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The evolution of non-invasive ultrasound used in meat quality evaluation to select the best animals – a review*

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Having in mind the demographic explosion and the pressing need to ensure food supplies for the entire world, this review came with a synthetic presentation of the most modern non-invasive technique of investigation used in meat quality evaluation for livestock that has evolved and developed in the last 60 years. These modern techniques such as ultrasound, Computer Tomography (CT) and Video Image Analyses (VIA) were first introduced in human medicine and afterwards were adopted by animal research and implemented gradually as a tool to predict meat at an early age. Ultrasound, CT and VIA developed very quickly and helped considerably the meat industry focusing on assurance of human health. These techniques became popular as they were able to accurately predict meat quality *in vivo* avoiding the need to slaughter the animals, which assisted in the evaluation of meat quality in breeding candidates. One of the evaluation methods presented above was adopted by Romania for the first -time to improve meat quality evaluation in sheep, and as a result some disadvantages regarding the classical procedure for evaluating sheep for meat production have been removed. The classical procedure for sheep meat evaluation used in Romania until 2012 was to slaughter the animal in order to obtain meat carcass measurements (commercial yield, slaughtering yield, dressing percentage and meat to bone ratio), a method which involves hard and expensive work and sacrificing the animal, which otherwise may have been used in reproduction. The ultrasound method was chosen as an option in sheep meat quality evaluation thanks to its efficiency with providing fast and accurate results, particularly since non-

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invasive ultrasound measurements very well correlated with meat traits. Ultrasound parameters were measured *in vivo* in two points on the *Longissimus Dorsi* muscle, which in Teleorman Black Head sheep is a muscle very well correlated with carcass meat amount. Very soon the ultrasound evaluation was used in goats of the Carpatina breed with similar ultrasound parameters recognized for meat quality. Consequently, the use of ultrasound measurements in genetic evaluation systems has been recommended to increase the rate of genetic improvement for carcass yield and quality traits. That is why the ultrasound method is recommended in meat quality evaluation to facilitate classification of animals specialized for meat quality. Animal breeders and farmers use ultrasound *in vivo* evaluation to maximize genetic gain for meat traits by selecting the best individuals. The application of this non-invasive technique provides prospects for livestock breeders and the meat industry for an accurate *in vivo* meat evaluation for quality carcass classification, very important in maximizing economically important traits.

KEY WORDS: carcass quality / meat evaluation / non-invasive method / ultrasound / ultrasound equipment

Meat quality and quantity were researched and improved over the years by slaughtering the animal to obtain commercial cuts, dressing percentage and the meat bone ration. The meat industry was supported with a new standard regulation adopted by the EU for carcass classification (EUROP), which led to a new approach regarding animal breeding, the environmental conditions and animal management systems used by farmers for their animals in order to obtain high meat carcass quality. The EUROP meat standard classification system (E – excellent, U – very good, R – good, O – fair and P – poor) combined various requirements that need to be met by animal breeders and farmers. To assure these qualities as a final requirement of the European consumers, while both food quality and animal welfare need to be monitored. Additionally, objective evaluation of carcass meat and payment in agreement with its quality are thus ensured. Each step that must be followed is going toward this goal, beginning with monitoring the entire life span of the animal focusing on health of the animal with a proper conformation fitted for meat production in accordance with consumer requirements. To facilitate animal breeding based on the evaluation of meat quality a multitude of modern techniques were developed to measure carcass traits as an important link to complete the technological aspect of animal selection. These research techniques include real time ultrasound measurements (RTU), followed by computed tomography (CT), dual energy X–ray absorptiometry (DXA), magnetic resonance imaging (MRI) and total body electrical conductivity (TOBEC). All these methods made the entire process easier and replace the slaughter method, which was expensive and time-consuming. Each advancement produced a clear image of the animal tissue and its physical composition, being highly useful in meat trait evaluation [Silva *et al*. 2012]. Increasingly advanced and improved techniques have been developed over time including the advantages mentioned above, with animals measured using non-invasive methods and providing more accurate and better results. Application of these non-invasive techniques offered new prospects to livestock breeders and the meat industry thanks to efficient meat carcass classification *in vivo*, which is very important to maximize economically important traits [Stanford *et al*. 1995, Dhanda *et al*. 1998, Pathak *at el*. 2011]. All these technological improvements helped considerably in meat evaluation and led to better animal carcass quality, benefiting both farmers and breeders.

Carcass components can be predicted using a non-invasive technique which is an accurate measurement tool of the *Longissimus Dorsi* muscle, very well correlated with carcass meat amount. Also, *Longissimus dorsi* provides very good indicators such as eye muscle area, eye muscle depth and fat thickness that covers this muscle [Teixeira *et al*. 2008, Daina *et al*. 2016]. Genetic gain in the case of meat production has raised many questions for animal breeders, who were aided by researchers in improving selection supported by ultrasound evaluation to produce the best animals in terms of meat carcass traits. Quality of meat is the final desirable complex trait required for human health, since humans are direct beneficiaries of continuous improvement of animals designed for meat production. A multitude of meat traits are jointly responsible for meat quality, such as color, juiciness, texture, marbling, fat content, muscle development, etc. Fat content is an important trait of the animal carcass which affects human health causing cardiovascular disease. This is why continuous attempts have been made to lower the content of fat deposits and to produce animals with greater muscle content. Consumer preferences directed the meat market to improve carcass quality over time by selecting the best animals with small amounts of fat deposits and a leaner and more muscular conformation improving meat yield. Then improvements of meat qualities targeted very good aroma and taste to attract consumers thanks to refined meat composition making it easier to prepare delicious meals. The non-invasive technique mentioned above has facilitated accomplishment of these special consumer requirements for meat quality.

