

RECENT DEVELOPMENT IN MEAT TENDERIZATION

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ABSTRACT

Meat tenderization is the disruption of meat structure, breaking the collagen subsequently resulting in good palatability and acceptance by consumer. Tenderization could be achieved by the traditional method of ripening for a long period in controlled temperature with due precautions to prevent meat spoilage. In this process endogenous muscle enzymes viz. calpains, cathepsins and caspases are responsible for proteolysis of muscle. Other processes adopted for tenderization include use of electricity, heat, physical force (hydrostatic pressure), ultrasonic waves, shock waves in water (hydrodyne), enzyme action, use of vitamins, ionic compounds, mineral salts, and chemical compounds. The electrical stimulus of low voltage is more popular than high voltage due to the cost involved. Like endogenous enzymes, plant based exogenous enzymes also cause tenderization, but their activity should be monitored to avoid over-tenderization. Chemicals, vitamins and ionic compounds activate the calcium-dependent proteases and lysosomal enzymes, which are responsible for tenderization.

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INTRODUCTION

Meat is a preferred source of protein of high biological value protein and essential nutrients. The taste of meat and meat products is well described by attributes like flavor, juiciness, and tenderness (Aaslyng and Meinert, 2017; Grunert *et al.*, 2004; Picard and Gagaoua, 2017); among which, tenderness is one of or the most discussed and desirable

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features that affects consumer's acceptability, purchasing decisions (Mennecke *et al.*, 2007; Bhat *et al.*, 2019) and in particular repeat buying. Tenderness is defined as the ease, perceived by the consumer, with which meat structure is disorganized during mastication (Lepetit and Culioli, 1992). The factors responsible for meat tenderness are the length of sarcomere, the intramuscular connective tissue, amount of connective tissue and fat and proteolytic effect of the muscle.

It is a challenge for the scientific community and meat industry to achieve products with standardized and guaranteed tenderness (Koochmaraie *et al.*, 1995). The critical component of processing meat is to ensure that meat reaches the optimum level of tenderness before consumption. In one of the processes meats is 'aged' up to five days in chillers to improve tenderness before being released to the market for consumption amounting to significant additional expense for the industry. Tenderization could be accelerated by electrical stimulation, to trigger muscle contractions and accelerate the depletion of muscle energy. Rigor mortis, the point at which all muscle energy is depleted, can be accelerated and the time could be reduced from 12 to 24 hours post- mortem to as little as 2 hours for attainment of the same. After the death of an animal, proteolysis occurs due to endogenous enzymes. Caspase is a proteolytic system which may be highly responsible for proteolysis (Nowak, 2011). Early achievement of rigor mortis while the muscles are still warm after slaughter implies

significant acceleration in the process of tenderization.

There are various methods available for meat tenderization. Apart from existing methods of meat tenderization like ageing and electrical simulation, newer methods of meat tenderization have been employed resulting better efficiency and high-quality meat products. (Woinue *et al.*, 2019).

Traditional aging

'Ripening' or 'conditioning' is an age long practice followed for improving tenderness, texture and flavor of meat by holding carcasses under controlled refrigerated conditions to avoid microbial spoilage for days or weeks after slaughter. Several biochemical processes including lipolysis and oxidation are involved during postmortem aging of meat but the most important process for tenderness is proteolysis of the myofibrils, leading to production of low molecular weight proteins.

Endogenous muscle enzymes responsible for activation of proteolysis are calpains, cathepsins, and caspases. Endogenous muscle enzymes responsible for degradation of myofibrillar and cytoskeletal proteins but calpain system is chiefly involved in proteolysis of cytoskeletal proteins, and is responsible for the majority of proteolysis during post-mortem as well as ageing process of meat (Koochmaraie *et al.*, 2002). The activity of calpain is altered by factors, such as temperature, pH, and oxidation. Aging is more effective in improving palatability of

meat cuts that have relatively small amounts of connective tissue.

