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EFFECTS OF ULTRASOUND ON TECHNOLOGICAL PROPERTIES OF MEAT A REVIEW

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Abstract
Ultrasound is well known to become an efficient tool for various processes in the food industry. The process industry demands that operations be performed in the most efficient way with respect to processing cost, reduced processing time, lower energy consumption without a negative impact on product quality. Therefore, alternative novel technologies have tried to find solutions to reduce the total processing cost while maintaining or enhancing product quality . Power ultrasound has been recognized as a promising processing technique to replace or complement conventional thermal treatments in the food industry. Several processes such as emulsification, homogenization, extraction, crystallization, dewatering, low temperature pasteurization, degassing, defoaming, activation and inactivation of enzymes, particle size reduction and viscosity alteration have been applied efficiently in the food industry.This review surveyed recent literature focused on ultrasound technique used in meat industry. Ultrasound technology is applied in the meat industry mostly as a modern tool for carcasses evaluation but many of its uses are still being researched. The parameters, mechanisms and results of different experiments that have used low and high frequency ultrasound in meat industry were presented. Thus, the process parameters across in many experiments, as well as many applications in ultrasonic field was examined. The ultrasound effect on pH, the water-holding capacity, the tenderness of sonicated meat was presented in detail. The ultrasound effect on meat brining and tumbling was also considered.

Keywords: water-holding capacity, pH, tenderness, brining, tumbling.

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1. INTRODUCTION

Application of ultrasound in food industry lies in the fact that power ultrasound can cause changes in physical, chemical or functional properties, offering a net advantage in terms of productivity, yield and selectivity as well as environmentally friendly (Chemat et al., 2011). Ultrasound represents mechanical waves, which can be divided into high frequency, low energy, diagnostic ultrasound in the MHz range and low frequency, high energy, power ultrasound in the kHz range (Mason et al., 1986). The basis of many applications of ultrasound in frequency range from 20 kHz to 1MHz is acoustic cavitation, which is the formation, growth and collapse of microbubbles within an aqueous solution (Leong et al., 2011). The properties of ultrasound are affected by the media through which it propagates. Ultrasound in liquids generates a number of physical forces that include acoustic streaming, cavitation, shear, microjet, and shockwaves. Vibration, heating and physical agitation are forces that can be generated in the absence of acoustic cavitation (Chandrapala et al., 2012). High power ultrasonic applications generally depend on complex vibration which produces cavitation in liquids or biological tissue. Applications of ultrasound at high intensities to provoke changes in physical and chemical properties of meat and meat products is of utmost interest as they supply an alternative to chemical or thermal means of processing (Jayasooriya et al., 2004).
Ultrasound started to be used in meat industry in 1950 as non-destructive means to evaluate the quality of beef carcasses based on the characteristic of ultrasonic sound which can travel more quickly through muscle tissues than fat tissues. Therefore, this method measures the velocity of the ultrasound from the transmitter to a receiver through a meat

sample giving an indication of composition (Pathak et al., 2011). Ultrasound techniques used for evaluating carcasses, such as A-mode, B-mode and real-time ultrasound technique, have several distinct advantages: may be used in live animals; may be used on slaughter floors before hide removal; may accurately predict traits related to palatability; offer no health hazards; would allow complete automation of grading and remove the element of human error; offer great compatibility with integrated artificial neural networking technology (Cross and Belk, 1994). Moreover the ultrasound technique was used also for predicting fat-to-lean ratio, thus easing the process of classifying carcasses (Hamlin et al., 1995, Liu and Stouffer, 1995, Morlein et al., 2005) and improving the reproduction and genetic selection programmes (Wilson, 1992, Reverter et al., 2000), low-intensity ultrasound being also used in differentiating the pure bred meat from mixed breed meat (Ventanas et al., 2007). Ultrasound proves useful at determining the chemical composition of raw-dry sausages and of a Spanish specialty (sobrassada), making possible to predict fat, water, protein content of these products without using any chemical analyses (Benedito et al., 2001, Simal et al., 2003).

As regards meat industry, there were many studies in which ultrasound was used both for a better processing time of certain technological processes but also for improving the technological properties of meat. Hence, the purpose of the present review was to present how ultrasound influenced both the technological properties of sonicated meat (water-holding capacity, colour, tenderness) and certain processes common for meat industry such as mixing, tumbling or brining.