Worldwide evolution of the non-invasive ultrasound technique in animal breeding for meat

The main reason for saving the best breeding candidates in the selection process has always been to establish genetic improvement of meat production traits using ultrasound parameters linked to body weight, which became one of the common indicators correlated with carcass quality and meat amount. These *in vivo* measurements allowed researchers and animal breeders to obtain accurate information concerning carcass structure without slaughtering the animals. The ultrasound method was used for the first time in humans. The aim was to provide images showing the anatomical structure and composition of organs and tissues with abnormalities that might be the result of a disease, or to show the physiological state, the stage of development in pregnancy, the growing process etc., greatly helping doctors to provide a diagnosis and treat the patient. In order to improve cattle carcass quality in America ultrasound was used for the first time in 1956 by Tample *et al*. [1956] to estimate fat thickness. Studies continued with ultrasound measurements in cattle to evaluate the rib eye of the *Longissimus Dorsi* muscle [Stouffer *et al*. 1959]. Research was further continued on pigs, cattle and sheep making a comparison between A- and B-mode ultrasound

[Stouffer *et al.* 1959]. Ultrasound film and image obtained in the B-mode is explained by the dot brightness, which is directly proportional to the amplitude of the ultrasound in real time. The ultrasound waves in the B-mode leave vertical traces indicating tissue depth. For a clear ultrasound image in the B-mode it is necessary for the animal to remain motionless and the technician eye to catch the best ultrasound measurement with the most accurate image [Hedrick *at el*. 1962, Gooden *et al*. 1980, Stouffer *et al.* 2004]. The ultrasound equipment evolved and appeared in 1987 with a 3D echography scanner used in their research by Szabo *et al*. [2004]. The first real time ultrasound application in animal selection to evaluate meat traits appeared in 1976 in response to demand of the meat industry to continuously improve breeding programs for cattle, sheep and pigs [Busk *et al*. 1984]. Mechanical B-scanners became popular only after 1980 when Real Time Ultrasound was developed, being a more accurate system producing greater image quality [Klein *et al.* 1981, Szabo *et al*. 2004]. In principle when supporting the RTU system it uses B–mode crystal transducers to create an echography image which is updated in real time. Technical studies explain how echography images are unrolled frame by frame every 30 milliseconds and the pictures are changed in real time, creating a motion image [Insana *et al.* 2006]. Recently RTU systems have become indispensable in meat carcass evaluations because of their efficiency in recording important information characterizing the complexity of meat traits, such as fat deposits, subcutaneous fat layer, eye muscle area, muscle depth, muscle perimeter on the *Longissimus dorsi* muscle, the marbling score etc. These are all traits selected to improve carcass quality using ultrasound images that are the same or better than those obtained with more complicated and more expensive technology. Animal science research and veterinary medicine are the main beneficiaries of the constant renewal and improvement of ultrasound equipment that provides images of various organs and tissues with sufficient quality and accuracy to facilitate reliable diagnosis, measuring muscle development to reach the standard of meat quality.

The evolution of ultrasound meat evaluation in Romania

Romania adopted the ultrasound technique in the last decade to avoid slaughtering animals in a local sheep population, replacing carcass measurements with *in vivo* measurements to improve meat quality [Lazar *et al*. 2012]. The ultrasound method proved to be more efficient and easier to apply compared to carcass measurements. The latter are more laborious and complicated because they imply sacrificing the animal to obtain commercial cuts and determine slaughtering yield, dressing percentage and meat : bone ratio. The reason that live animal measurements became popular was to allow measurements to be taken directly on breeding candidates, rather than having to slaughter siblings or use progeny records. High phenotypic correlations were obtained from weaning lambs of the Teleorman Black Head breed using ultrasound measurements from two points situated on the *Longissimus Dorsi* muscle which reflect the carcass meat amount and the genetic potential of the lambs. Ultrasound measurements were taken from two points on the *Longissimus dorsi* muscle and correlated with carcass measurements: muscle depth with body weight at birth (0.40, 0.54) and with weaning weight (0.55, 0.67). Also, high phenotypic correlations were found between muscle depth with eye muscle area (0.71, 0.76) and with eye muscle perimeter (0.90, 0.85), making it possible to compare Romanian sheep breeds with sheep meat breeds from abroad [Lazar *et al.* 2015]. Research continued to combine ultrasound with carcass measurements in a regression model fitted to make an accurate estimation of the carcass meat amount on Teleorman Black Head lambs to obtain genetic improvement by a non-invasive method and keep the lambs for reproduction [Lazar *et al.* 2016]. The same author continued the studies and extended this method as an investigation tool in the Carpatina goat breed to provide a better evaluation for carcass meat quality using ultrasound parameters on the *Longissimus Dorsi* level to point out fat thickness, eye muscle area, muscle depth, with great results within the limits recognized for mutton goat breeds [Lazar *et al*. 2017]. Also, in this study it needs to be stressed that one ultrasound measurement is sufficient to estimate meat amount in Carpatina goat kids *in vivo* improving their carcass evaluation. In Romania the ultrasound method was applied with success and it is recommended in view of its accurate measurement, easy use and helping many sheep and goat breeders to make a better classification for meat quality standard with great benefits for farmers.