Advancements in meat tenderization

Electrical stimulation

The development of electrical stimulation dates back to the 1950s (Troy and Kerry, 2010) and it was commercially introduced in New Zealand in the 1970s to manage toughening due to cold shortening of frozen lamb carcasses (Strydom and Frylinck, 2014). Electrical stimulation accelerates post-mortem glycolysis to produce lactic acid, which leads to fall in pH of the meat below 6.0 before the muscle temperature reaches 10°C during rapid chilling. This reduces the risk of cold shortening as well as accelerates meat tenderization by increasing the rate of proteolysis and by physically disrupting the muscle fibers by contractions and reduction in cross-linking of the collagen molecules (Lang *et al.*, 2016). Electrical stimulation is now widely used in many meat producing countries including New Zealand, Australia, the USA, South Africa, India, and some European countries.

Two ranges of voltage *i.e.*, high (300 to 1,000 V) and low (50 to 120 V) can be applied (Troy and Kerry, 2010). High voltage stimulation produces a greater rate of pH decline that is maintained without fluctuation (Simmons *et al.*, 2008). But safety precautions and cost are factors that popularize low voltage stimulation which has been found equally efficient for pH drop and improvement in tenderness. At low pH and

high temperature, the tenderness is further improved by disruption of the membranes of lysosomes and release of cathepsins (Dutson *et al.*, 1980).

Pulsed electric field (PEF) processing

In this technique electric field pulses with electric field strength varying from 0.1–80 kV/cm is applied for short duration to a food. During PEF processing, food is passed through or placed between two electrodes. It was first applied commercially to sterilize fruit juice. Membrane permeability could be altered by PEF processing (Bhat *et al.*, 2019) and activity of calpains is also affected leading to alteration in the rate and extent of tenderization during aging. Quality of meat in terms of color, texture, and water-holding capacity are improved and increased permeability of cell membrane facilitates brining and curing like processes. Potential of PEF for improving the tenderness of muscles during aging is validated in several studies.

Pulsed electric field processing has a wide range of applications for meat and meat products to enhance quality and/or to accelerate curing processes. However, the effect of PEF on meat material is highly dependent on processing parameters (electric field strength, specific energy, etc.), meat properties, and pre- and post-treatment of meat conditions (freezing, aging, etc.). A thorough and better understanding of the mechanism of action of PEF on different meat and meat products is therefore essential to develop PEF applications. At an industrial level, PEF conditions need to be optimized for each

product. The combined application of PEF with other meat processing conditions, such as freezing and aging could provide an additional means of improving meat quality while minimizing few negative effects. Therefore, the feasibility of PEF on a commercial scale in the meat industry requires further research. Research results to date suggest that PEF has a significant role to play in the meat industry for specific applications such as improving the tenderness and value of meat and in enhancing mass transfer and reducing processing time (Alahakoon *et al.*, 2016).

Enzymatic interventions

Exogenous enzymes of plant and microbial origin can be used to improve tenderness of the meat. Although intrinsic enzymes are mostly active against myofibrillar proteins, exogenous enzymes can degrade both myofibrillar and connective tissue proteins. Some enzymes have the potential to reduce the amount of detectable connective tissues with minimum degradation of muscle fibers by controlled proteolysis of targeted proteins. The exogenous proteases have the capability of digesting connective tissues as well as muscle protein (Mendiratta *et al.*, 2010). Plant based exogenous enzymes like cysteine proteases of the papain family, such as papain from papaya latex, bromelain from pineapple fruit and stem, actinidin from kiwi fruit, and the bacterial collagenase are commonly used in meat tenderization process. Problem faced with exogenous enzymes is regulation of their activity as they can result in an over-tenderized meat and the production of undesirable flavors.

