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Ultrasound as a Modern Tool for Carcass Evaluation and Meat Processing: A Review

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ABSTRACT

Ultrasound is a modern tool that can be utilized as non-destructive means for carcass evaluation and meat processing. It may also serve the purpose of value and quality-based marketing of live animals as well as the carcass and meat products at global level. Ultrasounds are the waves which can 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. Accuracy of prediction of carcass composition on live animals could be improved by the addition of ultrasonic fat and muscle depth measurements. By this way subcutaneous fat thickness in live animals could be accurately measured over the rib, lumbar and rump and that *longissimus* muscle area. Meat is inspected ultrasonically to determine fat-to-lean ratio and to obtain a three-dimensional computer image of the interior of the carcass showing the location, shape and nature of the various pixels of different materials (fat, lean, bone, abscesses or other tissues) in the carcass. On that basis grading of the carcasses can be easily done. Low-intensity ultrasound is a non-destructive technique that provides information about physicochemical properties like composition, structure, physical state and flow rate. High-intensity ultrasound is used to alter physical or chemical properties of foods, for example to generate emulsions, disrupt cells, promote chemical reactions, inhibit enzymes, tenderize meat and modify crystallization processes. Ultimately, ultrasound is a good tool for assessment of carcass characteristics in live animals, non-destructive method in quality evaluation of carcass and different meat product. It may also be the important means for marketability of the animal products through quality assurance.

Key words: Carcass, ultrasound, meat grading, meat processing, imaging

INTRODUCTION

Ultrasound refers to the sound which the human ear cannot detect. The term "ultrasound" applies to all acoustic energy with a frequency above human hearing (20,000 Hz or 20 kHz). Below this frequency, sound can be heard by the human ear and is referred to as infrasound. Ultrasound equipment generates high-frequency sound waves which travel into the body and are reflected from boundaries between tissues of differing densities (Houghton and Turlington, 1992). Quantities of muscle and fat are determined by measuring the echoes rebounding from back fat, semi-membranous muscle, rib eye muscle etc. Ultrasound technique is non-destructive, humane and provides a means of quantitative and qualitative identification of muscle and fatty tissue of the live animal (McLaren *et al.*, 1989).

The development of Ultrasound technology began with the piezoelectric effects in the year 1880 and was first utilized in World War II (in year 1940) in the form of SONAR (Sound Navigation and Ranging) (Hedrick, 1983; Houghton and Turlington, 1992). However, in meat industry the use of ultrasonics as a non-destructive and humane means of measuring fat and muscle in live animals was first described in the 1950s and has been used in the beef industry for more than 40 years (Hedrick, 1983; Houghton and Turlington, 1992). A-mode ultrasound has been available since 1950s. Series of research in the area over years led to the development of B-mode or real-time ultrasound in the 1980s (Stanford *et al.*, 1998) and most studies done since that time have utilized B-mode ultrasound. Using ultrasound technology, progeny testing for carcass traits can be completed in much shorter time because live animal ultrasound is non-invasive, carcass data can be collected on a much larger population of animals consisting of breeding stock and commercial producers (William, 2001).

Equipments and accessories for ultrasound: Ultrasound equipments exist in forms of amplitude (A-mode) machines, brightness (B-mode) machines and real-time ultrasound machines. A-mode measures echo amplitude against time and determine differences in tissues by the distance between echoes while B-mode or real-time ultrasound machines are used for determination of differing tissue densities by echo intensities that are reported as gray scales on a two-dimensional screen (Stanford *et al.*, 1998). Whereas, real time ultrasound machine is a modification of B-mode in which images can be seen almost instantaneously and changes with the orientation of the transducer to the tissue being evaluated for changes (Bates *et al.*, 1992; Schinckel *et al.*, 1994).

