BJECTIVE MEASUREMENTS OF CARCASS AND MEAT QUALITY

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ABSTRACT

Lost competitiveness and declining per capita consumption have forced U. S. meat industry sectors to become consumer ented and address issues related to quality shortfall. Because industry goals for value and quality-based marketing are coming reality, interest in objective carcass evaluation methodology has escalated. Even so, no official instrument grading stems are in place. Research addressing use of A-mode, B-mode and real-time ultrasound techniques indicated several distinct vantages: 1) it may be used in live animals; 2) it may be used on slaughter floors before hide removal; 3) with development, it ay accurately predict traits related to palatability; 4) it offers no health hazards; 5) it would allow complete automation of ading and remove the element of human error; 6) with development, it offers great compatibility with integrated artificial eural networking technology. However, other systems are now available which may present alternatives. Electrical nductivity (TOBEC) effectively predicts pork carcass composition, and is now used commercially. Potential exists for similar stems in the beef industry. Other instruments (NMR, CAT, PET), with continued development, offer advantages in image solution and accuracy, but are cost prohibitive at this time. Elastography, a new technique, offers exciting prospects for the ture with its potential to predict tenderness.

INTRODUCTION

Because of lost competitiveness and declining per capita consumption of red meat products, the U.S. meat and livestock ndustry is being forced to become consumer oriented. Most industry segments agree that retail value should reflect consumer emand and confidence. Retailers are beginning to purchase product which conforms to levels of fatness displayed in the retail ase, rather than traditional commodity products, where as much as 2.5 cm of external fatness is common. Retail fatness has declined—by over 27% in retail beef products (Savell et al., 1991). However, the 1991 National Beef Quality Audit, conducted by Texas A&M and Colorado State University to identify quality shortfalls, concluded that over 25% of the value of slaughter cattle n 1991 was lost (Lambert, 1992). These were costs passed on to consumers—opportunities to enhance the position of beef in the marketplace. Of the 25% lost value, 78% was due to defective composition and 10% was due to defective palatability traits.

If "value" and "quality" based marketing are to be fully implemented as outlined by U.S. meat and livestock industry organizations, then it will be crucial to reward quality conformity and consistency, and penalize the production of non-conformity and quality shortfall. Development and installation of a system for instrument assessment of carcass value will be critical for this to occur because livestock producers are not sufficiently confident in current, subjective grading systems.

Objectives of this manuscript were to outline the history of instrument grading research, present information pertaining to objective instrumentation of carcass evaluation, and evaluate the potential of these systems in applied industrial situations.

BACKGROUND

In 1978, a report by the U.S. General Accounting Office to the U.S. Congress concluded that the USDA needed to "increase research efforts to develop instruments to accurately measure beef carcass characteristics" (Comptroller General of the United States, 1978). As a result, in 1979 the USDA-FSQS (now the USDA Agricultural Marketing Service and the USDA Food Safety and Inspection Service) and NASA's Office of Technology jointly funded a study at the Jet Propulsion Lab to determine the feasibility of applying NASA technology to beef grading (Cross and Whittaker, 1992). Two technologies were identified th could potentially accomplish USDA goals—to enhance accuracy in carcass grading, increase speed and efficiency in the gr process, and provide a more objective means for disseminating information. Those two technologies were ultrasound and image analysis. Ultrasound previously had been identified as a potential method for evaluating live animals and carcasses (Hazel and Kline, 1959; Stouffer et al., 1961; Alsmeyer et al., 1963; Cross et al., 1983); but technological advances allowing application did not occur until the end of the 1970s.

In 1984, the USDA hosted two meetings with industry representatives. The status of instrument grading was discuss five state-of-the-art technologies with application potential in grading systems for beef, pork, and lamb were identified: nuclear magnetic resonance (NMR), 2) near infrared reflectance, 3) real-time ultrasound, 4) video imaging, and 5) CAT-S was felt that ultrasound technology offered the most realistic potential because the technical ability of the equipment, alon its durability, had progressed in the medical community.

By 1985, most researchers and industry representatives agreed that the selected instrument grading system should: 1) the capability to evaluate unchilled, unribbed carcasses, prior to hide removal, through non-invasive means, and 2) be abl evaluate both yield and quality attributes (Cross and Whittaker, 1992). As recently as 1989, at an Australian symposium on "Automated Measurement of Beef", ultrasound was identified as having the greatest potential for use in beef evaluation (C and Whittaker, 1992). Consequently, most applied efforts to develop on-line, real-time grading systems have focused on th of ultrasound technology. Despite this, research has continued on other forms of instrumentation, and several systems no promise for industrial use.