Effects of ultrasound on technological properties of meat

Several studies whose purpose was to obtain meat with better technological qualities after ultrasound treatment showed the ultrasound positive or negative effects on its technological properties. Although the results obtained were often contradictory, a presentation of its influence on pH, on the water-holding capacity, on colour and on sonicated meat tenderness was done.

Effects of ultrasound on pH

Although in some studies it was noticed that ultrasound had no influence on pH (*Dolatowski et al., 2000, Stadnik et al., 2008*), others led to the remark that this parameter was affected by the sonication treatment (Got et al., 1999, Jayasooriya et al., 2007). Therefore, in the case of beef samples (semimembranosus muscle) sonicated pre-rigor (2.6MHz, 10W/cm^2) one can notice that ultrasonic treatment induced an immediate increase in pH of about 0.2 unit, which was maintained over the following 2-4 hours after treatment but the ultimate pH did not significantly differ between control and treated samples (Got et al., 1999). Got et al., (1999) explained that the delay in muscle acidifying as effect of ultrasound treatment was caused by the damage to cell structure which releases ions into the cytosol or by the change in the protein structure that led to a modification in the position of some ionic groups. On the other hand, in the case of aged beef it was noticed that pH increased with ageing time and ultrasound treatment when high intensity ultrasound (12W/cm^2; 24kHz) was applied. Jayasooriya et al., (2007) supposes that this progressive rise during aging could be explained by conformational changes associated with the denaturation of protein by ultrasound treatment and the proteolytic degradation of the muscle fibres.

Effects of ultrasound on water holding capacity

Water holding capacity is an important characteristic of meat quality and unacceptable water-holding capacity costs the meat industry millions of dollars annually (*Huff-Lonergan and Lonergan, 2005*). Therefore, the analysis of this parameter in the case of meat treated with ultrasound is very important. Water holding capacity variations were observed as a result of myofibrillar proteins changes, and

Dolatowski et al., (2000) observing changes in protein's structures of meat sonicated (25KHz and 2W/cm^2) suggested that sonication accelerates the ageing of meat. Water holding capacity as well as water mobility of beef meat treated at 45KHz, 2W/cm^2 was also measured by Stadnik et al., (2008). Hence, water holding capacity of meat samples was measured with the filter paper press method and the results obtained were correlated with the analysis of water mobility done with NMR technique and also with the analysis of the sonicated meat microstructure. It was found out that after ultrasound treatment, samples had the highest water holding capacity, typical for meat in advanced post mortem stage suggesting that ultrasound treatment can cause acceleration of further ageing processes. Water holding capacity varied during ageing, reflecting the ultrasound influence on changing the structure of the myofibrils, changes also confirmed by the photograms of the microstructure (*Stadnik et al., 2008*).

Effects of ultrasound on colour

Colour perception plays a major role in evaluating the meat quality, and the analysis of color parameters is important. Most of the studies in which analyses were done on the colour parameter showed that CIE parameters were not affected by the ultrasound treatment. As a result of the fact that there were no significant differences between sonicated and control samples, it was supposed that although temperature rose during ultrasound treatment, the generated heat is insufficient for thermal denaturation and for colour pigments oxidation (Mb, MetMb) (Jayasooriya et al., 2007). Furthermore, some studies noticed that ultrasound limited MbO2 formation and slowed down the formation of MetMb (Stadnik and Dolatowski, 2011). However, there still were different results regarding the colour of sonicated meat. Thus, Pohlman et al., (1997a) after applying high ultrasound intensity (22W/cm^2) to beef noticed a change of the sonicated meat colour parameters, this being lighter in colour (lower L*), less red (lower a*), more yellow (higher b*), more orange (bigger hue angle), less bright than the control sample, the main cause being considered the heat generated during treatment.

Effects of ultrasound on tenderness

In order to evaluate the tenderness of the meat subject to ultrasound treatment at different parameters, some studies analysed the shear force at both raw and cooked meat, while others analysed the changes appeared in the collagen structure or in the microstructure of the muscular tissue exposed to sonication.