Amplitude modulation or A-mode: It is first display mode which was used for one-dimensional displays ultrasonic imaging (Temple *et al.*, 1956). In this mode Echoes spikes on display from the transducer. The height of the spike corresponds to sound amplitude at tissue depth (Widmer, 1993). The distance between each spike is related to the distance between successive interfaces (Wilson, 1992). A-mode is only capable of measuring fat depth and muscle depth in live animals. It does not allow for the measurement of the longissimus muscle area (Wilson, 1994).

Brightness modulation or B-mode: B-mode is an image display created by integrating multiple A-mode signals (Amin, 1995). It is two-dimensional and consists of dots or pixels. The brightness of each dot or pixel is determined by the amplitude of the echoes. Time taken by the echo to reflect back to the transducer determines the location or position of the dot or pixel on the screen (Wilson, 1994). These echoes are reproduced as varying shades of grey in the resulting ultrasound image. B-mode uses 64 shades of grey whereas A-mode uses 16 shades of grey. The echoes are changed to electrical signals and then into radio frequency waves by the transducer. The radio frequency waves are then converted into digital random access memory in the computer which allows for the assignment of grey scale numbers ranging from 1 to 64 shades. Thus the final display of the image is in shades of grey. Grey scale thus allows visualizing the differences in tissue texture (Widmer, 1993).

Real-time ultrasound: It is a version of B-mode ultrasound. However, real-time ultrasound creates images which are seen almost instantaneously and changes with the orientation of the transducer to the tissue being evaluated for changes. The result is a live, dynamic ultrasound imaging process. This technology is used for carcass trait measurement and uses high frequency sound waves (generally 2 to 10 MHz) on animal's hide while it is still alive. A sound-emitting probe or transducer is placed snuggly on the animal's back and the sound waves penetrate the tissues, reflecting off the boundaries between hide, fat and muscle layers. As the sound waves reflect back towards the probe, a cross-sectional image is created on the ultrasound machine monitor that allows measurement of the carcass traits like fat depth, muscle depth or muscle area without cutting the carcass. This process is harmless to the animals as well as for technicians (Houghton and Turlington, 1992). It needs expertise and skills for ultrasound imaging and for interpretation of results. There are computer aids for analyzing images which allow the interpretation of loin muscle area to be estimated quickly by adjusting an ellipse 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 (Got *et al.*, 1999).

Velocity of Sound (VOS): 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 (Schinckel *et al.*, 1994). 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 VOS was more precise for prediction of dissected percentage lean (RSD 1.3%) in young bulls than with 6 different A-mode and B-mode pulse-echo ultrasound scanners.

Transducer: Transducer is a vital component of the ultrasound equipment which lifts a thin slice of the tissue for evaluation and display of the image on the screen (Ginther, 1994). The function of transducer is to generate ultrasound and to transmit and receive the ultrasonic waves. Sound waves are transmitted 1/1000 of the time and received 999/1000 of the time during imaging. It uses piezoelectric materials to convert electrical energy to ultrasound. The piezoelectric materials or crystals are commonly made of crystalline quartz, tourmalene or man-made ceramics. These crystals are cut in the shape of a disc in which thickness determines the operating thickness and diameter determines the characteristics of the ultrasound beam. The configuration or thickness and composition of the crystals have a unique resonant frequency thus transducers are available at different frequencies (Widmer, 1993).