Worldwide influence of ultrasound measurements in animal meat evaluation

Ultrasound measurements are influenced by multiple factors, which has been demonstrated by a considerable body of research. In order to improve carcass meat quality many studies were supported by the ultrasound method, which included measurements on the *Longissimus lumborum* muscle, being very well correlated with carcass meat amount. Obviously, a factor with great influence in ultrasound measurement is highlighted by a study on weaning weight in Kivircik lambs, taken on the *Longissimus muscle* between the 12th and 13th ribs to observe fat thickness that covers the muscle, its depth, eye muscle area when the lambs were 26.8 kg on 125th day [Ibrahim *et al*. 2007]. The same author showed a significant influence of sex, birth type of lambs and flock, except for lamb age. The sex of lambs as a variable influenced significantly the muscle depth measure by ultrasound, in contrast to dam age and lamb birth type, which are not significant variables in echography measurements. The range of correlation values (0.36 and 0.85) obtained when combining ultrasound in Kivircik weaning weight was significant [Ibrahim *et al.* 2007]. This type of information is valuable for meat classification when the breeder must take a decision on the most convenient moment when Kivircik lambs could be sold at weaning age or later, as in the case of farmers from Anatolia or the Aylin province [Ibrahim *et al.* 2007]. The classical method for slaughtering a small number of lambs is extremely laborious, expensive and time-consuming to obtain necessary information concerning the quality of the lamb carcass. Therefore the non-invasive ultrasonic method was used efficiently with fast results to characterize animals for meat quality production *in vivo* [Ibrahim *et al*. 2007]. Body composition associated with weaning weight or market weight obtained by ultrasound helped considerably breeding programs to be developed and improved continuously for meat yield and quality traits in Kivircick lambs [Ibrahim *et al.* 2007]. A more complex tool for investigation is provided by computed tomography (CT), which was used in a study to obtain superior genetic gain in carcass composition in Scottish Blackface sheep produced in a selection program of approx. five years to compose a special index with body conformation and carcass composition [Karamichou *et al.* 2007]. The genetic gain obtained by this complex index is 0.11 phenotypic deviation per year and heritability of the index and of its components as a derivate CT from eye muscle area, muscle depth and fat thickness (0.41, 0.38, 0.41 and 0.30) [Karamichou *et al.* 2007]. Medium genetic correlations were obtained between the index with ultrasound muscle depth and with lamb carcass weight and negative correlations with fat class. The response of selection based on the CT index improved meat quality based on a new conformation with less fat classification. *In vivo* selection with CT scanning for live weight gives merit to carcass weight with the fair price for sheep breeders and farmers without influence on conformation score [Karamichou *et al.* 2007]. Research regarding the influence of sex was undertaken in Segurena lambs with the effect on slaughter weight and carcass weight, especially concerning the quantity of fat deposits [Pena *et al.* 2005]. Fat deposit weight provided carcass classification for hot carcass weight under 20 kg in class B and above 22 kg in class C. Pena *et al*. [2005] found that carcass weight had a significant impact on the other components such as fat deposits, bones, carcass structure, dressing percentage, and other types of carcass measurement. A significant influence was discovered between sex and age at slaughter, the other carcass components and carcass specific measurements for rib eye, fat deposits and commercial cuts such as neck, shoulder, leg and dressing percentage. The lamb carcass weight increased directly in proportion to carcass measurements. Commercial cuts of lambs such as leg, dressing percentage, carcass composition of lambs, they did not change at all even if body conformation was positively influenced [Pena *et al.* 2005]. Beef quality grades for meat standard classification were obtained when for the first time ultrasound was applied in a study investigating meat amount and carcass intramuscular fat (IMFAT) [Nam-Deuk *et al.,* 1998]. *In vivo* beef cattle were analyzed by ultrasound B mode image and ribeye muscle marbling (IMFAT) was predicted based on the picture resolution with software statistics and the gray-level co-occurrence matrix. Based on this software the analysis with a linear regression model enhanced meat quality evaluation for marbling grades in live beef cattle [Nam-Deuk *et al.* 1998]. Estimation of meat amount by non-linear multiple regression equations was accomplished for the first time in Romania on Teleorman Black Head lambs using *in vivo* and carcass measurements with high precision coefficients, showing that one echography measurement on the *Longissimus Dorsi* muscle was enough to improve carcass quality evaluation [Lazar *et al.* 2016]. The best precision coefficients were obtained with three echography parameters (muscle depth, eye muscle area and perimeter) on the *Longissimus Dorsi* level to select the most appropriate individuals for quality meat production [Lazar *et al*. 2016]. Very soon echography was adopted as an evaluation method on the local Carpatina goat breed and ultrasound parameters observed here were in the range recognized for meat quality production [Lazar *et al.* 2017]. The same tendency was observed in Carpatina goats as in the case of Teleorman Black Head sheep when using ultrasound measurement on the *Longissimus Dorsi* level, one measurement was sufficient to estimate meat amount by the regression model to choose the best animals and keep them for reproduction [Lazar *et al.* 2017]. A similar study was conducted by Ghita *et al.* [2017] using ultrasound measurements *in vivo* to analyze lamb meat quality in the Palas Merino and Palas Meat Breeds. The study continued with comparative research between Teleorman Black Head with both sheep breeds described above using ultrasound parameters (thickness of the subcutaneous fat layer, depth muscle, eye muscle area, muscle perimeter) on the *Longissimus Dorsi* level. The Palas Meat Breed stood out with the best performance, showing great potential to improve carcass quality of Romanian local sheep breeds [Ghita *et al.* 2017].

Table 1. Ultrasound and Video Imaging Analysis equipment for meat quality evaluation in cattle

Ultrasound measurement procedure	Equipment	Reference
Longissimus thoracis et lumborum measured by VIA for marbling and the impact on meat quality parameters	Video Image Analysis (VIA),	Giaretta *et al.* [2018]
In vivo ultrasound measurement for fat thickness and muscle area on *Longissimus dorsi* level before slaughter with 24 hours	Real-time ultrasound from Pie Medical 100 B-mode, linear probe of 6/8 MHz	Hernabdez *et al.* [2016]
Carcass ultrasound measurements to estimate total internal fat in different beef cattle breeds	Aloka 500V instrument with a 17-cm, 3.5-MHz probe (Aloka Co. Ltd., Wallingford, CT).	Ribeiro *et al.* [2015]
Ultrasound measurements on *Longissimus dorsi* area and fat in bulls to estimate hot carcass weight	CS-3000 Tokyo, Keiki, 10.1 cm, 3.5 MHz linear probe; Aloka SSD 1100 Flexus RTU (Aloka Co. Ltd., Tokyo, Japan)	Crew *et al.* [2012]
Ultrasound measurement on *Longissimus thoracis et lumborum* for intramuscular fat and software image analysis	Aloka SSD 500V real time scanner (Tokyo, Japan) 7.5 MHz linear probe connected to a video camera (Sony DCR-HC96E, Tokyo, Japan)	Silva *et al.* [2006]
Rib eye muscle ultrasound measurement on *Longissimus Dorsi* level	Real time ultrasound used by Red Angus Association of America	Speidel *et al.* [2007]
Ultrasound measurements in rib eye area, rib fat thickness between 12th and 13th rib, intramuscular fat	Ultrasound equipment	DuPonte *et al.* [2006]
Ultrasound measurement on *Longissimus Dorsi* muscle area, rump fat thickness, body wall thickness, fat thickness on 12 rib	Aloka 500 V RTU, 17.2-cm, 3.5 MHz linear transducer	Greiner *et al.* [2003]
Ultrasound measurements on yearling crossbred bulls for rib eye area, fat thickness, intramuscular fat	Ultrasound devise	Devitt *et al.* [2001]
Ultrasound Image Texture Analysis to determine *in vivo* the Intramuscular Fat Content in Beef Cattle	Aloka 500V equipment, 17 cm of 3.5 MHz linear probe, (Corrometrics Medical Systems, Inc., Wallingford, CT)	Naum-Deuk *et al*. [1998]

The worldwide ultrasound equipment and Video Imaging Analysis based on non-invasive ultrasound was used as a research tool to improve meat carcass evaluation in different animal species. The equipment has been modernized all along with new technologies and a multitude of studies appeared first in cattle (Tab. 1) followed by small ruminants such as sheep and goats (Tab. 2 and 3) and pigs (Tab. 4). Ultrasound

Table 2. Ultrasound and Video Imaging Analysis equipment for meat quality evaluation in sheep