Analysis of shear force

The studies which analysed the shear force at sonicated meat were different from the point of view of ultrasound application, using both ultrasound baths and ultrasound probes. Therefore, as regards beef sonication with ultrasound baths at low frequencies (30-40, 34-42, 47kHz) and high intensities (29.39, 62W/cm^2) done by Lyng et al., (1997) and Chang et al., (2009) (40KHz,1500W), no significant improvement of the shear force was noticed. Moreover, Lyng et al., (1997) in order to underline his statement used an electrophoretic study which did not show differences in the rate of appearance of characteristic bands of ageing or changes in the number of bands present showing that proteolysis was not influenced by the ultrasound treatment of meat, no matter the parameters applied. Regarding the meat treatment using ultrasound probes, it was noticed that the value of the shear force at the sonicated meat samples was not different from the control samples no matter the parameters used. Therefore, although high ultrasound intensities 62W/cm^2 at low frequencies of 20kHz were used, no improvement was noticed both in lamb and in beef sonicated samples (Lyng et al.,1998a, Lyng et al., 1998b). Furthermore, in the case of beef the lack of meat tenderness was also confirmed by SDS-page analysis, when no proof of proteolysis improvement due to lysosomal calpains and catepsines was detected at sonicated samples. In both cases, of lamb and beef, the lack of ultrasound effect on meat tenderness can be explained by the fact that it was not enough magnitude to influence meat tenderness, considering that sufficient ultrasound energy is needed to be transmitted into the meat sample in order to improve the proteolysis (Lyng et al., 1998a, Lyng et al., 1998b). Similarly, when high frequencies of 2.6MHz at intensities of $10W/cm^2$ were applied to beef (semimembranosus muscle) it was not noticed an ultrasound influence on tenderness rate. In this case, although high intensity ultrasound caused microstructure changes in pre-rigor phase, it did not lead to the improvement of meat tenderness (Got et al., 1999).

In the case of the shear force of sonicated cooked meat, the results were better, considering those studies which confirm the improvement of the shear force at sonicated samples. Thus, Smith et al., (1991) using an ultrasonic bath with lateral transducer (25.9kHz), noticed a significant decrease of shear force at beef sonicated and cooked at 75°C, and explained the meat tenderness as a consequence of acoustic cavitation, the cavitation bubble producing hydro-dynamic forces which affect the integrity of muscular structure.

However, Dolatowski et al., (2000), at 25kHz and $2W/cm^2$ noticed significant changes in shear force values (lower shear force values than for control samples) only for meat cooked at 50°C, but at 70°C the improvement of the shear force values was not noticed. Jayasooriya et al., (2007) using high intensities of $12W/cm^2$ at 24kHz, for beef, noticed that the shear force value at samples sonicated and then cooked at 70°C decreased significantly when the sonication time was increased. The possible explanations referring to tenderness in sonicated meat were related to heating of the tissue by 15-30°C which might have led to an increase in the activity of proteases in the muscle or could have led to muscular protein denaturation. Even the use of different parameters (45kHz, $2W/cm^2$) for beef showed that there was a decrease in the shear force values at sonicated samples compared with the control samples at meat cooked at 80°C (Stadnik and Dolatowski, 2011). Nonetheless, there were also studies which did not show any improvement of the shear force at cooked meat no matter how the ultrasound was applied or the parameters used (Pohlman et al., 1997a, Pohlman et al., 1997b).

Analysis of collagen

As regards the analysis of the way the ultrasound works on the collagen structure and, implicitly, on the connective tissue it is important to find out if these studies were done on meat components in solution or on entire meat system. The explanation would be that these components extracted from meat and sonicated in solution are not subject to mechanical constraint of sarcolemma, layers of connective tissue as entire meat, therefore being more sensitive to vibrations in sonic field. In addition, the effect noticed on components in solution could not be produced in entire meat system (Lyng et al., 1997).

Hence, Nishihara and Doty, (1958), using collagen extracted from calfskin exposed it to a ultrasonic field of 9kHz and 50 W, at temperatures of 8-11°C, obtaining the fragmentation of collagen molecules into shorter pieces which maintained three helicoid structures. Furthermore, it was noticed that the molecular mass of collagen varied from 336000 to 137000 (according to sonication time), variations explained by fragmentation of collagen macromolecule. Fragmentation of collagen molecules exposed to ultrasound was confirmed also by the analysis with electronic microscope, the tropocollagen molecules fragmenting on 45-55% of the initial length (Hodge and Schmitt, 1958).

Nevertheless, the degradation of the collagen molecules also noticed by Nishihara and Doty, (1958) did not happen on the entire piece of sonicated meat, Lyng et al., (1997) , Lyng et al., (1998b) and Got et al., (1999) did not notice any effect on the collagen insoluble after pre-rigor and post-rigor sonication of meat pieces. Nonetheless, Chang et al., (2009) showed that ultrasound had a significant effect on collagen characteristics, especially on its thermal properties, without having a significant effect on the content of insoluble collagen.