Ultrasound techniques for carcass evaluation: Ultrasound is regarded as a promising non-destructive technique to characterize tissue and evaluate carcass (Morlein *et al.*, 2005). Lost competitiveness and declining per capita meat consumption have forced global meat industry sector to become consumer oriented and focus on issues related to quality shortfalls. Value and quality-based marketing is the new business trend which can be easily fulfilled by the recent carcass evaluation methodology. Research focusing on use of A-mode, B-mode and real-time ultrasound technique indicated several distinct advantages: (1) it may be used in live animals (2) it may be used on slaughter floors before hide removal (3) it may accurately predict traits related to palatability (4) it is free from health hazards (5) it would allow complete automation of grading and remove the element of human error and (6) it offers great compatibility with integrated artificial neural networking technology (Cross and Belk, 1994). In pigs, back fat and lean tissue thicknesses can he accurately and consistently determined using ultrasound scanner (Schinckel *et al.*, 1994). It is also used to estimate marbling in beef cattle (Haumschild and Carlson, 1983). In poultry, this technology has been applied to measure the breast tissue depth (total thickness of the muscle and skin-fat layer) on Pekin ducks (Dean *et al.*, 1987). Ultrasound imagery and body shape have been used to predict meat yield of live animals in cattle (Busch *et al.*, 1969; Shepard *et al.*, 1996; Bergen *et al.*, 1997) swine (Gresham *et al.*, 1994; Cisneros *et al.*, 1996) and sheep (Berg *et al.*, 1996). Predicted meat yield could be used to identify breeding stock with higher meat yields (Maiti and Ahlawat, 2010; Huda *et al.*, 2010). Knowledge of carcass merit can assist the breeder in identifying superior stock and thus accelerate genetic improvement (Wilson, 1992).

The equipments for ultrasonic evaluation of carcass traits are very fast, non-invasive and most of them have low maintenance cost (William, 2001; Morlein *et al.*, 2005). Busk *et al.* (1999) developed fully automatic ultrasound based equipment (Autofom) for measuring fat and meat depth in pig carcasses for use at abattoirs during high speed line dressing (measuring up to 1250 carcasses per hour). The equipment can act as a suitable alternative to automatic on-line determination of lean meat percentage in pig carcasses. Fortin *et al.* (2003) developed computer vision system prototype for grading pork carcasses. The system consists of two components: ultrasound imaging to scan a cross-section of the loin muscle and video imaging to capture two-Dimensional (2D) and three-Dimensional (3D) images of the carcass. Muscle area and fat thickness (7 cm off the mid-line) measured by ultrasound at the next to last rib site, together with 2D and 3D measurements provided the most accurate model for estimating salable meat yield. Fortin *et al.* (2004) evaluated three commercially available ultrasound instruments (CVT-2, UltraFom 300 and AutoFom) for predicting salable meat yield and lean in the primal of pork carcass. Ozutsumi *et al.* (1996) found that an improved color scanning instrument consisting of a small size ultrasonic probe (2 MHZ) and LCD display was useful for estimating meat quality (marbling) in live Japanese Black steers. Acoustic parameters obtained by spectral analysis of ultrasound echo signals obtained by clinical B-mode device (equipped with a 3.5 MHz center-frequency transducer) can be used to estimate the Intramuscular fat content of porcine *longissimus* muscle (Morlein *et al.*, 2005).

Accuracy of prediction of carcass composition on live animals could be improved by the addition of ultrasonic fat and muscle depth measurements (Delfa *et al.*, 1995). Wallace *et al.* (1977) evaluated that subcutaneous fat thickness in live beef steers could be accurately measured over the rib, lumbar and rump and that *longissimus* muscle area could also be reliably measured with ultrasound. Fernandez *et al.* (1998) found that ultrasonic measurements of fat thickness and longissimus dorsi cross sectional area at 12th-13th rib taken before slaughter may be accurate predictors of cold carcass weight in lambs. Highest correlation was observed between ultrasound fat thickness and its corresponding carcass measurements taken between the 12 and 13th ribs. Orman *et al.* (2008) observed that ultrasonic measurement of fat thickness and longissimus muscle area in live Awassi male lambs in association with live weight could be used to estimate carcass fat thickness, carcass longissimus muscle area and carcass cold weight. Sahin *et al.* (2008) also showed that in vivo ultrasound fat thickness and measurement of area and depth of the longissimus dorsi muscle (between 12 and 13th rib) in association with live weight could be used to estimate muscle, total body fat and bone weight in Akkaraman lambs.