Ultrasound measurement procedure	Equipment	Reference
Fat layer thickness in different ages in lambs	Dynamic Imaging MCV Concept model 7.5 MHz linear probe	Orman *et al.* [2018]
In vivo and carcass measurements for meat quantity estimated by non-linear multiple regression model on Teleorman Black Head lambs	Echo Blaster 64 scanner, LV 7.5 65/64 probe. Ultrasound images analyzed by Echo Wave II 1.32, software, (TELEMED ultrasound medical systems, Lithuania)	Lazar *et al.* [2016]
In vivo ultrasound measurements of the 9th, 11th, 12th rib used in model equations to estimate the proportion of bone, muscle, fat in ewe and lamb carcasses	Áquila Veterinarion, 7 cm linear transductor, 6.0/8.0 MHz probe Pie Medical (Nutricell, Campinas, São Paulo, Brazil)	Morais *et al.* [2016]
Carcass characteristics in lambs for prediction equations to determine carcass weight components by ultrasound	Scanner 100LC, 8 MHz probe from Pie Medical company, Maestricht, Netherlands	Agamy *et al.* [2015]
In vivo fat depth and muscle weight prediction by real-time ultrasound at fat- and thin-tailed breeds	Real-time ultrasound Falco vet, B-mode, 12 cm linear transducer, with a 3.5 MHz probe	Hadhami Hajji *et al.* [2015]
Torki-Ghashghaii Sheep scanned for backfat layer thickness, on *Longissimus Dorsi* level for muscle depth, width and rib eye area	Falco 100, B mode ultrasound, 8 MHz linear probe and a 6.8 cm transducer (Pie Medical, Netherlands)	Hosseini *et al.* [2014]
Ultrasound measurements for predict carcass composition 3 commercial categories of lamb	Aloka SSD-900, 7.5 MHz linear array probe, 62-mm width (UST 5710-7.5, Aloka Spain, Madrid)	Ripoll *et al.* [2010]
In vivo validation for ultrasound measurements on *Longissimus* area and fat depth between 12th and 13th ribs to predict body composition for market lambs	Aloka 500 ultrasound, 11 cm transducer, 3.5 MHz probe, (Corometrics Medical Systems, Wallingford, CT)	Emenheiser *et al.* [2010]
Ultrasound measurement in *Longissimus Dorsi* muscle between 12th and 13th ribs for genetic improvement U.S. lamb composition	Aloka 500 ultrasound, 12.5 cm transducers, 3.5mHz probe, (Corometrics Medical Systems; Wallingford, CT)	Emenheiser *et al*. [2009]
In vivo ultrasound measurements of loin muscle and fat thickness in sheep to improve live animal prediction for subprime cuts weight	Aloka SSD-500V (Corometrics Medical Systems, Wallingford, CT) with a 3.5-MHz, 14.5-cm linear array transducer and standoff	Leeds *et al.* [2007]
RTU measurements on *Longissimus lumborum* for depth, width, eye muscle area, fat thickness between 12th and 13th rib	Pie Medical Falco 100, 6 cm, 6 MHz linear probe	Ibrahim Cemal *et al.* [2007]
CT scanning on *Longissimus Dorsi* for muscle area, muscle depth, fat depth, on 3rd lumbar vertebra	CT Dynamic Imaging real time ultrasound scanner, 7.5 MHz with 56 mm probe	Karamichu *et al.* [2007]
RTU measurements for fat thickness between 12th and 13th ribs and 3rd and 4rd lumbar vertebra in lambs	Aloka SSD-500 V, 2 probe with 5 and 7.5 MHz	Teixeira *et al.* [2006]
In vivo real-time ultrasound measurement to estimate body and carcass chemical composition in lambs	500-V real-time ultrasound, 7.5-MHz probe, combined with image analysis	Silva *et al.* [2005]

Table 3. Ultrasound and Video Imaging Analysis equipment for meat quality evaluation in pigs

Ultrasound measurement procedure	Equipment	Reference
Ultrasound measurements on *Longisimus Dorsi* muscle area, back fat thickness	Ultrasound equipment	Jiang X. *et al.* [2014]
Ultrasound measurements on 10th rib, loin muscle area, gluteal back fat, last rib	Aloka 500 V Holding Europe, Zug, Switzerland, 3.5 MHz, 12 cm probe	Ayuso *et al.* [2013]
Ultrasound measurements on *Longisimus Dorsi* muscle area, back fat thickness in 14th rib (last rib), 5th rib, between 10th and 11th rib	Ultrasound equipment used by National Pork Producers Council	Chad *et al.* [2010]
Ultrasound measurement on back fat thickness in pigs	SFK Pig Scan-A-Mode, Meritronics A-Mode Pulse Echo scanner	Magowan *et al.* [2006]
10 Rib fat, Last rib fat, Last lumbar fat, 10th Rib fat, Longissimus muscle area	Technicare 210 DX	Forests *et al.* [1989]
10 Rib fat, Last rib fat, *Longissimus* muscle area	Technicare 210 DX	Lopez *et al.* [1987]
10 Rib fat, Last rib fat, Back fat thickness	Technicare 210 DX	McLaren *et al.* [1989]
First Rib fat, Last rib fat, Last lumbar fat, 10th Rib fat, *Longissimus* muscle area	Technicare 210 DX	Turligton *et al.* [1990]
Ultrasound measurement on back fat thickness in pigs, eye muscle area	Sonotest TE/6, 5 MHz probe calibrated on 0.5mm, Scanoprobe 731	Giles *et al.* [1981]

Table 4. Ultrasound and Video Imaging Analysis equipment for meat quality evaluation in goats

Ultrasound measurement procedure	Equipment	Reference
Ultrasound measurement in Carpatina Goat for Meat Quality Evaluation in *Longissimus Dorsi* for fat thickness, muscle depth, eye muscle area, eye muscle perimeter	Echo Blaster 64, LV 7.5 65/64 probe, Echo Wave II 1.32, software, (TELEMED ultrasound medical systems, Lithuania).	Lazar *et al.* [2017]
Ultrasound measurement of eye muscle depth, fat thickness in goats used in linear and regression models	Advanced Livestock Services, Hamilton Victoria	McGregor *et al.* [2016]
In vivo ultrasound measurement in *Longissimus Dorsi* muscle between 12-13 ribs and 3rd and 4th sternebrae	Ultrasound Scanner	Gomez *et al.* [2013]
Linear and Ultrasound Measurements in Crossbred Goats for estimation of Live and Hot Carcass Weights	Ultrasound Scanner (Pie Medical 200 SLC, the Netherlands)	Stamper [2010]
In vivo estimation of goat carcass composition and body fat partition by real-time ultrasonography	Ultrasound Toshib Sonolayer, 5-MHz probe, software image analysis (SAC-32B, Toshiba Corporation, Otawara, Japan)	Teixeira *et al.* [2008]
In vivo ultrasound measurement in *Longissimus Dorsi* muscle for fat thickness between 12th -13th ribs, 1st and 2nd lumbar vertebras, 3rd and 4th lumbar vertebras, 1st and 2nd sternebrae and between 3rd and 4th sternebrae	Aloka SSD-500V, 7.5 probe	Cadavez *et al.* [2007]
Ultrasound measurements on *Longissimus Dorsi* muscle	Aloka 500V	Mesta *et al.* [2004]
In vivo ultrasound measurements on male kids to obtain slaughter value	100LC ultrasound device from Pie Medical, 8.0 MHz linear probe	Stanisz *et al.* [2004]
Ultrasound measurements on *Longissimus Dorsi* for eye muscle area between 12-13 ribs	LI-COR portable meter LI-3000A	Dhanda *et al.* [2003]
Ultrasound measurements on *Longissimus Dorsi* muscle for eye muscle area on crossbreed goats	Fiber Optic Probe, VIA Video Imaging Analysis	Dhanda *et al.* [1998]