Use of papain restricted in high performing meat industry as it decreases the juiciness as well as produce bitter peptides by proteolytic degradation. (Gerelt *et al.*, 2000). Bromelain has been identified with some drawback like over tenderization and mushy texture in the bromelain marinated meat. Bromelain, ficin, and papain from plants and the protease from *Bacillus subtilis* are approved by USDA's Food Safety Inspection Service as 'generally recognized as safe' (GRAS) for improving tenderness (Ha *et al.*, 2014). Exogenous proteases isolated from ginger rhizome (zingibain), fruits of *Cucumis trigonus Roxb* and *Asparagus officinalis* plants have also been characterized.

High hydrostatic pressure (HHP) processing

The use of high pressure on the products can critically alter the textural attributes like firmness, hardness, cohesiveness etc. One such high pressure technique is high HHP treatment of meat for better preservation and processing. HHP processing along with improving meat tenderness further inhibits meat spoilage by pathogens by bacteria possibly by destroying the cell membrane and cell wall of microorganisms and inactivating their enzymes (Han *et al.*, 2021). High pressure treatments might induce mechanical tissue disintegration and therefore tenderize the meat (Bajovic *et al.*, 2012). High pressure treatment can affect protein conformation by denaturation, aggregation or gelation by rupture of non-covalent interactions within protein molecules subsequent re-formation of intra- and inter-molecular bonds within or

among protein molecules. Depending upon the pressure, the temperature, and the duration of the pressure treatment, meat can be either tenderized or toughened. The springiness, and chewiness are increased upon HHP treatment. The use of HPP to tenderize meat has a potential to revolutionize red meat industry since tenderization effects are highly variable between meat carcasses.

Ultrasound treatment

Ultrasound is one of the new clean technologies applied to meat. Ultrasound generate oscillating waves and meat vibrates in this environment and changes occur in the meat proteins by the oscillating waves leading to improvement in the meat tenderness (Alves and Larissa de Lima, 2013; Jayasooriya *et al.*, 2007). Cavitation zones is created by ultrasound in the liquid media which causes generation of extreme temperature and pressure. The high temperature and pressure lead to generation of free radicals that aids in changing the meat properties, meat microstructure, and molecular reactions within resulting in tender meat. Frequency, intensity and exposure time to ultrasonic pulse influence the treatment of meat tenderization. The exposure time is dependent on the frequency and the used intensity directly influences the softness. Ultrasonic techniques possibly cause lysosomal rupture and disruption of myofibrillar protein and connective tissue which result in tenderization of meat. High intensity ultrasound (HIU), applied after storage has been tested safe method for tenderizing meat (Peña-Gonzalez *et al.*, 2019).

Hydrodyne processing

Hydrodynamic pressure resulting from a shock wave generated in a liquid medium within fractions of milliseconds. If enough shock pressure is generated, it results in tenderization of meat. A great reduction of about 72% in shear force was observed for the longissimus muscle using 100 g of explosives (Solomon *et al.*, 1997). Hydrodynamic pressure wave generated in a steel chamber was observed to be less effective as compared to disposable/plastic container for tenderizing meat. Even, the composition and configuration of the explosive containers influenced the magnitude of performance of hydrodynamic process on meat tenderization. Regardless of the type of meat cut and level of initial toughness, hydrodynamic pressure technology has been successful in increasing the value of these meat products by improving tenderness instantaneously (Solomon *et al.*, 1997). The original shock wave system was based on detonating explosives. This system was later modified and registered as the Hydrodyne process. As part of a research project in the early 1990s, Solomon's group, in collaboration with Hydrodyne, Inc., intensively studied the tenderization of meat and was the first to report tenderization in beef (Solomon *et al.*, 1998). Due to the technical challenges of the explosive method, a new equipment was developed; whereby, the shock wave was generated using a capacitor discharge system, to overcome the disadvantages of the explosive system (Long and Ayers, 2001). The culmination of research into this concept led to the development of the

Tender Class System (TCS) by Hydrodyne (Claus *et al.*, 2002).