The measurements collected using live animal carcass ultrasound can be used to estimate carcass retail yield and meat quality. Ultrasound measurements are collected at three points on the animal-Percent intramuscular fat, rib eye area and back fat and rump fat (Silcox, 2002).

Ultrasound techniques for meat grading: Modern real-time units combine many crystals which fire in sequence emitting high frequency sound waves. These sound waves bounce off tissue interfaces (such as a change from fat to muscle) and bounce back to the sending unit. These reflections allow the system to measure elapsed time and create constantly updated two dimensional images. These images represent a cross-sectional view of the tissues scanned. Minor anatomical features are visible and can be assessed for deviations from normal anatomy. The images are also recorded for later display on remote monitoring devices for more detailed analysis and grading by suitable pattern recognition techniques (Got *et al.*, 1999).

Meat is inspected ultrasonically to determine fat-to-lean ratio and to obtain a three-dimensional computer image of the interior of the carcass showing the location, shape and nature of the various pixels of different materials (fat, lean, bone, abscesses or other tissues) in the carcass. These results are achieved by passing ultrasonic pulses into and through the carcass, measuring the timing of both transmitted pulses and return pulses that are reflected from the carcass surfaces and from successive planes between the internal pixels and measuring the relative intensities of the reflected pulses, the latter measurement providing data on the attenuation coefficients of the various pixels from which their nature can be determined. The velocities of the ultrasonic pulses in the different materials being known, as well as their attenuation coefficients, a computer can calculate the fat-to-lean ratio and can construct the desired three-dimensional image. Measurements made with ultrasound can be influenced by both technician experience and machine differences. Inexperienced technicians often confuse shadows and multiple reflections with anatomical features, leading to inaccurate diagnoses or faulty measurements. For precise comparisons, quality images must be captured from fixed locations on each animal and subsequently interpreted. Considerable knowledge of the muscle structure of tissues scanned is required for accurate assessment. Experience and dedication are crucial components if precise measurements are to be attained. Technicians must repeatedly follow scanned animals through the slaughter process to evaluate carcasses and use this information to improve both image capture and analysis. Differences in ultrasound equipment can also influence image quality and subsequent analysis (Houghton and Turlington, 1992).

Ultrasound techniques in meat processing: Ultrasonic techniques are finding increasing use in the food industry for both the analysis and modification of foods (Jayasooriya *et al.*, 2004; McClements, 1995). Low-intensity ultrasound is a non-destructive technique that provides information about physicochemical properties like composition, structure, physical state and flow rate. High-intensity ultrasound is used to alter physical or chemical properties of foods, for example to generate emulsions, disrupt cells, promote chemical reactions, inhibit enzymes, tenderize meat and modify crystallization processes (McClements, 1995). The sonochemical and sonomechanical effects of sound waves (20-100 kHz) at a sufficiently high power range (100 W-10 kW) radiated through food (aqueous or semisolids) can alter the intrinsic property of the foods. The ultrasound radiation has inherent qualities of heat production and pressurization. High power ultrasound has the potential to be used efficiently in meat processing in place of chemicals, high temperatures and pressures and longer processing times under normal processing conditions (Jayasooriya *et al.*, 2004).

Effect of ultrasound on physicochemical, sensory and microbiological quality of meat: Ultrasound, when used at low frequencies and high intensities has the potential to improve meat tenderness. High power ultrasound is capable of improving tenderness of beef without compromising other quality parameters (Jayasooriya *et al.*, 2004, 2007). High power ultrasound (24 kHz, 12 W cm^{-2}) treatment of uncooked beef samples for 240 sec significantly reduced Warner Bratzler Shearforce (WBS) force and hardness. By disrupting muscle structure, high power ultrasound reduces both myofibrillar and collagenous toughness, thus improving tenderness (Jayasooriya *et al.*, 2007). High power ultrasound waves are also capable of fragmenting collagen macromolecules and reducing the denaturation temperature of extracted collagen (Nishihara and Doty, 1958). These waves also have capability of solubilising collagen fraction (Jayasooriya *et al.*, 2004).