Analysis of microstructure

The analysis of the structure of the sonicated muscular tissue was done either by measuring the sarcomeres length or the myofibrillar fragmentation index (MFI), or by electronic microscope analysis.
The values obtained by measuring the sarcomeres length can be important for assessing the contraction of the muscle and, implicitly, for its tenderness. Studies done on different pork muscles showed the importance of the sarcomere in tendering for unaged muscle and also for the correlation between the length of the sarcomere, the collagen content, the proteolysis rate and tendering (Wheeler et al., 2000). By treating beef (semimebranosus muscle) in pre-rigor and post-rigor to high intensities and frequencies (2.6MHz si 10W/cm^2) differences between the values of the sarcomere length were noticed. Therefore, in pre-rigor there was a significant increase in the sarcomeres length of the sonicated samples unlike the control samples, having as consequence changes of the Z-line and the extension of the intermyofibrillar spaces. Yet, after 6-day ageing these differences disappeared and the post-rigor ultrasound treatment did not cause microstructure changes (Got et al., 1999).
One of the most important changes occurring in the muscular tissue is a slight fragmentation of the myofibrils under controlled homogenization (a change which did not occur in the unaged tissue) which is called the myofibrillar fragmentation index (MFI) (Koohmaraie, 1994). MFI is linked to meat tenderness and was used as a method to estimate the tenderness degree, in several studies being a good predictor of the tenderness (Taylor et al., 1995). Hence, the myofibrillar fragmentation index of beef meat treated at 25kHz, 2W/cm^2 was measured by Latoch (2010), but no significant effect of post-slaughter sonication was noted on myofibrillar fragmentation index., the differences between the control samples and the sonicated samples being insignificant.
Examining the microstructure of sonicated meat by electronic microscopy was identified a more advanced modification of structural elements of sarcomere in sonicated as against control samples. Many Z-discs are broken, myofibrils and sarcomers completely destroyed in the sonicated samples, so ,the changes observed in structural elements of sarcomere led to the hypothesis that sonication accelerated the process of meat tenderization (Dolatowski et al., 2000, Stadnik et al., 2008).

Effects of ultrasound on meat brining

As brining is an important process in meat industry, some studies used ultrasound to accelerate meat brining. Furthermore, it was studied the ultrasound effect on bind strength, cooking yield, on the degree of myofibril and sarcoplasmatic proteins extraction at restructured beef roll. By applying ultrasound at mixing and tumbling meat it was noticed the improvement of both its binding capacity and its cooking yield at sonicated samples. Similarly, the ultrasound treatment had effects on the extraction of the myofibril proteins but had no effects on sarcoplasmatic proteins (Reynolds et al., 1978, Vimini et al., 1983). Siro et al., (2009) using vacuum tumbling and ultrasound at 20 kHz showed that ultrasonic treatment and tumbling caused favourable microstructural and textural changes and improved diffusion of salt and water-binding.
Using high-intensity ultrasound to increase salt diffusion in pork meat immersed in brine, Cárcel et al., (2007) noticed that the ultrasound intensity must be higher than 64W/cm^2 (20kHz), the ultrasound intensity influencing the quantity of salt accumulated in meat. It was assumed that high intensities which generate intense cavitation in brine, near the solid surface produces the formation of microjets that hit the solid surface and which could lead the microinjection of brine into the meat. These considerations could explain the increase of moisture and NaCl content at samples sonicated at high intensities, at low intensities

no effect being noticed. Furthermore, Jorgensen et al., (2008), showed that by applying low power ultrasound to marinated meat previously injected, positive effects were obtained in tendering pork. It was noticed the improvement of tenderness assuming that ultrasound led to better spreading the brine in meat. Not the same results were obtained when using low-power ultrasound bath in the case of marinated chicken which had not been previously injected (Smith, 2011).

2. CONCLUSIONS

Many researches on the use of ultrasound in meat technology showed contradictory results. Thus, one can notice that researches were done under different conditions, the parameters such as frequency, intensity, ultrasound exposing time were different in most of the cases. Moreover, two types of ultrasound systems are reported to be used in these researches, one using a horn as the sound emitter and the other using a bath. In addition, the meat used came from different species (beef, lamb, pork), the muscles used also being of different types (pectoralis, longissimus dorsi, semimebranosus), as well as ageing degree (aged or unaged), or geographic region. Therefore, in order for a part of these studies to move further from being merely lab studies it is necessary to pay special attention to the way the ultrasound is applied, to the parameters and the raw meat used. Although the researches in this review sometimes offer contradictory results on the ultrasound influence on meat technological properties, they represent starting points for their future implementation at an industrial level in meat industry, especially because they have the advantage of a lower cost than other technologies.