DISCUSSION

<u>Ultrasound technology</u>

Ultrasonic images are a record of sound waves interacting with physiological properties of a sample. The usefulness of mode (amplitude, one-dimensional representation), B-mode (brightness, two-dimensional gray-level imaging) and real-time scanning has been well documented. Information from echoing ultrasonic pulsations, generated by piezoelectric crystals in transducer and received by either the same (pulse-echo) or different crystals (through-transmission), is used to describe the mechanical properties of scanned meat samples (Thane, 1992; Whittaker et al., 1992).

Ultrasound imaging has some distinct advantages over alternative methods of objective measurement. These advantages include its low cost, ease of use and inherent safety features, along with potential to estimate both yield and quality traits. W (1984) stated that information provided by ultrasound "cannot be acquired by any more convenient or cost-effective technique Ultrasonic waves pose no apparent hazards at the levels used in imaging because the waves are nonionizing emission (Wells, 1984; Thane, 1992). However, at higher acoustic energy levels or if exposed for extended time periods, safety concerns could exist because ultrasound may induce thermal heating within tissues, cause cavitation (microbubbles of gas), or result in other disruptive occurrences affecting genetic replication and other cellular functions (Kremkau, 1989).

A-Scanning. Most basic A-mode research related to the use of ultrasound in prediction of composition and palatability traits is conducted to characterize fundamental theoretical parameters. These data aid in the future development of instrum specifically for use in carcass grading and evaluation. Most recognize that on-line operations will require real-time functio

Researchers at the University of Illinois recently evaluated the effects of operator error on the accuracy of fat depth estimates across A-mode and B-mode machines (McLaren et al., 1991). When scanned live, the A-mode machine was shown underestimate fat depth measures in all three meat species, especially in pork and cattle. In addition, although varying fro operator to operator, the highest correlations for ultrasonic measures of fat depth with carcass measures were obtained with B-mode machine. Variability across operators was accredited to variation in locating the scan site as well as variation in interpreting the results of scanning, with the latter probably contributing the largest proportion of variation. Results from Illinois studies supported the need to remove human error from instrument grading and live animal evaluation systems because such error contributes to increased subjectivity.

Texas A&M researchers have studied various characteristics related to the use of A-mode scanning (Whittaker et al., 1992) to detect palatability traits. In those studies, longitudinal velocity (speed at which an ultrasonic wave travels away from the origin) was influenced by fat and moisture content. Strong correlations were documented between longitudinal ultrasonic velocity and moisture content such that decreased velocity was associated with increased fat concentrations and increased velocity was associated with increased moisture content.

B-Mode and Real-Time Scanning. Evaluation of existing B-mode and real-time technology has primarily occurred with off-the-shelf instrumentation. In B-scan imaging, ultrasonic signals are ultimately digitalized, displayed and stored as an image. Digital processing allows for a dynamic range of acoustic signals to be mapped as image-brightness or gray-scale pictorial data. Gray-scale levels of intensity for an image correspond with individual elements of a picture. These elements are referred to as pixels. Evaluation of digitalized pixel data allows the development of quantitative models from which composition of a biological sample can be predicted.

Although images are generally not as detailed as those obtained by NMR or CAT techniques, over time, resolution has gradually improved because of improved pattern recognition and image enhancement technology. The main source of image background noise in B-scan imaging is speckle, which may degrade resolution by five-fold. Filtering systems for speckle have improved dramatically (Thane, 1992), and will continue to improve in the future.

Ultrasound Technology Development. Instrument grading technology has been identified as a research priority by the National Cattlemen's Association and the Beef Product Technology Development Subcommittee of the National Live Stock and Meat Board. Initiated on March 1 of this year, the University of Illinois began an industry sponsored project to develop instrumentation from scratch which will provide the best technology to evaluate both yield and quality of beef carcasses. High quality ultrasound data will be collected off-line (not in real-time) using previously identified electronic components and multiple-frequency transducers (2.5-10 MHz). Prototype technology will be evaluated across hot and chilled carcass systems, hide-on and hide-off systems, and across other environmental factors associated with on-line use in commercial packing facilities. It is estimated that final assembly of the selected equipment will begin in August of this year (personal communication with Jan Novakafski, Univ. Illinois).

