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Vimala Choudhary

Department of Livestock
Products Technology, College of
Veterinary and Animal Science
Rajasthan University of
Veterinary and Animal Sciences
(RAJUVAS), Bikaner,
Rajasthan, India

Rajkumar Berwal

Department of Livestock
Products Technology, College of
Veterinary and Animal Science
Rajasthan University of
Veterinary and Animal Sciences
(RAJUVAS), Bikaner,
Rajasthan, India

Sandeep Kumar

Department of Livestock
Products Technology, College of
Veterinary and Animal Science
Rajasthan University of
Veterinary and Animal Sciences
(RAJUVAS), Bikaner,
Rajasthan, India

Tanuj Kumar

Department of Livestock
Products Technology, College of
Veterinary and Animal Science
Rajasthan University of
Veterinary and Animal Sciences
(RAJUVAS), Bikaner,
Rajasthan, India

Rekha Berwal

Department of Home Science,
Ch. BRG, Govt. Girls College,
SriGanganagar, Rajasthan, India

Corresponding Author:

Rajkumar Berwal

Department of Livestock
Products Technology, College of
Veterinary and Animal Science
Rajasthan University of
Veterinary and Animal Sciences
(RAJUVAS), Bikaner,
Rajasthan, India

Noval tenderising techniques in meat industry: A review

**Vimala Choudhary, Rajkumar Berwal, Sandeep Kumar, Tanuj Kumar
and Rekha Berwal**

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Abstract

Tenderness of meat plays a dominant role in enhancing the meat palatability but, variation in meat tenderness is the main factor for consumer dissatisfaction. However, toughness is the major cause for low quality meat due to rigor mortis and biochemical changes, which can be solved by tenderization. The post-slaughter tenderising techniques like electrical stimulation, suspension methods, blade tenderization, tumbling, use of exogenous enzymes, and traditional aging are used by the meat industry for improving tenderness. To reduce undesirable effects some natural tenderizers like plant protease actinidin, zingibain, papain, bromelain and microbial enzyme preparations are the recent interest due to controlled meat tenderization because it contains proteolytic enzymes responsible for tenderization of tough meat. In camel meat burger found significant increase in collagen solubility and sensory scores by using ginger, papain and their mixture and significant reduction in the shear force. Over the time, technological advancement resulted in development of several novel methods, such as pulsed electric field, ultrasound, Shock wave technology, Shock waves improve tenderness in beef from 37% to 68%. Hydrodynamic-pressure processing, high-pressure processing, Smart Stretch™, Pi-Vac Elasto-Pack^R system, for maximizing the tenderness, which are being projected as quick, economical, non thermal, green, and energy-efficient technologies. The development of novel interventions for improved tenderness would greatly contribute to increased revenue, economical value and profitability for the meat industry, as well as greater customer satisfaction.

Keywords: Tenderization, tumbling, shock wave technology, electrical stimulation, enzymes

1. Introduction

Meat is the most valuable livestock product and for many people serves as their first-choice source of animal protein. Meat is either consumed as a component of kitchen-style food preparations or as processed meat products. After slaughter of animals' natural process or rigor mortis shorten muscle protein fibres and results the meat to become tough. The eating quality of meat is dependent on a complex interaction between biological and biochemical processes during the conversion of muscle to meat, and is highly variable between animals and in muscles within an animal. Eating satisfaction results from the interaction of sensory properties, including tenderness, juiciness, and flavour. Meat tenderness is influenced by many factors along the entire value chain from farm to fork. Preslaughter and animal production factors such as breed, age, sex, nutrition, handling, transport, and carcass composition, as well as processing, value adding, and consumer cooking methods and preferences, influence meat tenderness.

The variation in the meat tenderness results in the consumer dissatisfaction. It is challenge to the scientific community and to the meat industry to solve the problem of variation in meat tenderness to assure and/or to give guarantee about the meat and meat products to the consumer. Consumers understand the meat tenderness variability so; production of consistently tender meat is required to retain consumer confidence in quality meat which is competing with other types of meat that do not have toughness problem. The industry has developed a number of techniques (Hutchison *et al.*, 2014)^[15] to achieve this ranging from

traditional aging to novel methods such as hydrodynamic-pressure processing. These can be broadly classified, based on their mechanism of action, into electrical, mechanical, chemical, and enzymatic interventions (Bhat *et al.*, 2018) ^[4]. The present review provides an overview of the emerging techniques of tenderisation of meat in commercial meat processing industries.