Vitamin D supplementation

The role of calcium in meat tenderization during aging was demonstrated over 50 years ago (Davey and Gilbert, 1969) indicated that weakening and disappearance of muscle structure during post-mortem aging was inhibited by ethylene diamine tetra acetic acid (EDTA) possibly due to its chelating action on calcium. In normal muscles, calcium is primarily present in compartmentalized structures. Presumably vitamin D supplementation causes Ca^{2+} mobilization in serum increases the activity of proteolytic enzymes belonging to calpains (calpain enzymes) and accelerates the aging process which, results in significant improvement of beef tenderness and reduction of ageing time. Significant improvement in meat tenderness resulted when vitamin D3 was supplemented at high doses in the last phase of fattening in cattle (Montgomery *et al.*, 2000; Carnagey *et al.*, 2008).

Infusion of ionic compounds

Calcium-dependent proteases and lysosomal enzymes are the most likely candidates to bring about tenderness changes during post mortem storage. Calpains are Ca^{2+} -dependent proteases and responsible for 90% or more of the tenderization that occurs during postmortem storage. Tenderization process was accelerated in wether lamb's carcasses on injection with CaCl_2 immediately after death (Polidori *et al.*, 2000). Pre-rigor

ionic compound injection to change the rate of glycolysis, rate and state of contraction, and rate of proteolysis appears to be a feasible method of post-mortem meat tenderization. Infusion of bovine carcasses with salt solutions caused a considerable improvement in tenderness. Salts generally influence the functional properties of meat products and possibly affect contraction and shortening, protein-protein interactions, protein solubility, proteolytic enzyme activity and lattice swelling (Polidori and Francesco, 2003).

Chemical interventions

Salts, organic acids, phosphates and various salts can be incorporated in meats through immersion, injection, or marination and have well-established effects on tenderness. (Berge *et al.*, 2001). These chemicals improve the tenderness of meat by affecting the structure of the muscle through altering protein solubility or the action of proteases. Processes like vascular infusion have become the commercial reality and several infusion mixes have come up with promising results. Traditional marinades contain oil, seasonings, sugar, and acidic constituents, including vinegar, wine, or fruit juices. Use of marination effectively enhanced the palatability characteristics of beef steaks, especially when marinade solutions contained a beef-flavoring additive. In addition to improving perceived tenderness, marinades that incorporated a beef-flavoring agent also reduced off-flavors and increased total cooked product yields. Marination of beef steaks, especially with a beef-flavoring agent, is an

effective and practical means to improve cooked beef palatability (Scanga *et al.*, 2000). The various additives which could be used in marination to improve the tenderness are organic acids (mainly acetic, citric, and lactic) and various salts, including calcium salts (Whipple and Koohmaraie, 1993), sodium chloride (Goli *et al.*, 2014), phosphates (Vote *et al.*, 2000), and ammonium hydroxide (Naveena *et al.*, 2011).

Thermal treatment

Thermal treatment is one of the most important ways to change the components of muscle that control toughness. The cooking at a high temperature can denature the protein that results in structural changes in the meat such as the destruction of cell membranes, shrinkage of meat fibers, shrinkage and solubilization of the connective tissue, aggregation and gel formation of myofibrillar and sarcoplasmic proteins. The meat proteins, approximately 20% of muscle weight, represent the constituent that make up the structure of the meat product. They undergo structural changes on heating and quality of the meat product, which is governed by the meat structure, also changes drastically when cooking (Mărgean *et al.*, 2017). Most of the sarcoplasmic protein aggregate between 40 and 60 °C, but coagulation can extend up to 90 °C. For myofibrillar proteins unfolding starts at 30-32 °C, followed by protein-protein association at temperature 36-40 °C and subsequent gelation at 45- 50 °C. At temperatures between 53 and 63°C, the collagen denaturation occurs, followed

by collagen fibre shrinkage. If the collagen fibres are not stabilized by heatresistant intermolecular bonds, it dissolves and form gelatine on further heating (Tornberg, 2005).