3. REFERENCES

[1] Benedito, J., Carcel, J.A., Rossello, C., Mulet, A. (2001). Composition assessment of raw meat mixtures using ultrasonics. Meat Sci.,57, 365-370.

[2] Carcel, J. A., Benedito, J., Bon, J., Mulet, A. (2007). High intensity ultrasound effects on meat brining. Meat Sci., 76, 611-619.

[3] Chemat, F., Zill-E-Huma., Khan, M.K. (2011). Applications of ultrasound in food technology: Processing, preservation and extraction. Ultrason. Sonochem.,18, 813-835.

[4] Chandrapala, J., Oliver, C., Kentish, S., Ashokkumar, M. (2012). Ultrasonics in food processing, Ultrason. Sonochem. doi:10.1016/j.ultsonch.2012.01.010**e**

[5] Chang, H.J., Xu, X.L., Zhou, G.H., Li, C.B., Huang, M. (2009). Effects of characteristics changes of collagen on meat physicochemical properties of beef semitendinosus muscle during ultrasonic processing. Food Bioprocess Tech, 5, 285,297.

[6] Cross, H,R., and Belk, K.E. (1994). Objective measurements of carcass and meat quality. Meat Sci.,36(1-2),191-202

[7] Dolatowski, Z., Stasiak, D.M., Latoch, A. (2000) Effect of ultrasound processing of meat before freezing on its texture after thawing. Electr J Polish Agric Univer, 3(2), http://www.eipau.media.pl

[8] Got, F., Culioli, J., Berge, P., Vignon, X., Astruc, T., Quideau, J.M., Lethiecq, M. (1999). Effects of high-intensity high-frequency ultrasound on ageing rate, ultrastructure and some physico-chemical properties of beef. Meat Scie., 51, 35–42.

[9] Hamlin, K.E., Green, R.D., Cundiff ,L.V., Wheeler,T.L., Dikeman, M.E. (1995). Real-time ultrasonic measurement of fat thickness and longissimus muscle area: II. Relationship between real-time ultrasound measures and carcass retail yield. J. Anim. Sci., 73 (6), 1725-1734.

[10] Hodge, A. and Schmitt , F. (1958). Interaction properties of sonically fragmented collagen macromolecules. Proc. Nat. Acad. Sci., 44, .418-424.

[11] Huff-Lonergan , E. and Lonergan, S.M. (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Scie., 71, 194–204 [12] Jayasooriya, S.D., Bhandari, B.R., Torley, P., D'Arcy, B.R. (2004). Effect of High Power Ultrasound Waves on Properties of Meat: A Review. Int J Food Prop., 7(2), 301-319.

[12] Jayasooriya, S.D., Torley, P.J., D'Arcy, B.R ., Bhandari, B.R. (2007). Effect of high power ultrasound and ageing on the physical properties of bovine Semitendinosus and Longissimus muscles. Meat Scie, 75, 628-639.

[13] Jorgensen, A.S., Christensen. M., Ertbjerg, P. (2008). Marination with kiwifruit powder followed by power ultrasound tenderizes porcine M. biceps femoris, International Conference of Meat Science and Technology, International Congress of Meat Science and Technology (ICoMST).

[14] Koohmaraie, M. (1994). Muscle proteinases and meat aging. Meat Sci.,36 ,93-104.

[15] Latoch, A. (2010). Selected properties of I-Z-I band proteins of sonicated beef . Pol. J. Food Nutr. Sci., 60 (1), 51-55

