biological applications.

Due to differences in acoustical impedance in different tissue types, ultrasound pulses will be reflected at the intersections between these tissues. In the pulse echo mode, which is most commonly used in animal science, the echoes returned to the ultrasound transducer are measured as a function of time. The position of the intersections can be estimated by knowing the pulse velocity in the medium. The depth range of the ultrasound waves depend on the frequency. A high frequency cause a lower depth penetration, but gives a high resolution. In meat applications, a 2.5 MHz signal is usually used, which results in a depth measure of approximately 3 inches.

Application: Aloka/AUSi

The medical field has always inspired other research fields, and the ultrasound imaging scanners (also known as B-mode scanners) are a typical example of this adaptation of techniques and systems. Imaging scanners have been tested widely for live and carcass measurements on both beef and pork. AUSi (Animal Ultrasound Systems Inc., NY) has developed the system commercially for grading purposes. However, no research applications for meat quality have been developed further than the research state. Recent improvements in data collection techniques and software analysis of the images may lead to future use of the ultrasound imaging techniques in quality assessment. For example, the work of Dr. Kevin Ragland at Iowa State is promising for the evaluation of marbling in live hogs.

Application: Strain Image Analysis

Strain image analysis, or elastography (as the technique was first called), is another technique recently adapted from the medical field. The technique combines compression of the meat with ultrasound imaging. Compression is applied externally to the meat, and the degree of strain internally is estimated by comparing ultrasound signals to the uncompressed image. Thereby, the strain in the meat can be displayed for the total image. In the strain image, soft areas appear light and hard areas appear dark (Ophir et al. 1994). Dr. Miller and Dr. Berg at Texas A&M University are currently investigating the possibility of using this technique for determining fresh quality parameters in pork and beef. For example, the strain image analysis shows R^2=0.46 to IMF on 45 pork samples (Berg et al. 1998A).

Application: Autofom

The Autofom is a fully automatic grading system for pork using ultrasound. 16 transducers are embedded in a U-shaped frame, each performing up to 200 A-scans along the back of the carcass. The measurement of carcasses is carried out with no manual labor and is therefore totally objective. The measurement is triggered automatically, and the software determines the orientation of the carcass and performs the data analysis with reference to the midline of the carcass. Real time digital image analysis and data regression is performed with processing speeds allowing up to 1,250 carcasses per hour to be measured (Brøndum et al. 1998). This system is used for grading the total carcass and the meat primals for leanness. The results are combined with an identification system scanning the ID number from the gambrel and forwarded to the host in the plant. Currently, the possibility of obtaining information regarding the meat quality (intramuscular fat, loin size characterization, and belly grading) with the Autofom is also being studied.

Nuclear Magnetic Resonance

Nuclear Magnetic Resonance (NMR) has been known as a measurement technique since 1945. It's use has been rapidly increasing in the medical field, but there is a growing interest, in the research environments.

NMR is based on the spin of the nuclei (the cores of the atoms). Because nuclei carry a small electronic charge, spin generates a magnetic field called the magnetic moment. By applying an external magnetic field, the main ratio of the atoms are aligned in a certain direction. A radio frequency pulse is used to re-align the atoms briefly. By measuring the absorption of the nuclei as they fall back to equilibrium, distinction between different media can be made.

Two aspects of NMR measurement are of importance in different applications: resolution and sampling domain. When discussing resolution, a distinction between low field and high field instruments is often made. Low field instruments measure the nuclei response at frequencies below 60 MHz, whereas high field instruments measure at higher frequencies. Low field instruments often use a proton sensitive probe for data collection, and the response is usually made in the time domain. In the high field systems a more refined data collection is made and a distinction between more media can be made using the frequency domain. However, the disadvantage of the high field systems is that they are far more expensive, measure smaller sample quantities, and require longer sampling time. For more on NMR theory, see Hemminga (1992), and Wilson (1994). See Beauvallet and Renou (1992) for a introduction to NMR measurements on meat.

Application: Maran Low Field NMR

In low field NMR, several approaches have been taken in meat research. Wahlgren from SMRI measured beef, Engelsen from KVL measured fish, and current studies by Broendum on pork are ongoing; all with a 25 MHz ^{1}H Maran low resolution system (Resonance Instruments, Oxford, UK). Engelsen (1998) has reported very good results in the prediction of water and fat contents (R » 0.99), and also a significant relation to drip loss in fish meat (unpublished). Wahlgren (1998) obtained less accurate fat and water predictions, but the technique would still be useful in many circumstances. It is unlikely to be implemented on-line, but may very likely be seen as an advanced laboratory tool, presenting fast and easy acquisition of fat, water, and water holding information simultaneously. Protein information can be perhaps derived from the studies as well.

Application: High Resolution

High field NMR has also been used in meat applications. Swatland describes the use of high resolution NMR to characterize Adenosin Triphosfat (ATP) in muscle metabolism (Swatland 1995). This technique is used to describe the ATP concentration in meat in the rigor phase, and can thus be used to classify PSE, RFN, and DFD samples. Currently, the high resolution technique is very much an analytical tool for research purposes, and online or at-line applications will not be seen for many years.

Electrical Measurements

When applying electrical currents to meat, both resistance and capacitance can be measured. The change in the relationship between the intra- and the extracellular fluid lead to the assumption that the electrical properties in the meat changes post mortem. This is utilized in some of the measurement equipment.

Application: Conductivity or Impedance Meter

Several manufacturers have developed conductivity and impedance probes, like the LF Star (SFK Technology, Herlev, Denmark), LF 191 (Fa. WTW, Weilheim, Germany), and the Meat Check (Sigma Electronic GMBH, Erfurt, Germany). The success of these systems has been discussed in many research reports, but these systems have never gained wide use in plants. Dr. John Forrest and co-workers at Purdue University used the phase information of the impedance measurements at two times post mortem, and obtained positive indications, but the technique has not been fully studied.

Application: TOBEC

The electrical characteristics in meat are also utilized in the TOBEC (total body electrical conductivity) (MQI, Springfield, IL). As meat is passed through a magnetic field, the electrical conductivity in meat causes a change in the electrical magnetic field. Different responses in lean and fat meat samples have facilitated calibration of the system, see Berg (1994), and Calkins (1997). The use of the system for determining meat quality has not been investigated to the knowledge of the author.

Conclusion

This paper has presented a line of new technologies for determining meat quality in beef and pork plants. Spectroscopic (near infrared reflectance, fluorescence, and vision systems), nuclear magnetic resonance, ultrasound, and electrical measurement techniques have all been described. An important common feature for most of these techniques is that they are fast and therefore applicable to on-line measurements of each carcass. The NMR technique is the only method described which currently fails this criteria. But the NMR technique has such high potential that it very likely can be an "at-line" system used for laboratory testing in the plants. Some of the techniques have already been adapted into industrial systems, whereas others are likely to be seen in the near future.

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