measurements has gained interest of breeders and farmers and is recognized as easy to apply, accurate, efficient and without hurting the animal, with very good premises for research to boost meat quality by increasing the genetic gain in beef cattle, pigs, sheep and goats. Until full application of the ultrasound gains interest of the meat industry it was a very long period for research opportunities to solve some concerns concenring technical aspects, and subsequently the pig ultrasound information became very useful in meat quality classification. The same uncertainties were explained by Houghton *et al.* [1992] when linked to practical conditions in ultrasound measurements, on sheep in terms of data variation in fat thickness and eye muscle area in lambs. In time the equipment was improved and ultrasound measurements were more accurate and precise with solid stability for the results helping considerably the sheep meat classification. The same author studied beef cattle to obtain *in vivo* measurements concerning fat thickness and eye muscle area on the *Longissimus Dorsi* level, which were enough to predict the exact moment when cattle could be slaughtered with accurate data on the body composition end point [Houghton *et al.* 1992]. The evolution of the ultrasound procedure based on the scientific point of view enhanced confidence of animal breeders in ultrasound measurements of eye muscle area on the *Longissimus Dorsi* level, which were fitted to an appropriate model equation very efficient in sketching meat quantity in real time.

A brief presentation of the EUROP standard carcass meat classification and the law enforcement frame that must be adopted by each country as an active participant in the European meat industry. In order to bring all meat market participants in the same system regarding evaluation of carcass classification in small ruminants and beef the EUROP carcass classification system was developed with specific regulations to be followed by farmers, helping them to be adequately paid for meat quality [Commission Regulation (EEC) No. 461/93, 1993; Council Regulation (EEC) No. 2137/92, 1992]. This system was established as necessary when the economy of the European Union developed in time with the market and animal breeders and farmers increased exchange by grading carcasses with the EUROP classification system [Eypor 2011, Pathak *et al*. 2011]. Numerous research studies began to develop and support the EUROP system for meat grading. This standard offered a fair price to farmers for each small ruminant category in the case of sheep, classified for mutton, yearling mutton, lamb and suckling lamb meat. The performing protocol of the EUROP classification provides information for an objective assessment of animal conformation in terms of the fat class and carcass weight, supported by research linked to their visual assessment [Wnek *et al*., 2016; Schulz and Sundrum, 2020]. Animal conformation first of all describes the body type shaped for a specific production such as meat, meat and milk, or milk production. Therefore, meat animals exhibit some characteristics regarding aspects of carcass profiles, convex or concave one, which indicates meat quantity in relation with the animal skeleton. The human factor and the equipment involved in meat evaluation had to describe the subcutaneous fat on the carcass surface with classes from 1 to 15, where grade 1 is P- for conformation class and 1 for the fat class. The E+ conformation class is attributed to grade 15 and 5+ represents the fat class. Regarding these two aspects a conformation class with a high value is related with great muscle development, while in the case of fat classification a high value indicates a high amount of carcass external and internal fat deposits. The the EU Commission regulation specifies the range with the absolute maximum deviation admissible for abattoirs regarding the conformation and fat classes to be between 0.3 and 0.6, respectively [Commission Regulation (EC) No. 1215/2003, 2003].

The EU Commission presented the limits for conformation and fat classes at slaughterhouse that must be well fitted between ±0.15 and 0.30 from 1 [Commission Regulation (EC) No. 1215/2003, 2003]. The EUROP standard carcass classification system is well divided into 5 classes (E – excellent, U – very good, R – good, O – fair and P – poor), which are in agreement with food quality and safety requirements of consumers and support a fair evaluation of meat quality, offering a justified payment for farmers [Grill *et al*., 2015]. All these details are legislated by the EU Commission [Regulation (EEC) No. 2137/92, No. 461/93, 1992/1993; Commission Regulation (EEC) No. 461/93, 1993; Council Regulation (EEC) No. 2137/92, 1992]. Also, these legislations specify the range for certification and validation of official assessors that must be approved and validated each year by the EU Commission regulation (EC) No. 1215/2003. The meat quality system for pig carcasses is classified in a different manner by predicting lean meat percentage correlated with subcutaneous back fat and *Longissimus Dorsi* muscle depth. The total body fat situates the pigs to the first place with 68%, while for sheep it is 43% and cattle 24% for total body fat [Warriss 2000]. In the case of pigs, the higher subcutaneous backfat layer is more accurately measured compared with sheep and cattle, where backfat is thinner.

Individual training of official evaluators regarding the correct and objective application of the EUROP assessment scheme implies standard image examples as reference for an objective carcass evaluation. These standard image acts as an etalon which supports evaluators in identifying differences they observe at the time of measurement activity (the human factor), even when it is very well prepared with good equipment calibrated in agreement with the standard image and a set of specific parameters.