Several researchers are now making progress in estimating intramuscular fat content using ultrasonic data. Speckle scores and attenuation have been used to estimate marbling within the ribeyes of meat animals (Brethour, 1990; Perry et al., 1991, Whittaker et al., 1992). In addition, Green et al. (1991) recently demonstrated that discriminant analysis techniques in the evaluation of pixel data, when combined with video image analysis of ultrasonic ribeye measures, can produce a substantial increase in the accuracy with which feedlot steers are segregated into representative USDA Quality grades (accuracy's as high as 100 and 97% correct classification).

At Texas A&M, B-mode experiments to detect marbling have shown that ultrasonic images for live cattle correspond better with visual assessments of marbling score than the ultrasonic images from carcasses. Regression equations were developed from B-mode images to predict marbling scores in live cattle (R^2 = .46 with enhanced images) and in carcasses (R^2 = .23 with enhanced images). The increased accuracy in live cattle, as opposed to slaughtered carcasses, was attributed thus far to the loss of vascularity following slaughter (Whittaker et al., 1992).

Park and Whittaker (1990) used ultrasonic frequency analysis of Fourier spectra for predicting intramuscular fat content of beef muscle. Correlations as high as .86 were obtained, and an optimum frequency for fat classification in beef tissue of 1.92

MHz was determined. More recently, methods of image enhancement, temporal averaging and spatial filtering were evaluated and prediction equations were developed to predict intramuscular fat content (Thane, 1992). Mean error terms in that study were about 1.1% fat content for live cattle data and 1.2 to 1.4% from carcass data.

Estimates of fatness for pigs and beef cattle are usually highly accurate when measured in either the live animal or the carcass, and one of the advantages of using an ultrasonic system is that it may offer potential to evaluate live animals as well as carcasses (Terry et al., 1989; May et al., 1992). However, further development will be required if muscling is to be evaluated effectively (May et al., 1992; Smith et al., 1992). Recent research by May et al. (1992) suggested that ultrasonic measures of fat prior to slaughter were very effective in predicting trimmable carcass fat (r = -.78) and boneless, trimmed subprimal yields (r = -.73), but ultrasonic measures of ribeye area were extremely ineffective (P > .05) in predicting either response (r =.07 for both response variables).

The U.S. "War on Fat" has also prompted interest in the private sector to develop on-line carcass grading systems. Although little information is available at this time, Eli Lilly has made known its intentions to develop on-line ultrasonic evaluation systems. Animal Ultrasound Service Inc. (J.R. Stouffer), Ithaca, NY, is providing ongoing services to develop ultrasonic evaluation systems for use in predicting loin eye area and fat depth in both live cattle and pigs, and also in carcasses. In addition, CSB-Systems Inc. Software Development and Management Consulting Company, who already has integrated systems on-line in Germany, is developing carcass evaluation systems to be used in the U.S. This system may be ready for commercial use by the end of this year.

Perhaps the next most useful advancements, in terms of predicting carcass composition and quality in real-time, will come in the form of artificial neural networking of the computer systems handling digitalized data. These systems were first inspired by the structure of the human brain, and their development began a totally new approach in computing. These systems train themselves, through trial and error, to solve complex pattern-recognition problems, indentify handwritten characters, and determine objects viewed from different perspectives. Such systems are usually better at accomplishing these tasks than conventional computers (Thane, 1992). McCauley et al. (1992) recently reported that Adaptive Logic Networks perform better than other beef fat ultrasound image prediction methods to date, and that they offer a viable, accurate alternative to using statistical techniques in predicting composition with B-scan image technology. Similar advancements in the prediction of intramuscular fat using A-mode scanning were reported by Whittaker et al. (1991).

<u>Other technology</u>

Kempster et al. (1982), Wells (1984), Topel and Kauffman (1988), and Forrest et al. (1989) have all summarized technologies offering potential to objectively determine both yield and quality in meat animals. Detailed descriptions of those procedures are presented in those reports. Brief descriptions of some of those technologies with practical application potential in live animal and carcass evaluation, other than ultrasound, are presented in Table 1.

