Update on Current Carcass Evaluation Techniques

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Effective value-based marketing programs require accurate techniques for assessing composition, palatability and other factors associated with consumer acceptance of meat products. The techniques must be rapid enough to occur at slaughter or cut line speeds in excess of 1,000 pieces per hour. The cost of the equipment, labor and maintenance must be kept low enough to maintain a satisfactory cost/benefit ratio. Ideally, instrumentation that is capable of assessing composition and palatability traits must be interfaced through computers to an appropriate accounting system to establish carcass value based upon demand for product leaving the slaughter plant. Only then can a marketing system for meat animals be established based upon the demand set by the consumer.

This update is based primarily on information presented at the recent international symposium "Electronic Evaluation of Meat in Support of Value-Based Marketing" held at Purdue University in March 1991. That symposium assembled experts from around the world to disseminate state-of-the-art information on meat electronic evaluation and technological standards for value-based marketing.

Requirements for Value Determination

The ultimate test for a carcass evaluation technique should be the precision and accuracy with which the technique establishes carcass value. Realistic carcass values can only be established by determining the value of the products that result from the carcass based upon the selling price of those products as they leave the plant less the cost of production and profit margin. Lorenz (1991) stressed that the introduction of electronic evaluation technology in a slaughter house should not be a goal per se, it is only useful if it helps management in the business of buying animals and selling meat products. Specifications for the ideal carcass classification system should be based upon a detailed systems analysis of the slaughter business in order to identify strategic variables.

Component Pricing

When quality is constant, the two most important components in meat products are lean and fat. While bone is a significant component of some consumer meat products and probably should be taken into consideration in the most precise price models, bone is the least variable of the tissues in the carcass and therefore can be included with by-product value when determining component prices.

It is extremely important to establish the value of lean and fat as components. Any product that contains fat sells the fat component for the same price as the lean component. If consumers are willing to pay a high price for a fat cut such as bacon, the value of the fat in the bacon should be established at that level. The fat that is trimmed away from other cuts to make them acceptable to the consumer is sold or salvaged at a very few cents per pound. The weighted average value for fat as sold in various products should give an accurate indication of what consumers are willing to pay for the fat component in meat. As long as consumers choose leaner meat products, the value of the fat component will decrease. If consumers find a point where very lean meat products are less palatable, they will shift purchases to those products that taste better; perhaps because of a little higher fat content sending a signal to the industry that animals have reached a level of fat that is too low.

By the same token, the willingness of consumers to pay the higher costs for very lean products would be signaled in the market by increasing lean value or at least widening differentials between fat and lean until the proper balance of lean and fat is reached, at which time the differential might cease to change or even narrow.

Each slaughter plant knows the actual selling price of every product that leaves their plant. They would also need to know the average lean-fat composition for every product, then calculate the value of fat and lean after all the production costs and profit margin have been deducted. The third component, by-product, may have a fixed per-animal value or it may be valued on a per-pound basis. Lean mass and fat mass within the carcass would simply be multiplied by the bid price for each, then added to the by-product value to establish the price for the carcass (Akridge et al., 1991).

Once these values are established, the plant can determine a bid price for lean, for fat and for by-product (Akridge et al., 1991). Table 1 presents the characteristics of two pigs used to illustrate how differential pricing of lean and fat would work in a component pricing system. These examples were selected because they were essentially the same live and carcass weight but were one standard deviation above and one standard deviation below the mean for percent lean in a population of 212 randomly selected pigs. They do not represent extremes in the population. Table 2 shows the value comparisons. The bid prices of $101.92 for lean and $20.71 for fat were calculated using 1989 average National Provisioner Yellowsheet prices adjusted by adding overages typically obtained by Indiana packing plants. Values for ham and loin were calculated for closely trimmed boneless product

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Reciprocal Meat Conference Proceedings, Volume 44, 1991.

Table 1. Characteristics of Two Hogs Used to Illustrate Lean/Fat Differentials in a Component Pricing System.

Characteristic	*Lean Hog*	*Fat Hog*
Slaughter Weight (lb)	230.0	230.0
Hot Carcass Weight (lb)	171.0	168.0
Optical Probe Measure—10th Rib Backfat (in)	0.91	1.73
Optical Probe Measure—Loin Muscle Depth (in)	1.93	1.48
Predicted Lean (lb)	91.1	76.4
Predicted Lean (% of Carcass Weight)	53.3	45.5

Akridge et al. (1991)

while all other cuts were priced on a wholesale basis. All processing costs and a profit goal were deducted before calculating the final bid price. The lean hog had 14.7 pounds more lean and 17.6 pounds less fat, resulting in a overall value differential of $12.83. The next step in a true value-based marketing system would require a means of determining how much lean, fat and by-product is delivered to the plant in each animal as well as a means for detecting quality problems.