Conclusion

The most recent advances in the ultrasound technique have been introduced both worldwide and in Romania, thus having an impact on animal meat quality evaluation. The evolution of the ultrasound technique lead to improvements in equipment used in research. Numerous studies confirmed this observation, as shown in summary in this paper based on species important for meat production. This review comes to underline the great potential of the ultrasound technique developed year by year with the evolution of the meat industry and becoming increasingly sensitive to oncumser requirements. The evolution of the ultrasound procedure was supported by a multitude of studies, which enhanced confidence of animal breeders in the ultrasound measurements made on the *Longissimus Dorsi* level. All these ultrasound measurements e.g. for fat deposits, subcutaneous fat layer, eye muscle area, muscle depth, muscle perimeter on the *Longissimus dorsi* muscle were fitted to an appropriate model equation, highly efficient in estimating meat quantity in real time. A brief review of the evolution of ultrasound as a means of assessing meat quality in the main farm animal species outlines the positive impact generated in the last six decades. Also, the ultrasound technique was linked to the EUROP system grading evaluation by studies directed to a specific improvement, such as fewer fat deposits in carcass composition and more lean meat in attempts to fulfil meat quality requirements and support a fair evaluation and payment for farmers. Grading carcasses using the EUROP system became a necessity in order to conform to the same economic conditions in the European countries which intensified and developed exchange between animal breeders and farmers, thus increasing their chances at the competitive meat market. Also, ultrasound shows opportunities that must be embraced by animal breeders and farmers to maximize the genetic progress in order to select the best individuals for meat production. Ultrasound investigation is a non-harmful technique that came to support animal breeding with great results for genetic progress improving generation by generation and thus benefiting both animal breeders and farmers.

REFERENCES

1. AGAMY R., ABDEL-MONEIM A.Y., ABD-ALLA M.S., ABDEL-MAGEED I.I., ASHMAWI G.M., 2015 – Use of ultrasound measurements to predict carcass characteristics of Egyptian ram-lambs. ***Asian Journal of Animal Veterinary Advances*** 10, 203-214,
2. AGUILAR-HERNANDEZ E., CHAY-CANUL A.J., GOMEZ-VAZQUEZ A., MAGAÑA-MONFORTE J.G., RÍOS-RINCÓN F.G., CRUZ-HERNANDEZ A., 2016 – Relationship of ultrasound measurements and carcass traits in Pelibuey ewes. ***The Journal of Animal & Plant Science*** 2, 325-330.
3. AYUSO D., GONZALES A., HERNANDEZ F., CORRAL J.M., IZQUIERDO M., 2013 – Prediction of carcass composition, ham and foreleg weight, and lean meat yields of Iberian pigs using ultrasound measurements in live animals. ***Journal of Animal Science*** 91, 1884-1892.
4. BUSK H., 1984 – Improved Dan scanner for cattle, pigs and sheep. In: Lister, D. ed., In vivo measurement of body composition in meat animals. London: Elsevier. 158-62.
5. CARR C., JOHNSON D., SHUFFITT M., 2010 – Ultrasound and carcass merit of youth market hogs. IFAS extension. Florida University. AN252,
6. COUNCIL REGULATION (EC) No. 1099/2009 of 24 September 2009 on the protection of animals at the time of killing, Council Regulation (EC) No. 1099/2009 of 24 September 2009 on the protection of animals at the time of killing. Text with EEA relevance (europa.eu).
7. COUNCIL REGULATION (EC) No. 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) 1255/97, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:003:0001:0044:EN:PDF.
8. CREW D.H., KEMP R.A., 2012 – Genetic parameters for ultrasound and carcass measures of yield and quality among replacement and slaughter beef cattle. ***Journal of Animal Science*** 79. 3008-3020.

9. Commission Regulation (EEC) No. 461/93. Commission Regulation (EEC) No. 461/93 of 26 February laying down detailed rules for the Community scale for the classification of carcasses of ovine animals. Commission regulation (EEC) No. 461/93.
10. Community scale for the classification of carcasses of ovine animals of 1992/1993. Regulation (EEC) No 2137/92, No 461/93.
11. Commission Regulation (EC) No. 1215/2003 of 7 July 2003 amending Regulation (EEC) No. 344/91 laying down detailed rules for applying Council Regulation (EEC) No. 1186/90 to extend the scope of the Community scale for the classification of carcasses of adult bovine animals. No. 1215/2003.
12. Council Regulation (EEC) No. 2137/92 of 23 July 1992 concerning the Community scale for the classification of carcasses of ovine animals and determining the Community standard quality of fresh or chilled sheep carcasses and extending Regulation (EEC) No. 338/91. Council regulation (EEC) No. 2137/92.
13. DAINA K, DACE B., 2016 – Quality evaluation of fattening lambs using ultrasonic scanner mind ray dp-50 vet. ***Engineering for Rural Development***. 750-755.
14. DEVITT C.J.B., WILTON J.W., 2001 – Genetic correlation estimates between ultrasound measurements on yearling bulls and carcass measurements on finished steers, Beef Research update, 99/00. Centre for Genetic Improvement of Livestock. Guelph University.
15. DHANDA J.S., TAYLOR D.G., MCCOSKER J.E., 1998 – Growth, carcass and meat quality of buck kids reared to produce capretto carcasses. ***Animal Production in Australia*** 22. 161-164.
16. DHANDA J.S., TAYLOR D.G., MURRAY P.J., 2003 – Growth, carcass and meat quality parameters of male goats: effects of genotype and live weight at slaughter, ***Small Ruminant Research*** 50, 57-66.
17. DUPONT M.W., FERGERSTROM M.L., 2006 – Application of Ultrasound Technology in Beef Cattle Carcass Research and Management: Frequently Asked Questions, Cooperative Extension Service, ***Livestock Management***, UH-CTAHR publication. 13, http://www.ctahr.hawaii.edu/freepubs
18. EMENHEISER J.C., GREINER S.P., LEWIS R.M., NOTTER D.R., 2010 – Validation of live animal ultrasonic measurements of body composition in market lambs. ***Journal of Animal Science*** 88, 2932-2939.
19. EMENHEISER J.C., 2009 – Use of ultrasound technology in the genetic improvement of U.S. lamb composition, Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Master of Science in Animal and Poultry Sciences.
20. EYPOR EINARSSON, 2011 – Objective evaluation of lean meat yield and EUROP scores for Icelandic lamb carcasses by video image analysis, Thesis for Master of Science, Faculty of Land and Animal Resources, Agricultural University of Iceland, MS_thesis_Eythor_13des2011_skilaeinktak.pdf (skemman.is).
21. FORREST J.C., KUEI C.H., ORCUTT M.W., SCHINCKEL A.P., STOUFFER J.R., JUDGE, M.D., 1989 – A review of potential new methods of on-line pork carcass evaluation. ***Journal of Animal Science*** 67, 2164.
22. GIARETTA E., MORDENTI A.L., CANESTRARI G., BROGNA N., PALMONARI A., FORMIGONI A., 2018 – Assessment of muscle Longissimus thoracis et lumborum marbling by image analysis and relationships between meat quality parameters. ***PLoS ONE*** 13.8: e0202535.
23. GILES L.R., MURISON R.D., WILSON B.R., 1981 – Backfat studies in growing pigs 2. A comparison of ultrasound and ruler probe predictors of back fat and eye-muscle measurements in the live pig. ***Animal Production*** 32, 01, 47-50.
24. GHITA E., ROTARU C., LAZAR C., PELMUS R., GRAS M., 2017 – Non-invasive, ultrasound evaluation of lamb carcass quality, ***Archiva Zootechnica*** 20, 2, 95-104.

