Instrumentation to Measure Pork Quality

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Introduction

Cannon et al. (1995) describe pork "*quality*" as being associated with such characteristics as freshness, wholesomeness, grade, color (appearance), eating satisfaction and processing attributes (functionality). Grandin (1994) reported that ultimate pork quality is the responsibility given 50% to the producer and 50% to the packer. The producer is responsible for selection of swine genotypes that possess acceptable pork quality traits, must provide environmental conditions to optimize *composition* (growth) and *quality* of the final food product, and must guarantee proper care and handling to the point of delivery to the packing plant. The packer accepts the responsibility of optimizing pre- and post-slaughter conditions to ensure optimal meat quality. The terms of this discussion will define quality as the economic attributes that affect pork functionality (use in further processed or value-added products) and consumer acceptance (retail marketability).

Solutions to the problem of poor pork quality have been confounded by the large number of factors attributed to the reduction in the various aspects of quality. Cannon et al. (1995) listed eight production and processing factors which influence pork quality characteristics: 1) genetics; 2) nutrition; 3) growth promotants; 4) pre-slaughter handling and transportation; 5) immobilization (stunning procedure); 6) dehairing; 7) post-slaughter handling; and 8) packaging and storage. Development or identification of electronic equipment used for measurement of pork quality must account for, or attempt to quantify, functional quality from basic meat biochemical, physiological, molecular, and structural factors that influence ultimate pork quality.

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Standards for Quality Measurement

Muscle pH and Temperature

Early postmortem measurement of pH and temperature are common measurements taken to identify potential meat quality problems. Below is a description regarding how muscle pH will affect different aspects of pork quality.

How pH affects meat color. When pH declines rapidly before the muscle has been significantly cooled, a partial denaturation of sarcoplasmic (proteins in the muscle cell's cytoplasm) and myofibrillar proteins occurs resulting in a pale appearance (Kauffman and Marsh, 1987).

How pH affects meat firmness. Conditions affecting the structural integrity of postmortem muscle will ultimately affect overall meat quality and functionality. The contractile proteins actin and myosin are the major proteins associated with formation of the myofibrillar protein lattice. Myosin binds to actin to initiate muscle contraction and forms a permanent rigor. The low pH may denature the globular protein head of myosin and affect myosin's ability to bind actin. The degree of myosin denaturation will affect both drip loss and softness associated with PSE meat (van Laack and Solomon, 1995). A reduced affinity of myosin for actin and (or) the shrinkage of the protein lattice can be associated with the *softness* of PSE lean.

How pH affects water-holding capacity. The net electrical charge of myosin becomes minimal as the pH of meat nears the isoelectric point (*p*I) of myosin (*p*I = 5.4) resulting in a low water binding capacity (Wismer-Pedersen, 1987). Also, in fresh meat, the mobility of water is determined by the spatial arrangement of the muscle proteins. Therefore, the degree of myosin denaturation has an affect on the ability of muscle to hold moisture (van Laack and Solomon, 1995). Offer (1991) reported the rapid decline of pH at a higher muscle temperature caused a denaturation (shrinkage) of the myosin globular head resulting in a compression of the myofibrillar lattice causing the expulsion of water.

According to van der Wal et al. (1995), obtaining a muscle pH at 45 min (pH_{45}) after stunning was the best sorting criterion for muscle quality. The correlation between pH_{45} and drip loss ranged from -0.32 to -0.52. On average, a pH_{45} of 6.08 was associated with carcasses possessing what the authors referred to as *slight PSE*, while a pH_{45} of 5.84 was associated with *severe* cases of PSE meat. Accurate, consistent, and rapid measurement of muscle pH is difficult to obtain at existing line speeds on the kill floor. It is more common for

packing plants to measure pH at 20 to 24 h postmortem (ultimate pH; pH_{ult}) when the carcasses are hanging stationary in the chilling cooler. The correlation between pH_{ult} and drip loss has a range of -0.38 to -0.61. Kauffman et al. (1997) reported a correlation of -0.47 and -0.53 between pH_{ult} and percentage drip loss (%Drip) from meat samples collected from the ham (semimembranosus) and loin respectively. Table 1 lists the average pH values associated with different quality parameters from van der Wal et al. (1995).

Bowker et al. (1999) reported that pH_{ult} is not always indicative of final meat quality. The authors reported a significant difference ($P < .0001$) between pH_{ult} of electrically stimulated (ES) and nonES pork carcasses, however, the difference between LS means was only 0.05 pH units. Despite the small difference, the authors found relatively large discrepancies in meat quality between ES and nonES meat. Bowker et al. (1999) also found that loin pH and temperature measurements recorded at timed intervals up to one hour postmortem did not differ in pigs classified as heavy muscled, normal muscled, or light muscled. Likewise, early postmortem pH and temperature did not differ between halothane classifications (Nn vs. NN), yet large differences were observed in fresh pork quality between phenotype and Hal status.