Technology for Measuring Carcass Composition

The options available for measuring carcass composition are well known to most of you in this audience. Most techniques are not adaptable to on-line measurements for one reason or another. These include ribbing the carcass to measure loin muscle area and fat depth, grinding carcass sides or parts to measure chemical lean and fat, specific gravity, radioactive tracers, D_2O dilution and K^{40}.

Magnetic resonance imaging (MRI), magnetic resonance spectroscopy and X-ray computed tomography (CAT-scan) are highly accurate but may not have much potential for on-line operation as they are currently configured. They are too slow and generally too expensive. These technologies, however, may perform an important function in the validation of other instruments. Future technological breakthroughs could even make these feasible for on-line use.

The current contenders for on-line composition determination include the optical fat-lean probes, real time ultrasound, velocity of sound, digital A mode ultrasound, video image analysis, bioimpedance analysis and electromagnetic scanning.

Optical Fat-Lean Probes

The optical fat-lean probes are well established in most countries in Europe and are in operation in numerous plants in the United States. They are utilized primarily to predict lean meat percentage. Walstra (1989) reported that the accuracy range for predicting lean meat percentage with various probes is $R^2 = .68$ to .86 with RSDs ranging from 1.79% to 2.37%. Klinth-Jensen (1991) reported that the Danish pig carcass classification centre with 15 probes per side predicts lean meat percentage with an $R^2 = .81$, RSD = 1.34%. He further reported that the application of neural network techniques to the interpretation of probe profiles will allow the reduction of the number of probes in the classification centre to 7 without loss of accurancy, $R^2 = .82$, RSD = 1.29%. Predicted lean meat percentages are placed in a pricing grid to establish premiums and discounts relative to a base price for the carcass. In many European countries, the premiums and discounts are established by a commission and are uniform throughout the country. In the United States, the grids, base prices and premiums and discounts are established by each individual processor and are very confusing to producers who must make decisions regarding where they are going to market animals.

Ultrasound

Ultrasound technology exists in at least three distinct formats, real-time imaging ultrasound (RTU), velocity of sound (VOS) and digital A mode ultrasound.

Real-time Imaging Ultrasound

Real-time imaging ultrasound creates cross-sectional images at various carcass locations which facilitates the measurement of fat depth, muscle depth or muscle area without cutting the carcass. The disadvantages of imaging ultra-

Table 2. Value Comparisons of Two Example Hogs Under Component Pricing System 1.[a]

		Lean Hog		*Fat Hog*	
Component	*Price ($/cwt)*	*Quantity (lbs)*	*Total ($)*	*Quantity (lbs)*	*Total ($)*
Lean	$101.92	91.1	$ 92.85	76.4	$77.87
Fat	20.71	26.2	5.43	36.6	7.58
By-Products /Inedibles	***	112.7	11.16	117.0	11.16
Total	***	230.0	$109.44	230.0	$96.61

[a]System 1 components are total dissected lean and total dissected fat with a fixed credit used to value by-products/inedibles.

Akridge et al. (1991)

sound include the skill required to obtain a good image, the skill required to interpret and measure the image as well as the speed with which all of this can be accomplished in an on-line situation. There are computer aids for analyzing images which allow the interpretation of loin muscle area to be estimated quickly by adjusting an elipse to the cross-sectional shape of the loin muscle area image on some of the newer instruments. There are also light pen and computer mouse techniques for establishing area measurements. Some progress is being made in grey level automated image analysis, but to my knowledge, no completely automated systems are yet commercially available. Lake (1991) stated that the human is still the best interpreter of current ultrasound images. The predictive accuracy of properly interpreted ultrasound images appear to be comparable to or slightly better than optical fat lean probes (Ferguson 1991). It would appear that much development is required before real-time ultrasound imaging can become practical for on-line operation.