25. GREINER S.P., ROUSE G.H., WILSON D.E, CUNDIFF L.V., WHEELER T.L., 2003 – The relationship between ultrasound measurements and carcass fat thickness and longissimus muscle area in beef cattle. ***Journal of Animal Science***. 81, 676-682.
26. GRILL L., RINGDORFER F., BAUMUNGA R., FUERST-WALTL B., 2015 – Evaluation of ultrasound scanning to predict carcass composition of Austrian meat sheep, ***Small Ruminant Research*** 123, 260- 268.
27. GOMEZ H.F.B., GONÇALVES H.C., NETO A.P., CAÑIZARES G. I. L, ROÇA R.O., MARQUES R.O., OLIVEIRA G.M., E.O., 2013 – Common factors method to predict the carcass composition tissue in kid goats, ***Revista Brasileira Zootecnica***. 42, 3, 193-203.
28. GOODEN J.M., BEACH A.D., PURCHAS R.W., 1980 – Measurements of subcutaneous back fat depth in live lambs with an ultrasonic probe. New Zealand. ***Journal of Agriculture Research*** 23, 161-165.
29. HADHAMI H., NAZIHA A., BEN HAMOUDA M., 2015 – *In vivo* fat and muscle weight prediction for lambs from fat- and thin-tailed breeds by real-time ultrasonography, ***Animal Science Papers and Reports*** 33, 2015 3, 277-286.
30. HEDRICK H.B., MEYER W.E., ALEXANDER M.A., ZOBRISKY S.E., NAUMANN H.D., 1962 – Estimation of rib-eye area and fat thickness of beef cattle with ultrasonic. ***Journal of Animal Science*** 21, 362-365.
31. HOSSEINI V., MIRAEI S.M., ASHTIANI S.R., PAKDEL A., MORADI SHAHREBABAK H., 2014 – Accuracy of Real – time Ultrasonography in Assessing Carcass Traits in Torki – Ghashghaii Sheep. ***Journal of Agriculture Science and Technology*** 16, 791-800.
32. HOUGHTON P.L., TURLINGTON L.M., 1992 – Application of Ultrasound for Feeding and Finishing Animals: A Review. ***Journal of Animal Science***. 70, 930-941.
33. IBRAHIM C., ORHAN K., TUFAN A., OZDAL G., MURAT Y., ONUR Y., 2007 – Ultrasound measurements of eye muscle properties and backfat thickness in Kivircik lams. ***Journal of Biological Sciences*** 7, 89-94.
34. INSANA M.F., 2006 – Ultrasonic imaging. In: Akay, M. and Hoboken, N. J., eds., Encyc. of Biomed. Eng., New York: John Wiley and Sons. 3640-3648.
35. JIANG X., ZHANG L., CHEN S., WANG K., CHEN Z., CHEN L., WANG J., ZHEN, L., 2014 – Ultrasound measurement of back fat thickness and longissimus muscle area in live swine: Effect of equipment, personnel and pig pose, ***Journal of Animal and Veterinary Advances*** 13, 8, 506-513.
36. KARAMICHOU E., MERRELL B.G., MURRAY W.A., SIMM G., BISHOP S.C., 2007 – Selection for carcass quality in hill sheep measured by X-ray computer tomography. ***Animals*** 1, 3-11.
37. KLEIN H.G., 1981 –Are B-scanners' days numbered in abdominal diagnosis? ***Diagnostic Imaging***. 3, 10-11.
38. LAZAR C., PELMUS R.S., GRAS A.M., GHIȚĂ E., 2012 – Comparative study between non–invasive ultrasound with classical methods for improving evaluation of sheep meat production on Teleorman Black Head lambs in Romania. 11^{th} Int. Symposium of Animal Biology and Nutrition, Book of Abstracts 14.
39. LAZAR C., GRAS AL. M., ROTAR M.C., PISTOL G.C., PELMUS R.S., GHIŢĂ E., 2015 – Evaluation of meat quality in Teleorman Black Head by ecographic method and identification of calpastatin (*cast*) gene polymorphism correlated with carcass quality. ***Scientific Papers - Animal Science Series - Seria Zootechnie*** 64, 67-72.
40. LAZAR C., GRAS M.A., PELMUS R.S., ROTAR C.M., GHITA E., BURLACU R., 2016 – Estimation of meat amount by non-linear multiple regression equations using *in vivo* and carcass measurements on Teleorman Black Head lambs. ***Journal of Animal and Feed Sciences*** 25, 292-301.