Smart Stretch and Pi-Vac Elasto-Pack system

SmartStretch™ /Smartshape™ is designed to reduce the contraction of hot-boned primals during rigor or by stretching these muscles. The system has been adopted commercially in Australia (Hopkins, 2014) and uses external air pressure to stretch and reform hot-boned primals into a uniform size and retain the stretch during rigor by using restraining packaging. The system requires specialized equipment to wrap the hot-boned prerigor muscles. It is very flexible as it can be applied to any target muscles but behaves differently with meat from different species and seems to be more effective in the case of sheep meat than beef (Taylor *et al.*, 2010). Applying the SmartStretch™ treatment using a prototype stretching device to hot-boned sheep topsides (semimembranosus) found significant reduction in shear compared to non-stretched meat (Toohey *et al.*, 2012).

CONCLUSION

Technological interventions like electrical stimulation, thermal treatment, enzymatic interventions and aging are currently applied in the meat industry for improving tenderness. However, there are some limitations and disadvantages of using these methods. Emerging tenderization techniques like HPP, hydrodyne technology,

ultrasound, Smart Stretch and Pi-Vac Elasto-Pack system provide some advantages over the applied methods; however, would require initial capital investments and changes in the meat plant design. Further, more research is required to optimize the process parameters for different muscles and cuts before some of these novel methods could find commercial application in the meat industry.

REFERENCES

- Aaslyng, M.D. and Meinert, L. (2017). Meat flavour in pork and beef from animal to meal. *Meat Science*, **132**: 112 – 117.
- Alahakoon, A.U., Faridnia, F., Bremer, P.J., Silcock, P. and Oey, I. (2016). Pulsed electric fields effects on meat tissue quality and functionality. *Springer International Publishing*, DOI 10.1007/978-3-319-26779-1_179-1.
- Alves and Larissa de Lima (2013). The ultrasound on meat tenderization. *Ciencia Rural*, **8**(43): 1522 - 1528.
- Bajovic, B., Bolumar, T. and Heinz, V. (2012). Quality considerations with high pressure processing of fresh and value-added meat products. *Meat Science*, **92**(3): 280 - 289.
- Berge, P., Ertbjerg, P., Larsen, L.M., Astruc, T., Vignon, X. and Møller, A.J. (2001). Tenderization of beef by lactic acid injected at different times postmortem. *Meat Science*, **57**: 347 – 357.
- Bhat, Z. F., Morton, J. D., Mason, S. and Bekhit, A.E.D. (2019). Current and future prospects for the use of pulsed electric field in the meat industry. *Critical Reviews in Food Science and Nutrition*, **59**(10): 1660 - 1674.
- Carnagey K.M., Huff-Loneragan E.J., Lonergan S.M., Trenkle A., Horst R.L. and Beitz D. C. (2008). Use of 25-hydroxy vitamin D₃ and dietary calcium to improve tenderness of beef from the round of beef cows. *Journal of Animal Science*, **86**: 1637 – 1648.
- Claus, J.R., Sagili, L. and Sammel, L. (2002). Tenderization of beef and pork with shock waves produced with a capacitor discharge system. 55th Annual Reciprocal Meat Conference, Lansing, Michigan, USA. 142.
- Davey, C. L. and Gilbert, K.V. (1969). The effect of sample dimensions on the cleaving of meat in the objective assessment of tenderness. *Food Science Technology*, **4**(1): 7 - 15.
- Dutson, T.R., Smith, G.C. and Carpenter, C.L. (1980). Post-mortem conditioning of meat. *Advances in Meat Research*, **1**: 45.
- Gerelt, B., Ikeuchi, Y and Suzuki, A. (2000). Meat tenderization by proteolytic enzymes after osmotic dehydration. *Meat Science*, **56**(3): 311- 318.
- Goli, T., Ricci, J., Bohuon, P., Marchesseau, S. and Collignan, A. (2014). Influence of