Velocity of Sound

Ultrasound waves travel more quickly through muscle tissues than fat tissues. Measuring the velocity with which a sound wave passes from a transmitter to a receiver through a meat sample gives an indication of composition. VOS and digital A mode ultrasound both show more promise than RTU but are currently in developmental stages. In a study with beef steers, Ferguson (1991) reported that the mean reciprocal velocity measurement of VOS was superior to fat depth measurements for the prediction of percentage muscle and fat. Wood et al. (1991) reported that in a recent study conducted by the Meat and Livestock Commission in the UK involving 49 young bulls, VOS was more precise for prediction of dissected percentage lean (RSD 1.3%) than with 6 different A-mode and B-mode pulse-echo ultrasound scanners. When VOS was applied to beef carcasses, prediction of percentage lean was more accurate than that given by an optical fat lean probe but was not superior to visual classification scores. However, research to date would encourage further development and refinement of the VOS principle.

Digital A-mode Ultrasound

Digital A mode technology with automated data collection is being developed by Elanco Animal Health, Lilly Research Laboratories and Systems Research Laboratories at Greenfield, Indiana and Dayton, Ohio. If measurement accuracy can be maintained, automated data collection would be a significant step forward in ultrasound technology. Any form of ultrasound is non-invasive (Lake, 1991), however, all current forms of ultrasound require a direct contact with sample surfaces through a sound conducting medium.

Video Image Analysis (VIA)

VIA operates on the principle that areas of different light intensity received by a video camera's photosensitive element generate different voltages so that areas of light (fat) can be quantitatively differentiated from areas of dark (lean) (Wood et al., 1991). VIA has been studied in at least three different formats. Cross et al., (1983) predicted carcass composition from VIA measurements made on the cut surface of the quartered side. It has also been used to estimate fat content in comminuted meat moving on a conveyer belt under camera lens, and finally as a means of measuring carcass conformation and fat cover in beef carcasses and conformation in pork carcasses. The Danish Beef Carcass Classification Center couples VIA with a Fat-O-Meater probe to measure fat and muscle thickness. The correlation of classification center predictions with actual percentage lean was .73. It was interesting to note that weight plus visual EUROP classification scores gave nearly the same correlation ($r=.74$).

Bioimpedance Analysis (BIA)

BIA operates on the principle that there is a conductivity differential between the fat free mass and fat. As carcass fatness increases, the impedance to the flow of electricity increases. BIA has been shown to be highly accurate in predicting the fat-free soft tissue content of lamb carcasses (Jenkins et al., 1988). Swantek and co-workers (1989) reported that BIA accounted for 48% of the variation in fat-free mass in chilled pork carcasses.

Electromagnetic Scanning

Electromagnetic scanning, often referred to as TOBEC (Total Body Electrical Conductivity), is also based upon the principle that there is a conductivity differential between lean and fat tissue. Electromagnetic scanners consist of a coil of copper wire wrapped around a large plexiglass tube, which forms the scanning chamber (Funk, 1991). When current is applied to the coil, a 2.5 MHz electromagnetic field is created. Carcasses or meat cuts passing through the field absorb energy from the coil. The amount of energy absorption detected in the coil is an index of the conductive mass of the carcass or meat cuts. Since the fat-free mass is approximately 20 times more conductive than the fat, the conductivity index is highly correlated with the lean tissue mass. This measurement is obtained without any direct electrical contact to the sample.

Electromagnetic scanning is a non-invasive technology capable of scanning full carcasses, individual primal cuts or boxed meat. Electromagnetic scanning of the full pork carcass sides accurately measures lean mass in the carcass ($R^2=.90$, RSD$=1.64$ kg), predicts dissected lean meat percentage ($R^2=.70$, RSD$=2.38$%) at a level that would be acceptable under European Community (EC) standards, and predicts the lean mass within individual primal cuts from full carcass scans. Electromagnetic scanning can be applied to uneviscerated warm carcasses, eviscerated warm carcass sides, or chilled carcass sides with nearly equal prediction accuracy.

Combination of TOBEC conductivity index readings, including carcass weight, length and temperature, with a single fat depth measurement provides even greater accuracy and could make the technology useful for composition and growth biology research applications.

In an initial study where beef hind and forequarters were scanned separately, the R^2 for predicted dissected lean weight in the hindquarter ranged from .91 to .94, RSDs$=1.6$

to 1.3 kg. Prediction of dissected lean in the forequarter ranged from $R^2 = .86$ to $R^2 = .91$ RSD = 2.27 kg to 1.81 kg. Full beef carcasses could be scanned if the chamber size were enlarged.