[16] Leong, T., Ashokkumar, M., Kentish, S. (2011). The fundamental of power ultrasound-A review. Acoustics Australia, 2 (39), 54-63.
[17] Liu, Y. and Stouffer, J.R. (1995). Pork carcass evaluation with an automated and computerized ultrasonic system. J. Anim. Sci., 73 (1), 29-38.
[18] Lyng, J.G., Allen, P., Mckenna, B.M. (1997). The influence of high intensity ultrasound baths on aspects of beef tenderness. J Muscle Foods, 8, 237-249.
[19] Lyng, J.G., Allen, P., Mckenna, B.M. (1998a). The effects of pre- and post-rigor high-intensity ultrasound treatment on aspects of lamb tenderness. Lebensmittel Wissenschaft und Technologic., 31(4), 334-338.
[20] Lyng, J.G., Allen, P., Mckenna, B.M. (1998b). The effect on aspects of beef tenderness of pre- and post-rigor exposure to a high intensity ultrasound probe. J Scie Food Agric, 78(3), 308-314.
[21] Mason, T.J., Paniwnyk, L., Lorimer, J.P. (1986). The uses of ultrasound in food technology. Ultrason. Sonochem.,3, 253-260.
[22] Morlein, D., Rosner, F., Brand, S.,Jenderka, K.V., Wicke, M. (2005). Non-destructive estimation of the intramuscular fat content of the longissimus muscle of pigs by means of spectral analysis of ultrasound echo signals. Meat Sci.,69 (2),187-199.
[23] Nishihara, T. and Doty, P. (1958). The sonic fragmentation of collagen macromolecules. Proc. Nat. Acad. Sci., 44, 411-417.
[24] Pathak, V.,Singh,V.P., Sanjav,Y. (2011). Ultrsaund as a modern tool for carcass evaluation and meat processing;a review. Int J Meat Scie., 1(2),83-92.
[25] Pohlman, F.W., Dikeman, M.E., Kropf, D.H. (1997a). Effects of high intensity ultrasound treatment, storage time and cooking method on shear, sensory, instrumental color and cooking properties of packaged and unpackaged beef pectoralis muscle. Meat Scie., 46(1), 89-100.
[26] Pohlman, F.W., Dikeman, M.E., Zayas, J.F. (1997b). The effect of low-intensity ultrasound treatment on shear properties, color stability and shelf life of vacuum packaged beef semitendinosus and biceps femoris muscles. Meat Scie., 45(3), 329-337.
[27] Reverter, A., Johnston, D.J., Graser, H., Woltcott, M.L., Upton, W.H. (2000). Genetic analyses of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. J. Anim. Sci.,78**,** 1786-1795.
[28] Reynolds, J.B., Anderson, B., Schmidt, G.R., Theno, D.M., Siegel, D.G. (1978). Effects of ultrasonic treatment on binding strength in cured ham rolls. J Food Scie., 43(3), 866-869.
[29] Simal, S., Benedito, J., Clemente, G., Femenia, A.,Rossello, C. (2003). Ultrasonic determination of the composition of a meat-based product. J. Food Eng., 58(3), 253-257.
[30] Siro, I., Ven, Cs., Balla, Cs., Jónás, C.G., Zeke, I., Friedrich, L. (2009). Application of an ultrasonic assisted curing technique for improving the diffusion of sodium chloride in procine meat. J Food Eng., 91,353-362.
[31] Smith, D.P. (2011). Effect of ultrasonic marination on broiler breast meat quality and *Salmonella* contamination. Int J Poultry Scie., 10, 757-759.
[32] Smith, N., Cannon, J., Novakofski, J., Mckeith, F., O'Brien, W. (1991). Tenderization of Semitendinosus muscle using high intensity ultrasound. In Proceedings of the IEEE ultrasonics symposium (pp. 1371–1374), Orlando, FL, USA .
[33] Stadnik, J., Dolatowski, Z., Baranowska, H.M. (2008). Effect of ultrasound treatment on water holding properties and microstructure of beef (m. semimembranosus) during ageing. Food Sci Technol., 41, 2151-2158.
[34] Stadnik, J. and Dolatowski, Z.J. (2011). Influence of sonication on Warner-Bratzler shear force, colour and myoglobin of beef (m. semimembranosus). Eur Food Res Tehnol., 233, 553-559.
[35] Taylor, R., Geesink, G., Thompson, V., Koohmaraie, M., Goll, D. (1995). Is Z-disk degradation responsible for postmortem tenderization? J. Anim Sci.,73, 1351-1367.
[36] Ventanas, S., Ventanas, J., .Ruiz, J., Bon, J., Benedito,J. (2007). Use of low intensity ultrasound in the Longissimus dorsi muscle from pigs with different genetic background. Options Mediterraneenes,Seria:A,Seminaires Mediterraneenes.
[37] Vimini, R.J.,. Kemp, J.D., Fox, J.D. (1983). Effects of low frequency ultrasound on properties of restructued beef rolls. J Food Scie., 4, 1572-1573.
[38] Wheeler, T., Shackelford, S., Koohmaraie, M. (2000). Variation in proteolysis, sarcomere length, collagen content, and tenderness among major pork muscles. J. Anim Sci., 78, 958-965.
[39] Wilson, D.E. (1992). Application of ultrasound for genetic improvement. J. Anim. Sci., 70, 973-983.