Ultrasound treatment did not cause any harmful effect on color of beef muscles (Jayasooriya *et al.*, 2004, 2007). Ultrasound assisted cooking by increasing the water holding properties of meat and the binding strength which are responsible for increased cooking yield (Reynolds *et al.*, 1978). Jayasooriya *et al.* (2007) also reported a significant reduction in the cook loss of ultrasonically treated beef muscles.

High power ultrasound treatment of uncooked beef muscle samples significantly increased pH (Got *et al.*, 1999; Jayasooriya *et al.*, 2007). This increase in pH could be due to release of ions from the cell structure into the cytoplasm or due to a change in the protein structure, which would led to the modification in the position of some ionic groups, enabling them to support in buffering the muscle (Got *et al.*, 1999).

Ultrasound technique can assist in extraction, gelation and restructuring of meat proteins. It can replace/reduce salt in restructured beef roll manufacture and results in superior color (Vimini *et al.*, 1983; Balev *et al.*, 2010). High intensity ultrasound treatment of pork loin muscle during brining resulted in significantly higher water content of samples in comparison to samples brined without ultrasonic treatment. NaCl transfer to meat samples also increased proportionally with the increase in ultrasonic intensity (Carcel *et al.*, 2007; Selvan *et al.*, 2007).

Low-intensity ultrasound treatment (1.55 W cm^{-2} for 8, 16 or 24 min) of vacuum packaged beef muscles had no effect ($p>0.05$) on storage purge loss, cooking loss and textural properties. Microbial levels were initially reduced ($p<0.05$) by the ultrasound treatment (0 days) but differences in microbial numbers between ultrasound-treated samples and controls disappeared ($p>0.05$) during refrigerated storage (Pohlman *et al.*, 1997).

Uses of ultrasound in determination of meat composition: Ultrasonic velocity measurement can be used to assess the composition of meat products such as dry fermented sausages rapidly and non-destructively. Benedito *et al.* (2001) and Simal *et al.* (2003) used ultrasonic velocity measurements to determine the composition of dry fermented sausages. Sigfusson *et al.* (2001) determined the fat, water and solids-non-fat content of mackerel tissue by analyzing the temperature dependence of the ultrasonic velocity in the tissue using a semi-empirical equation. There was good agreement between the fat, water and solids-non-fat content determined by ultrasonic velocity and proximate analysis methods. Ultrasonic velocities differed in pig fat samples (at a temperature range of 4 to 20°C) from different breeds and with differing feeding regimes. Ultrasonic techniques could be useful in the characterization and differentiation of pig fat samples (Ninoles *et al.*, 2007; Kumar *et al.*, 2007) and subcutaneous fat from dry-cured hams (Ninoles *et al.*, 2008) with different genetics and type of feeding. Ninoles *et al.* (2010) evaluated the feasibility of using ultrasounds/ ultrasonic measurements to characterize the melting properties of fat from Iberian dry cured hams. They found that ultrasonic measurements could be a reliable technique to estimate the %MF and subsequently the related sensory attributes in Iberian dry-cured ham. Ultrasonic velocity was related to the percentage of melted fat (%MF) showing an increase of 5.4 ms^{-1} for 1% increase of melted fat (%MF above 60%).

CONCLUSION

Consumer buying decisions are influenced both by product quality and price. Increased portion size of muscle cuts and decreased fatness are two factors that could increase consumer acceptance of meat. In this aspect ultrasound technology allows *in vivo* estimation of carcass composition with an acceptable degree of accuracy and repeatability. Although other technologies such as x-ray computed tomography, nuclear magnetic resonance and electromagnetic scanning are now available with greater measurement precision and accuracy, ultrasound appears most feasible from a standpoint of cost and portability to improve composition. Ultrasound technology has also find use in meat processing. More research is needed to make the use of this technology for commercial application.

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