When Akridge et al. (1991) compared TOBEC, optical fat-lean probes and live pricing as to relative accuracy in predicting the true value of market hogs based upon component pricing, they found TOBEC measurements resulted in the lowest standard deviations from the true value of the animals (Table 3). Greatest pricing accuracy was achieved when separate values were assigned to lean from the ham, loin, and all other lean in a dissagregate component pricing mode. Single probes are not capable of differentiating lean mass within primal cuts. Therefore, only TOBEC could be tested using the dissagregate price model.

Eustace and Thornton (1991) reported that electromagnetic scanning is being commercially applied in Australia to determine composition of boxed boneless beef. Correlation coefficients, r, were 0.75, 0.88, and 0.88 for cartons containing large, intermediate and small meat pieces, respectively.

Technology for Evaluating Quality

Carcass "quality" encompasses a broad range of carcass traits or characteristics including wholesomeness, nutritive value, appearance, water-holding capacity (WHC), palatability (tenderness, juiciness, flavor) and consistency. Many times, even composition is included as carcass quality. Therefore, it is always necessary to specify those aspects of quality being addressed.

The measurement and evaluation of most quality traits in an on-line early post-mortem carcass represents an even greater challenge than measuring composition. Traditional indicators of fresh meat quality include physiological maturity, marbling, color of lean, texture of lean, firmness of lean, wateriness of cut lean surfaces and firmness of fat. These indicators are typically evaluated subjectively, making them time-consuming and subject to human error. Many principles have been and are being pursued to objectively predict some of the quality traits.

Table 3. Standard Deviations in Pricing Systems Using TOBEC and an Optical Probe.

Pricing System	*Technology*	*Std. Dev. \$/hog*[a]
Live Price - Grade Sort	None	6.83
Live Price - No Sort	None	6.43
Lean, Fat, By-product Credit	Optical Probe	5.01
Lean, Fat, By-product Price	Optical Probe	4.79
Lean, Fat, By-product Credit	TOBEC	4.26
Lean, Fat, By-product Price	TOBEC	4.09
Disaggregated[b]	TOBEC	3.86

[a]Base live price adjusted to remove bias attributed to market or transportation differentials when comparing Yellowsheet River Area prices with Louisville terminal market prices.

[b]Disaggregated pricing system uses three lean components—ham lean, loin lean, and other lean—and two fat components—external fat and trimmable fat. By-products/inedibles are valued on a per-pound basis in this system

Akridge et al. (1991)

Meat and Fat Color Standards

Nakai (1991) developed sets of standard color models for the lean and fat of beef based upon Hunter L. a.b. values taken from carcasses representing the full range of colors encountered in Japanese beef. A similar set of models were developed for Australian beef. Pigments were added to silicone resin until proper L, a, and b values were achieved to match desired grade standards. This approach still involves visual assessment; however, scientifically developed color models provide objective standards for direct comparison and matching to color scores.

Halothane

Halothane genetic testing is the most practical means of identifying stress-susceptible animals. Pigs that react positively when administered halothane gas are said to carry the halothane gene. The reduction of the halothane gene in swine herds reduces the incidence of stress-susceptible pigs and in turn reduces the incidence of pale, soft exudative (PSE) muscle in carcasses. However, halothan testing is useful only in genetic selection programs on live animals and does not completely eliminate PSE muscle. Some form of on-line testing for quality would be desirable, especially when product is to be shipped into the export markets.

pH

Measurement of muscle pH at 45 min post-mortem has proven to be one of the most reliable methods for early detection of PSE muscle. This involves either the insertion of a pH electrode into the muscle or the excision of a small muscle sample and preparation of a slurry. The second technique is usually considered to be most accurate. The application of this technique on-line is difficult, because of the slow speed and accuracy required. Kauffman (1990) concluded that muscle pH measured at 45 minutes post-mortem is not a perfect predictor of final eating quality of pork, but it is sufficiently accurate to divide carcasses into either two or three classifications that could serve as an initial approach to identifying variations in quality. "Desirable" and "undesirable" populations based on water-holding capacity and muscle color were identified using 45 min post-mortem pH. Logical groupings could be based on pH values of <5.8, 5.8-6.3, and >6.3.

Dielectric Loss Factor

Measurement of the dielectric loss factor, which essentially measures electrical conductivity on muscle membrane at a low frequency, may offer opportunities for detection of early post-mortem changes. Kleibel and co-workers (1983) indicated that the dielectric loss factor measured at 15 kHz is ten times higher in PSE than normal muscle. However, results have been variable. Fortin and Raymond (1988) found that neither dielectric loss factor nor electrical conductivity could reliably distinguish among the various Canadian quality standards used to identify PSE/DFD in pork. Further development appears to be required to improve its accuracy and commercial feasibility.