- sodium chloride and pH during acidic marination on water retention and mechanical properties of turkey breast meat. *Meat Science*, **96**: 1133 – 1140.
- Grunert, K. G., Bredahl, L. and Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector: A review. *Meat Science*, **66**: 259 – 272.
- Ha, M., Bekhit, A.E.D. and Carne, A. (2014). Effects of L-and iso-ascorbic acid on meat protein hydrolyzing activity of four commercial plants and three microbial protease preparations, *Food Chemistry*, **149**: 1 - 9.
- Han, G., Chen, Q., Xia, X., Liu, Q., Kong, B. and Wang, H. (2021). High hydrostatic pressure combined with moisture regulators improves the tenderness and quality of beef jerky. *Meat Science*, **181**: 108617 – 108626.
- Hopkins, D.L. (2014). Tenderizing mechanisms: Mechanical. In M., Dikeman and C. Devine (Eds.), *Encyclopedia of meat science* (3). London, UK: Academic Press, Elsevier.
- Jayasooriya, S.D., Torley, P.J., D'Arcy, B.R. and Bhandari, B.R. (2007). Effect of high-power ultrasound and ageing on the physical properties of bovine Semitendinosus and Longissimus muscles. *Meat Science*, **75**(4): 628 - 639.
- Koohmaraie, M; Killefer, J; Bishop, M.D., Shackelford, S.D., Wheeler, T.L. and Arbona, J.R. (1995). Calpastatin-based methods for predicting meat tenderness. In: Ouali, A.; Demeyer, D.; Smulders, F. (Eds.) *Expression of Muscle Proteinases and Regulation of Protein Degradation as Related to Meat Quality*. Audet Tijdschriftenb.v., Nijmegen, The Netherlands, 395 - 412.
- Koohmaraie, M., Kent, M.P., Shackelford, S.D., Veiseth, E. and Wheeler, T.L. (2002). Meat tenderness and muscle growth: is there any relationship. *Meat Science*, **62**(3): 345 – 352.
- Lang, Y., Sha, K., Zhang, R., Xie, P., Luo, X., Sun, B. and Liu, X. (2016). Effect of electrical stimulation and hot boning on the eating quality of Gannan yak longissimus lumborum. *Meat Science*, **11**(2): 3 - 8.
- Lepetit, J. and Culioli, J. (1992). Mechanical properties of meat, *Meat Science*, **36**: 203 – 237.
- Long, J.B. and Ayers, R.A. (2001). Shock-wave food processing with acoustic converging wave guide. *The Journal of the Acoustical Society of America*, **110**(6): 2819-2819.
- Mărgean, A., Măzărel, A., Lupu, M.I. and Canja, C.M. (2017). Tenderization, A Method to optimize themeat sensory quality. *Agricultural Food Engineering*, **10**(59): 1.