Olsen (1997) reported the reproducibility (average difference) of consecutive pH measurements taken in the ham semimembranosus and longissimus dorsi were 0.064 and 0.072, respectively. Based on these findings, Andersen et al. (1999) determined that the largest difference between two neighboring measurements on the same muscle would be of the order of $2 \times \sqrt{2} \times 0.072 = 0.2$ pH units (with 95% confidence). Andersen et al. (1999) also state that obtaining duplicate measurements improve the precision of the combined measurements by a factor of $\sqrt{2}$ resulting in an overall precision of $0.072/2 = 0.05$. Based on these calculations, Andersen et al. (1999) recommend that meat pH values be represented by only one digit after the decimal point.

Appraisal of Acceptable Pork Color

According to the new *Pork Composition and Quality Assessment Procedures* (NPPC, 2000), consumers object to a fresh pork color that is too pale or too dark. Pale muscles rapidly turn gray in the retail case and are often tough and dry after cooking. Dark muscle possesses a shorter shelf life because they traditionally have a higher pH and are more prone to bacterial growth. Also, most consumers assume that darker pork has been in the display case for a prolonged period of time or was obtained from older animals.

Subjective human analysis of color. Pork color is a strong selection criteria for consumers and is associated with the functionality of the muscle for further processing (paler pork has a lower water-binding capacity), therefore, some packing plants use visual analysis of fresh pork color as a means of distinguishing fresh pork quality. Employees are stationed on the loin fabrication table to evaluate the sirloin end of the loins as they pass on the conveyor. Those with acceptable color are sorted by weight while unacceptable loins are sorted elsewhere. A similar evaluation may be made of the butt face of the ham on the ham fabrication line.

Video image analysis of color. There is a certain degree of error associated with subjective human analysis. Humans are prone to fatigue and distraction and may unintentionally reject primal cuts that possess acceptable quality (or keep cuts with poor quality). Computerized vision analysis has been developed that can identify and sort acceptable and unacceptable colored lean. A vision system used in one large Midwest packing plant evaluates the butt face of hams as they pass before a video camera. The ham is positioned so the cut lean surface of the ham is facing a video camera as it passes through a light box. The computer is programmed to identify unacceptable color and sort those hams from the production line.

According to Morgan and Forrest (1997), color vision classification of meat is a two-step process. The first step classifies the video image of the lean tissue into a predetermined color class after evaluation of the color of each pixel within the image. Since lean tissue is not homogenous regarding color, color standards such as the Japanese color scale (1 to 6) or the NPPC (2000) color standards (1 to 6) are used as references. The second step determines the overall quality of the sample based on the distribution of colors within the image. The second step of classification may place the sample in a quality category (such as an NPPC color score of 3) based on the highest percentage of pixels found in the image fitting that color category.

Objective analysis of light reflectance. Classification of meat color can also be performed with colorimeters or spec-

TABLE 1. The overall means (X) and standard deviations (SD) and mean values per quality category for muscle pH measured at 45 min or 20 h postmortem (van der Wal et al., 1995).

			Serious DFD	Slight DFD	Excellent	Normal	Slight PSE	Serious PSE
n	1,969		50	142	870	739	138	30
	X	SD	*X*	*X*	*X*	*X*	*X*	*X*
pH_{45}	6.36	0.33	6.39^{ab}	6.43^{a}	6.43^{a}	6.33^{b}	6.08^{c}	5.84^{d}
pH_{ult}	5.71	0.25	6.15^{a}	6.04^{b}	5.73^{c}	5.63^{d}	5.54^{e}	5.44^{f}

Means with a common superscript are not significantly different ($P < 0.05$).

trophotometers. Morgan et al. (1997) describe color as a three dimensional coordinate system such as color space or color scale. The CIE L*, a*, b* system is used to standardize products that have been pigmented or died such as textiles, paints, and plastics. This scale was designed to represent the human perception of color. The a* scale is a measure of the relative intensity of red and green while b* considers the intensity of the colors blue and yellow (both sets of colors are considered opposite on the color scale). The L* value represents the overall lightness or darkness of the object (0 = black: 100 = white). The Minolta chromameter is one of the more common colorimeters used to measure meat lightness (L*), redness (a*), and yellowness (b*). The National Pork Quality Project (Kauffman et al., 1997) surveyed 1,220 pork carcasses in eight packing plants. The project reported that measures of L* taken on the dissected cross-section of the *semimembranosus* (SM; inside ham muscle) and *longissimus dorsi* (loin) muscle had a correlation of 0.44 to SM and 0.62 to loin percentage drip loss. Table 2 provides the average L*-values associated with the numeric score (in order of lightest to darkest) for the new NPPC (2000) color standards.