Forrest et al. (1989), in a review of potential on-line pork carcass evaluation methodology, concluded that "technology exists for further development of highly sophisticated, accurate, rapid methods for determination of carcass composition and value in modern high-volume slaughter facilities". Pork industry efforts in the U. S. to develop on-line carcass and product evaluation equipment helped prompt funding at Purdue University, which has indeed resulted in the development of accurate, rapid, on-line grading systems for pork carcasses using the TOBEC HA-2 electromagnetic scanner (Forrest et al., 1989). Regression equation R^2 values for predicting fat-free lean in the carcass (R^2 = .92), independent of gender, level of backfat, or weight, indicated that the system may offer a feasible alternative to dissection techniques in research (Kuei et al., 1991). As such, the system has also offered substantial opportunity in the commercial arena.

As a direct result of research at Purdue, the first on-line TOBEC machine has been installed in the U.S. In a collaborative pilot project, the National Pork Producers Council, Purdue University and Farmland Industries have installed a TOBEC HA-2 scanner in Farmland's Sioux City, IA plant. This machine is currently operational and has worked effectively to date.

For the 1992-93 funding year, as a result of the TOBEC/pork carcass research at Purdue, the Beef Product Technology subcommittee of the National Livestock and Meat Board has listed electromagnetic scanning as a research priority. A beef industry-sponsored project is currently being conducted by Purdue University (J. Forrest) and the University of Nebraska (C. Calkins) to develop on-line electromagnetic grading systems for beef. Results to date are very promising for the beef industry.

Reflectance fat probes (Hennessy, Fat-O-Meater, Destron, etc.) have already gained acceptance in several countries, and are currently being used to evaluate fatness in all three of the primary meat species (Kempster et al., 1985). Although evaluations of fat probes are on-going in the U. S. for pork and lamb carcass evaluation, such probes are not used commercially to any large extent. One drawback to using reflectance probes to date has been the requirement of human intervention in determining scan sites and performing the procedure. Fat probes would most likely offer greater potential if robotics were developed, at a reasonable cost, to remove human error from the system. One interesting note relative to fat probes is work published by Swatland (1991), at the University of Guelph in Canada, where optical connective tissue probes are being developed. Probes evaluating connective tissue characteristics offer potential in predicting a component of toughness in muscle, . Such a probe could be combined with a back fat probe for use in quality grading. However, further development is necessary before such technology would be commercially feasible.

Video image analysis currently is used in Australia for carcasses, and, as already described, is being researched in conjunction with ultrasound and discriminate analysis techniques at Texas Tech University (Green et al., 1991) to predict marbling scores. Clark et al. (1991) recently suggested that near-infrared reflectance may offer substantial potential in predicting composition of ground products. In that study, a NIR Systems Model 6500 with a fiber optic attachment predicted fat content of ground beef with R^2 values in excess of .97 and minimal variation.

Although nuclear magnetic resonance (NMR) imaging and X-ray tomography offer exciting prospects in terms of resolution capabilities, the expense of adopting such a system for on-line grading in commercial production facilities is still inhibitory. In fact, the expense is such that very little research has even been conducted to develop grading systems utilizing this technology. Most work with computerized axial tomography (CAT) systems has occurred in the medical community. That in animals has primarily been in veterinary physiology research in dogs (Burk, 1991), and some compositional research in rats (Ross et al., 1991). However, some positive results were recently published by researchers in Denmark (Sorensen et al., 1987). In that study, CAT scan was used to estimate parenchymal tissue in heifer mammary tissue during pubertal development with positive results (r-values from .61 to .81). Positron emission tomography is a relatively new technology which is still in the development stage—little information is available.

A recent development in the U. S. of considerable interest is that related to the elastography technique. Developed in a collaborative effort between the University of Texas Health Science Center at Houston and Texas A&M University, this technique offers exciting potential to develop instrumentation which predicts palatability characteristics in muscles. The technique uses ultrasonic pulses to track internal displacements of small tissue elements in response to externally applied physical stress. Strain values (difference between pre- and post-compression signals) are converted to Young's modulus values which are in turn used in the development of an image (elastogram). Preliminary evaluation indicated that the procedure may describe muscle structure at the muscle-bundle level. Further details of this technique were discussed by Ophir et al. (1991) and are presented at this conference. Extensive development will be required before the technology is commercially feasible.

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Table 1. Potential, non-invasive technologies, other than ultrasound, to objectively determine yield or lean eating quality in live animals and/or carcasses in commercial applications[a].