- Mendiratta, S.K., Sharma, B.D., Narayan, R. and Mane, B.G. (2010). Effect of proteolytic enzyme treatments and pressure cooking on quality of spent sheep meat curry. *Journal of Muscle Foods*, **21**(4): 685 - 701.
- Mennecke, B.E., Townsend, A.M., Hayes, D.J. and Lonergan, S.M. (2007). A study of the factors that influence consumer attitudes toward beef products using the conjoint market analysis tool. *Journal of Animal Science*, **85**: 2639 – 2659.
- Montgomery J. L., Parrish F.C. Jr, Bietz D.C., Horst R.L., Huff-Lonergan E.J. and Trenkle A. H. (2000). The use of vitamin D₃ to improve beef tenderness. *Animal Science*, **78**: 2615 –2621.
- Naveena, B.M., Kiran, M., Reddy, K. S., Ramakrishna, C., Vaithyanathan, S. and Devatkal, S. K. (2011). Effect of ammonium hydroxide on ultrastructure and tenderness of buffalo meat. *Meat Science*, **88**: 727 – 732.
- Nowak, D. (2011). Enzymes in tenderization of meat - the system of calpains and other systems- a review. *Polish Journal of Food and Nutritional Sciences*, **61**(4): 231 - 237.
- Peña-Gonzalez, E., Alarcon-Rojo, A.D., Garcia-Galicia, Ivan., Carrillo-Lopez, L. and Huerta-Jimenez, M. (2019). Ultrasound as a potential process to tenderize beef: Sensory and technological parameters. *Ultrasonics Sonochemistry*, **53**: 134 - 141.
- Picard, B. and Gagaoua, M. (2017). Proteomic investigations of beef tenderness. In M. L. Colgrave (Ed.), *Proteomics in food science from farm to fork*, Cambridge, Massachusetts, USA: Academic Press, 177 – 197
- Polidori, M. C., Mecocci, P., Cherubini, A. and Senin, U. (2000). Physical activity and oxidative stress during aging. *International Journal of Sports Medicine*, **21**(3): 154 - 157.
- Polidori P. and Francesco F. (2003). Use of ionic compounds to improve meat tenderness: a review. *The International Journal of Applied Research in Veterinary Medicine*, **1**(2): 112 - 121.
- Scanga, J.A., Delmore Jr., R.J., Ames, R.P., Belk, K.E., Tatum, J.D. and Smith, G.C. (2000). Palatability of beef steaks marinated with solutions of calcium chloride, phosphate, and (or) beef-flavoring. *Meat Science*, **55**(4): 397 - 401.
- Simmons, N.J., Daly, C.C., Cummings, T.L., Morgan, S.K., Johnson, N.V. and Lombard, A. (2008). Reassessing the principles of electrical stimulation. *Meat Science*, **80**: 110 – 122.
- Solomon M.B., Long J. B. and Eastridge, J.S. (1997). The hydrodyne: a new process

- to improve beef tenderness. *Journal of Animal Science*, **75**(6): 1534 - 7.
- Solomon, M.B., Carpenter, C.E., Snowden, G.D. and Cockett, N.E. (1998). Tenderizing callipyge lamb with the hydrodyne process and electrical stimulation. *Journal of Muscle Foods*, **9**: 305 – 311.
- Strydom, P.E. and Frylinck, L. (2014). Minimal electrical stimulation is effective in low stressed and well-fed cattle. *Meat Science*, **96**: 790 – 798.
- Taylor, J. M., Hopkins, D.L. and van de Ven, R. (2010). The effect of a meat-stretching device on the tenderness of hot-boned beef topsides and “rostbiffs”, In: Proceedings of the 56th International Congress of meat science and technology, **72**: 1 - 4, Jeju, Korea.
- Toohey, E.S., Van de Ven, R., Thompson, J.M., Geesink, G.H. and Hopkins, D.L. (2012). SmartStretch™ technology improving the tenderness of sheep topsides (m. semimembranosus) using a meat stretching device. *Meat Science*, **91**: 142 – 147.
- Tornberg, E. (2005). Effects of heat on meat proteins-Implications on structure and quality of meat products. In: *Meat Science*, **70**: 493 - 508.
- Troy, D.J. and Kerry, J.P. (2010). Consumer Perception and the Role of Science in the Meat Industry. A Review. *Meat Science*, **86**: 214 - 226.
- Vote, D. J., Platter, W. J., Tatum, J. D., Schmidt, G. R., Belk, K. E., Smith, G.C. and Speer, N. C. (2000). Injection of beef strip loins with solution containing sodium tripolyphosphate, sodium lactate, and sodium chloride to enhance palatability. *Journal of Animal Science*, **78**: 952 – 957.
- Whipple, G. and Koohmaraie, M. (1993). Calcium chloride marination effects on beef steak tenderness and calpain proteolytic activity. *Meat Science*, **33**: 265 – 275.
- Woinue, Y., Ayele, A., Hailu, M. and Chaurasiya, R.S. (2019). Comparison of different meat tenderization methods: a review. *Food Research*, eISSN: 2550 - 2166.