The use of colorimeters has limited application as an on-line method of fresh pork color assessment due to accelerated line speeds and the absence of an exposed lean surface on the carcass (carcasses are not ribbed in the packing plant). Colorimeters are, however, widely used as a research tool to report differences in lean tissue color brightness. Problems arise when one begins to compare the different research findings. A number of different instruments are available to measure lean color. Comparisons of these instruments may be difficult because individual instruments may possess different size measuring heads or may use a different protocol for instrument color standardization. Meisinger et al. (1997) reported significant differences between separate instruments tested. The muscle and site of measurement also play an important part in comparison of research results and (or) classification of quality categories. Meisinger et al. (1997) found large differences regarding the location of measurement within the loin muscle as loins were found to be paler in the center than at the ends.

Colorimeters vs. vision system. Morgan and Forrest (1997) provide an excellent comparison of the use of colorimeters versus vision systems in an on-line situation. Colorimeters provide a single color coordinate (such as L*-, a*-, b*-values) for the entire lean surface. Therefore, marbling or fat in the sensor's field of view will contribute to this measurement resulting in a lighter color measurement. A vision system generates a color coordinate for each pixel in the image of the exposed lean surface and (ideally) should be capable of separating fat from lean.

Determining Water Holding Capacity

It has been stated that muscle pH and color are significantly correlated to tissue water holding capacity (WHC). Water holding capacity (WHC) is the ability of meat to retain water during cutting, heating, grinding, and pressing (Baas and Mabry, 1998). Water holding capacity of pork may be the single most important quality characteristic because poor WHC results in product weight and nutrient loss, and will affect texture, appearance, and juiciness of the cooked product (Kauffman et al., 1997). Percentage of lean tissue drip (purge or exudate) loss is often used as the most reliable method to estimate a muscle's WHC. Determining percentage drip loss is calculated as the loss in the meat sample weight (due to drip and evaporation) divided by the original sample weight, multiplied by 100, and reported as % drip (NPPC, 2000). This labor intensive and time-consuming procedure is, of course, not applicable in an industry setting. It is, however, widely used as a research tool.

A more rapid (and less accurate) measure of drip loss evaluates the amount of exudate on the cut lean surface of the loin or ham butt face (for example). This method is referred to as the *filter paper wetness test* (Kauffman et al., 1986). A preweighed piece of laboratory grade filter paper (45 mm diameter) is placed on the cut lean surface for 3 seconds. The filter paper and the absorbed exudate are then re-weighed and the difference in weight is used as a reference to that particular muscle's WHC.

The National Pork Producers Council's Quality Solutions Team (1998) developed a series of pork quality targets listed as minimums or ranges for quality attributes in fresh pork loins. These values are described as *rough targets* for different members of the pork chain to use as they see fit as they develop programs to improve pork quality and are not intended to be specifications or standards for industry use.

On-line Technologies for Measuring Quality

PH-STAR™

SFK Technology (Denmark) market a pH probe capable of rapid, on-line pH measurement. The PH-STAR™ pistol allows computer-based measurement of meat quality similar to the online capabilities of a Fat-O-Meater grading probe. The PH-STAR™ pistol is capable of serial transmission of data to

TABLE 2. The National Pork Producers Council pork quality color standards* (1 – 6) and respective Minolta L*-value using D65 daylight light source.

	NPPC Color Standards					
NPPC Numeric Standard	1	2	3	4	5	6
Minolta L*-value	61	55	49	43	37	31

NPPC, 2000.

TABLE 3. NPPC pork quality targets*.

Attribute	Target	Comment
Color	3.0 to 5.0	Utilizing a 6-point scale
pH	5.6 to 5.9	
Tenderness	< 7 lb. (3.2kg)	Utilizing Warner/Bratzler shear at 7-days
Flavor	Robust pork flavor	(no off-flavors)
Intramuscular Fat (marbling)	2 to 4%	
Drip Loss	<2.5%	

*NPPC, 1998.

the plants main computer. On-line data collection will allow printouts of pH values for suppliers, buyers, or other internal use such as classification and sorting. The PH-STAR™ pistol is advertised to be accurate within 0.01 pH units and has an ergonomic shape which allows obtaining indefinite measurements without recalibration.