Technology	Description	Advantages/disadvantages	Country/institution
X-ray techniques	Maps density differences across tissues with such techniques as computed axial tomography (CAT) or positron emission tomography (PET) scanning.	Highly correlated with intramuscular fat content and composition. Provides good resolution. Equipment is expensive and is not yet ready for on-line production.	Denmark/Natl. Inst. Anim. Sci. USA/Anim. Med. Center, NY (dogs) Canada/Univ. of Montreal (rats)
Nuclear magnetic resonance (NMR) imaging	Measures energy differences between magnetic moments of naturally occurring, intrinsically magnetic atomic nuclei and that when external magnetic fields are imposed.	Very highly correlated with lipid, water and protein content (> .985) as well as good resolution. Very expensive, requires special shielding and is somewhat slow.	USA/USDA-ARS & Howard Univ.
Electrical conductivity analysis	Conductivity is measured within a electromagnetic chamber. Tissues with different electrical conductivity affect magnetic fields, thus allowing estimation of composition, e.g., electronic meat measuring equipment (EMME) and total body electrical conductivity (TOBEC).	High correlations with carcass fat and fat- free body weight (usually > .95) for TOBEC. Correlations for the EMME have been less desirable (.79 for fat, .40 to .79 for muscle). The systems are fast and more suited to on-line plant production.	USA/Purdue & Univ. of Nebraska Aust./AUS-Meat
Near-infrared reflectance (NIR)	Measures absorption of infrared wave-lengths to isolate differences between fat and lean.	Technique is simple and relatively inexpensive, but requires further development.	USA/USDA-ARS

Table 1 (cont.). Potential, non-invasive technologies, other than ultrasound, to objectively determine yield or lean eating quality in live animals and/or carcasses in commercial applications[a].

Technology	Description	Advantages/disadvantages	Country/institution
Video image analysis (VIA)	A camera, placed within 15° of perpendicular from lean surfaces, transmits images to a computer where digitalization occurs. Measures of fatness and muscling are made electronically which may be used to predict composition.	More accurate than physically measured traits. Generally well-suited to on-line production and robotic applications. Sytems are now available to evaluate conformation. Cross-sections and standarization of conditions would be required.	USA/Texas Tech, Kansas State Univ. Canada/Nova Scotia Agric. Coll. UK/AFRC Aust./AUS-Meat Denmark/DMRI
Optical fat/lean probes	Measures reflectance of muscle and fat components, e.g., New Zealand Hennessey, Danish Fat-O-Meater and Canadian Destron probes.	Fat is estimated more accurately (R^2 = .82) than lean. Percent muscle is approximated more closely when used in conjunction with weight and carcass length (R^2 = .77).	USA/Miss. State Univ., Purdue, Texas A&M Canada/Univ. of Guelph
Optical connective tissue probes	Measures fluorescence of connective tissues within muscle via single optical fiber probe.	Connective tissue toughness can be estimated. Probe may be used with existing fat probes. Technology requires further development.	Canada/Univ. of Guelph
Bioelectrical impedance analyzer (BIA)	Measures resistance and reactance of constant alternating current passed through tissue. Composition can be estimated because fat insulates and lean conducts.	Initial data suggests relationships (r = .77 live, .83 carcass) between current volume and fat-free mass. More development is necessary before commercial use is possible.	USA/N. Dakota State Univ., USDA-ARS

Table 1 (cont.). Potential, non-invasive technologies, other than ultrasound, to objectively determine yield or lean eating quality in live animals and/or carcasses in commercial applications[a].

Technology	Description	Advantages/disadvantages	Country/institution
Velocity of Sound (VOS)	Measures ultrasound velocity which varies depending on the tissue.	Predicts as well as physical measures, requires further development.	UK/AFRC
Elastography	Measures internal displacement of small tissue elements in response to externally applied stress using ultrasonic pulses. Light colored regions in images correspond with softer, more elastic tissue.	Initial research suggests that elastograms may be capable of depicting muscle structure at the muscle bundle level, and of detecting differences in elasticity of muscle bundles, connective tissue amounts and quantity of intramuscular fat.	USA/Univ. of Texas Health Sci. Center at Houston & Texas A&M

[a]Sources: Cross et al. (1983); Kempster et al. (1985); Sorensen et al. (1987); Topel and Kauffman (1988); Cook et al. (1989); Forrest et al. (1989); Burk (1991); Ross et al. (1991); Swatland (1991); Akridge et al. (1992); Ophir et al. (1992); Swantek et al. (1992); Thane (1992).