Fiber Optic Probes

Fiber optic probes (FOP) have been developed to assess pork quality through measurement of muscle reflection or light scatter via fiber optics. Since color changes often do not occur within the first hour post-mortem, this technique seems to work better after carcasses have been chilled for a few hours. This time delay can cause problems in modern-day slaughter plant facilities.

Optical Fat-lean Probes

Some optical fat-lean probes have been designed to detect color and marbling. These probes suffer from the same problems as the fiber optic probe when applied on the slaughter line in that major color changes may occur after the carcasses have been placed in the chill room. Eiklenboom and Nanni Costa (1988) in a review of various studies stated that the relationship between slaughterline measurements with either the optical fat-lean probe or fiber optic probe and ultimate meat quality attributes appeared to be of a low to moderate nature. A German study of the Fat-O-Meater resulted in higher accuracy.

Chemical Determination of Intramuscular Fat

Development of a rapid technique for determination of fat within the muscles could eliminate the need for subjective scoring of marbling. Carcasses could be grouped on the basis of percentage intramuscular fat (<3%, 3-7%, >7%). Currently these tests are slow and not commercially viable.

Boar Odor Assessment

Skatole or androsterone content in fat of boars could be used to separate boars that may have odor and flavor problems when used as fresh meat (>.24 ppm skatole: >.5 μg/g androsterone).

Several other potential quality-assuring factors may exist that could be added to the above list. The suggested items are based on currently available research that should be utilized to improve meat quality. They are typical of the types of information that will be needed throughout meat distribution channels to find the best possible end use of meat.

Kauffman (1991) described a study where carcasses were evaluated at 45 minutes post-mortem using light reflections and scattering by the Fat-O-Meater, Hennessy Chong, Sensoptic Invasive Probe, Colormet and Fiber Optic probes; electrical conductivity and impedance by the Sensoptic Probe and Pork Quality Meter; pH 45 by the Ingold Glass Electrode and Sensoptic Metal Electrode; temperature by the Omega Thermometer, and carcass stiffness by the IVO rigorometer on the exposed gracilis and by subjectively scoring the angle and rigidity of the thoracic limb. Of all approaches tested, separately or in combination, the only one having some predictive potential and practical application for intact hot carcasses moving rapidly on a disassembly line was pH for water-holding capacity, color and possibly tenderness (beef). However, he stated that pH is not infallible and must be further refined before it could even be considered as a commercially satisfactory measure of quality.

Technology Certification Systems

The European Economic Community (EEC) has established well-defined procedures for obtaining approval for adoption of electronic grading technology within a given country. A Commission of the European Communities, with technical representatives from each member country, oversees the approval process utilizing data submitted by the member country (Walstra, 1991).

The conditions for estimation of lean meat percentage are defined in EEC Regulation No. 2967/85. A sample of 120 pork carcasses representing the pig population within a country must be dissected according to the EEC Reference method. An electronic system of grading and classification will be approved by the EEC commission only if the R^2 for prediction of percentage lean is higher than .64 and the RSD is lower than 2.5%.

In Canada, the Canadian Pork Council, Canadian Meat Council and Agriculture Canada collaborated to devise a set of strict specifications for the approval of electronic devices. Lean Yield prediction equations must be derived from a data base consisting of approximately 220 carcasses, representative of the Canadian pig population. A field test is then conducted to verify reliability under abattoir conditions. Finally a comparison test is made against a baseline probe (Fortin 1989).

The United States has no organized system for testing and approval of technology that is applied in the measurement of the composition and quality of pork carcasses. Such a system could be organized by industry or the government, utilizing the talents, facilities and data available at various universities and research centers across the country. Interests of both producer and processor must be represented and protected in any technology certification program.

Conclusions

The optical fat-lean probes appear to be the most promising of techniques currently being utilized in commercial operations for the determination of carcass composition. Technologies that are currently in various stages of research and development include velocity of sound, digital A-mode ultrasound with automated data collection, video image analysis, bioimpedance analysis and electromagnetic scanning. Electromagnetic scanning is already being successfully applied in Australia for determining composition in boxed boneless beef, and is on the threshold of commercial application for pork carcass composition in the United States.

Early on-line objective evaluation of meat quality by electronic techniques is in need of innovative research and development. Measurement of pH at 45 minutes post-mortem seems to be the only currently available technology having some predictive potential and practical application for intact hot carcasses on the slaughter line. This would predict water-holding capacity and possibly tenderness.

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