Meatcheck™

The Meatcheck™ is a "*handheld measuring device with data logger for assessing quality of raw meat*" marketed by Sigma Electronic GmbH (Erfurt, Germany). The working end of the Meatcheck™ is two parallel probes approximately 5 cm long spaced approximately 2.5 cm apart. Both probes have a gold plated, stainless steel tip coated in high strength plastic casings at the base. The Meatcheck™ is designed to measure the "*structural condition*" and temperature of fresh pork and has a separate attachment for measuring pH if desired. Measurement of structural condition (termed the "Py" measurement) correlates with the drip loss of the muscle that is being probed based on the electrical impedance (resistance and reactance) of the lean tissue located between the two probe tips. The Py value is reported on a numeric scale between 0 and 100. According to company literature, a Py reading below 40 obtained on an intact carcass equates to a PSE-type condition within the muscle being measured. Lower numbers indicate a lower electrical impedance, greater muscle cell damage, and greater extracellular (free) water which would ultimately generate more purge from the cut lean surface. The Meatcheck™ is capable of rapid measurement and has been reported to be an adequate classification tool for identifying PSE carcasses (Kauffman et al., 1997). Best results have been obtained with the Meatcheck™ when carcasses are measured approximately 4 hours postmortem, after carcasses have exited the blast chill tunnel or upon entry into the chiller (Cannon, personal communication).

Fiber Optic Probes

Forrest et al. (1997) describe the principal of using optical probes for measurement of pork quality parameters. Optical reflectance probes exploit the concept that the perceived color of an object will be determined by its reflectance of light. An example of an optical probe is the Fat-O-Meater grading probe. This probe is capable of determining a fat and loin tissue depth because white fat will reflect back more light than red lean. Fiber optic probes (FOP) basically use the same principle. Forrest et al. (1997) describe four factors that must be considered when using the optical properties of meat to measure its quality: 1) wavelength of the emitted light; 2) the angle of the light to the muscle fibers; 3) the mode of light measurement (i.e., scattering, absorbance, or reflectance); and 4) contact at the meat-probe interface. Forrest et al. (1997) concluded that the ability of FOP instruments to predict the functional component of pork (water holding capacity) is totally dependent on the marginal relationship between fresh pork color and WHC. Kauffman et al. (1997) found that the combination of the Hennessy FOP (Aukland, New Zealand) light reflectance reading and pH_{ult} was the most accurate means of determining %Drip explaining 57% of the sample variation.

Forrest et al. (2000) recently reported that early postmortem prediction of water holding capacity of the pork longissimus muscle may be possible by analysis of the near infrared (NIR) spectra obtained from a FOP probe collecting changes in the NIR spectra over time (as opposed to a single measurement obtained at 45 min postmortem). The authors found that NIR spectroscopy with fiber optic sampling used on the slaughter line had the potential for estimating drip loss at 24 h post-slaughter. Total measuring time was 2 min per carcass. Results indicated a correlation of 0.84 and a root mean square error of prediction of 1.8% drip loss.

Ultrasound

Use of realtime ultrasound (RTU) is the only *noninvasive* industrial technique used in U.S. packing plants to measure quality. Ultrasound is a familiar technique for measurement of tissue depth on live animals and has recently been incorporated into slaughter plants as a means of determining fat and loin tissue depth by noninvasive means. Computer software has been developed for ultrasonic technology to predict an aspect of pork quality that has yet to be addressed in this review; intramuscular fat (marbling). Measurement of marbling is the main quality grading criteria in the beef industry, but has received little attention in the pork industry. Several U.S. packing plants use RTU as a means of carcass procurement through estimation of percentage carcass lean. The longitudinal scan RTU device has replaced the optical grading

probe in several U.S. pork plants because it provides an average of several external fat depths, is noninvasive, and has the capacity to estimate marbling.

Marbling and pork. Jeremiah (1997) has written an excellent review of `*Marbling and Pork Tenderness'* for *Pork Facts* published by the NPPC. Jeremiah (1997) states that consumers demand fresh pork that has minimal fat. Consumers will not purchase chops with excess trimmable fat or chops with a noticeable degree of marbling. This is in direct contrast with consumer taste preference for pork. Consumers have clearly demonstrated a preference for intramuscular fat when sampling and rating pork in blind taste tests (NPPC, 1996). This makes for a difficult marketing situation; consumers like the taste marbling provides but won't buy it at the meat case.

Summary

Accurate instrumentation allowing packers to identify pork carcasses possessing inferior meat quality early in processing would allow ample time for sorting and possibly establish a basis for monetary compensation or discounting of these carcasses. The functionality of pork can be determined by laboratory methods evaluating various physicochemical aspects of the lean tissue, yet rapid, online methods of evaluation have yet to exhibit a high degree of accuracy. Until technology is developed that accurately assesses fresh pork quality, the best solution to the problem is that all aspects of the pork quality chain strive to use existing information regarding production and processing of live pigs and pork carcasses to develop a system that assures every pig will possess excellent pork quality.

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