41. LAZAR C., GRAS M.AL., PELMUS R., GHITA E., ROTAR M.C., 2017 – Improvement of Meat Quality Evaluation by Ultrasound in Carpatina Goat Breed. ***Scientific Papers: Animal Science and Biotechnologies*** 50, 1, 249-253.
42. LEEDS T.D., MOUSEL M.R., NOTTER D.R., LEWIS G.S., 2007 – Ultrasound estimates of loin muscle measures and backfat thickness augment live animal prediction of weights of subprimal cuts in sheep. Proceeding Western Section. ***American Society of Animal Science*** 58, 97-100.
43. LOPES D.M., WILLIAMSON S.A., JACOBS J.A., THOMAS M.W., 1987 – Estimation of fat depth and longissimus muscle area in swine by the use of real-time ultrasonography. Proceeding. Western Sect. ***American Society of Animal Science*** 38-155.
44. MAGOWAN E., MCCANN M.E.E., 2006 – A comparison of pig back fat measurements using ultrasonic and optical instruments. ***Elsevier***. ***Livestock Science*** 103, 116-123.
45. MCGREGOR B.A., 2017 – Relationships between live weight, body condition, dimensional and ultrasound scanning measurements and carcass attributes in adult Angora goats. ***Small Ruminant Research.*** 147, 8-17.
46. MCLAREN D.G., MCKEITH F.M., NOVAKOFSKI J., 1989 – Prediction of carcass characteristics at market weight from serial real-time ultrasound measures of back fat and loin eye area in the growing pig. ***Journal of Animal Science*** 87, 1657.
47. MESTA C.G., WILL P.A., GONZALEZ J.M., 2004 – The Measurement of Carcass Characteristics of Goats Using the Ultrasound Method, ***The Texas Journal of Agriculture and Natural Resource*** 17, 46-52.
48. MORAIS M.G., MENEZES B.B., RIBEIRO C.B., WALKER C.C., FERNANDES H.J., SOUZA A.R., FERREIRA ÍTAVO C. B., FEIJÓ G.L., 2016. – Models predict the proportion of bone, muscle, and fat in ewe lamb carcasses from *in vivo* measurements of the 9th to 11th rib section and of the 12th rib. Semina: Ciências Agrárias, Londrina. 37. 2. 1081-1090, mar./abr., DOI: 10.5433/1679-0359.2016v37n2p1081.
49. NAM-DEUK K., AMIN V., WILSON D., ROUSE G., UDPA S., 1998 – Ultrasound Image Texture Analysis for Characterizing Intramuscular Fat Content of Live Beef Cattle. ***Ultrasonic imaging*** 20, 191-205.
50. ORMAN A., ÜLKE Ç.G., MUTLU TEMIZEL ÇAĞDAŞ E., KARA H.G., ÜNAL C., 2018 – The usefulness of leptin measurements and ultrasound fat thickness for assessment of body fat reserves of Awassi lambs, ***Italian Journal of Animal Science*** 17, 3, 706-713.
51. PATHAK V., SINGH, V. P., YADOV SANJAY., 2011 – Ultrasound as a modern tool for carcass evaluation and meat processing: a review. ***International Journal of Meat Science*** 1, 2, 83-92.
52. PE˜NA F., CANOB T., DOMENECHA V., ALCALDE MA J., MARTOS J., GARCIA-MARTINEZ A., HERRERA M., RODERO E., 2005 – Influence of sex, slaughter weight and carcass weight on “non-carcass” and carcass quality in segure˜na lambs. ***Small Ruminant Research*** 60, 247-254.
53. RIBEIRO F.R.B., TEDESCHI L.O., 2015 – Using real-time ultrasound and carcass measurements to estimate total internal fat in beef cattle over different breed types and managements, ***Journal of Animal Science*** 90, 3259-3265, doi:10.2527/ jas2011-4697.
54. RIPOLL G., JOY M., SANZ A., 2010 – Estimation of carcass composition by ultrasound measurements in 4 anatomical locations of 3 commercial categories of lamb. ***Journal of Animal Science*** 88, 3409-3418.
55. SANTOS V.A.C., SILVA S.R., AZEVEDO J.M.T., 2008 – Carcass composition and meat quality of equally mature kids and lambs. ***Journal of Animal Science*** 86, 1943-1950.
56. SCHULZ L., SUNDRUM A., 2020 – Determining relationships between marbling scores and carcass yield traits of German beef bull carcasses using video-image analysis at the 12th and 10th rib position of longissimus thoracis and EUROP classification. ***Applied Sciences*** 11, 269.

57. SILVA ET AL., 2012 – Real-time ultrasound (RTU) imaging methods for quality control of meats, Chapter 11, Woodhead Publishing Limited, 277-329.
58. SILVA S.R., AFONSO J.J., SANTOS V.A., MONTEIRO A., GUEDES C.M., AZEVEDO., DIAS-DA- SILVA J.M.T., 2006 – In vivo estimation of sheep carcass composition using real-time ultrasound with two probes of 5 and 7.5 MHz and image analysis. ***Journal of Animal Science*** 84, 3433-3439.
59. SILVA S.R., GOMES M.J., DIAS-DA-SILVA A., AZEVEDO J.M.T., 2005 – Estimation in vivo of the body and the carcass chemical composition of growing lambs by real-time ultrasonography. ***Journal of Animal Science***. 83, 350-357.
60. SPEIDEL S.E., ENNS R.M., BRIGHAM B.W., KEENAN L.D., 2007 – Genetic parameter estimates for ultrasound indicators of carcass, Proceeding Western Section ***American Society of Animal Science*** 58, 39-42.
61. STAMPER N., 2010 – Linear and Ultrasound Measurements in Crossbred Goats as a Predictor of Live and Hot Carcass Weights, Thesis, University of Tennessee at Martin, Master of Science Agriculture and Natural Resources Systems Management. 1-33.
62. STANFORD K., MCALLISTER, T.A., MACDOUGALL, M., BAILEY, D.R.C., 1995 – Use of ultrasound for the prediction of carcass characteristics in Alpine goats. ***Small Ruminant Research*** 15, 95-201.
63. STANISZ M., SLOSARZ P., GUT A., 2004 – The live ultrasound measurements to assess slaughter value of meat-type male kids. ***Animal Science Papers and Reports*** 22, 4, 687-693.
64. STOUFFER J.R. 1959 – Status of the application of ultrasonic in meat animal evaluation. ***Proceedings of the Reciprocal Meat Conference*** 12, 161-169.
65. STOUFFER J.R., WALLENTINE M.V., WELLINGTON G.H., DIEKMANN A., 1961 – Development and application of ultrasonic methods for measuring fat thickness and rib-eye area in cattle and hogs. ***Journal of Animal Science*** 20, 759-67.
66. STOUFFER J.R., 2004 – History of ultrasound in animal science. ***Journal of Ultrasound in Medicine*** 23, 577-84.
67. SZABO T.L., 2004 – Diagnostic Ultrasound Imaging: Inside Out. Connecticut: Academy Press Series in Biomedical Engineering.
68. TEIXEIRA A., JOY M., DELFA R., 2008 – In vivo estimation of goat carcass composition and body fat partition by real-time ultrasonography. ***Journal of Animal Science*** 86, 2369-2376.
69. TEIXEIRA A., MATOS S., RODRIGUES S., DELFA R., CADAVEZ V., 2006 – In vivo estimation of lamb carcass composition by real–time ultrasonography. ***Meat Science*** 74. 289-295.
70. TEMPLE R.S., STONAKER H.H., HOWRY D., POSAKONY G., HAZALEUS M.H., 1956 – Ultrasonic and conductivity methods for estimating fat thickness in live cattle. Proceeding, Western Section, ***American Society of Animal Science*** 7, 477-81.
71. TURLINGTON L.M.,1990 – Live animal evaluation of swine and sheep using ultrasonic. M.S. Thesis. Kansas State University, Manhattan.
72. WARRISS P.D., 2000 – Meat Science – An introductory text. 0-85199-424-5. CABI Publishing.
73. WNĘK K., GOŁĘBIEWSKI M., PRZYSUCHA T., BALCERAK M., 2016 – Accuracy of visual assessment of beef carcasses EUROP performed by the national assessors and assessor from the abattoir. ***Annals of Warsaw University of Life Sciences- SGGW Animal Science*** 127-134.