2. Meat Tenderization

The tenderization process, which can be affected by both pre- and post-slaughter interventions, starts immediately after an animal's death and is followed with the breaking down of muscle fibres in the meat to soften the texture and taste better by different methods of tenderization (Bhat *et al.*, 2018) ^[4]. It is also called as ageing/conditioning/ripening/setting-up of meat or carcasses. Conditioning is the term applied to the natural process of tenderization when meat is stored or aged post-rigor (pork 4-10, lamb 7-14 and beef 10-21 days at 1°C). The most common methods of meat tenderization are physical/mechanical, chemical, and biological processes. Mechanical processes such as the suspension method, electrical stimulation, tumbling, grinding, pounding, and blade tenderization are used in the industry. Chemical methods of meat tenderization such as marinades are rapid and less labour intensive. Early Mexicans used to package meat by wrapping it in papaya leaves for tenderization. Tenderization of the meat is also carried out using marinades with needles that inject it into the carcasses or its deeper parts or by using a meat tumbler. Lastly, biological methods use intrinsic enzymes during the aging process or exogenous enzymes are added to the meat for meat tenderization (Azmi *et al.*, 2023) ^[21]. The Meat quality traits, particularly tenderness, depend on intrinsic and extrinsic factors. These factors include (i) pre-slaughter factors such as species, genotype, nutrition and age of the animal (many of which affect fatness and weight of the carcass), pre-slaughter stress and (ii) post-slaughter factors such as electrical stimulation and hanging of the carcass, ageing of the meat and packaging and conditions during storage (Channon *et al.*, 2016; Hocquette *et al.*, 2014; Strydom & Rosenvold, 2014) ^[35, 14, 7]. The major determinants of meat tenderness are; connective tissue and cross-links, myofibrillar integrity, sarcomere length, protein denaturation and intramuscular fat (Warner *et al.*, 2022) ^[43].

3. Emerging Modern Mechanical Method of Meat Tenderization

The various mechanical methods are employed for the tenderization of meat. These methods include hanging by achilles/pelvic suspension to blade tenderization, tumbling, massaging, and many more. In mechanical method the partial destruction of connective tissue and severance of muscle fibers by using closely spaced needles or thin blades having sharpened edges which physically disrupt muscle fibres and connective tissues leading to reduced resistance to shear force. Some novel approaches have been developed for improve tenderness of meat like hydrodynamic-pressure processing, high-pressure processing, Ultrasound processing, Pulsed electric field, Muscle stretching technology, Electrical stimulation, Smart StretchTM, Tender bound or Pi-Vac Elasto-Pack^R system.

3.1 Shock wave technology / Hydrodynamic-pressure processing

Shock wave processing involves the application of high-pressure waves or pulses of up to 1 GPa within fractions of milliseconds, creating pressure fronts in the 70-100 MPa

range. These mechanical pressure pulses can be generated either by detonating explosives (the first systems developed) or by discharging electrical currents under water (second generation). (Sikes & Tobin 2021) ^[32]. The wave is characterized by the intensity (pressure level) and its propagation along time (rise time). Shockwaves are mechanical pressure pulses which propagate through the meat and induce a "rupture effect" that tears the muscle structure due to the dissipation of mechanical stress at the boundaries of acoustic impedances. (Bhat *et al.*, 2018) ^[4]. Various studies elucidating the effect of hydrodynamic-pressure processing on the tenderness of different muscles like Bolumar *et al.* (2014) ^[6] worked on Beef loin steaks muscle and gave treatment of muscle that is one single pulse, 36 kV (11,664 J per pulse), 20 cm distance from meat to spark (prototype based on electrical discharge under water) and found that 18% reduction in Warner-Bratzler shear force. Zuckerman *et al.* (2013) ^[49] studies on beef semi-membranosus muscle treated with 150 g of explosives were detonated 35.6 cm above the surface of the meat (plastic container), 450 g of explosives were detonated 61.0 cm above the surface of the meat (stainless steel commercial prototype unit) and estimated that 37% reduction in Warner-Bratzler shear force in plastic container and 25% in steel commercial unit immediately post-treatment and disrupted the integrity of the collagen fibril network of the endomysium. Hydrodynamic pressure has been reported to result in a 10% to 70% reduction in shear force depending upon several factors such as treatment conditions, animal species and muscles, rigor stage, aging time, muscle-fiber orientation, and background toughness (Bhat *et al.*, 2018). This process of tenderization has been reported as low-cost and non-invasive with no negative impact on the chemical and microbial stability of meat (Bolumar *et al.*, 2014) ^[6]. Although hydrodynamic pressure processing could produce remarkable improvements in the tenderness of the product in a very short treatment time with low processing costs, there has been no commercial application of this technology and further research is required to overcome the existing limitations, such as development of an industrial size continuous system with a consistent shockwave delivery as well as prevention of packaging damage during processing (Bolumar & Toepfl, 2016) ^[5].

3.2 High-pressure processing

High-pressure processing (HPP) or high-hydrostatic-pressure processing is a novel green, non-thermal preservation technology used to improve food products' microbial safety by destroying microorganisms in food and extend the quality and shelf-life of food products with minimal effects on the sensory and nutritional characteristics quality. HPP treatment improves the tenderization of meat by increasing protein solubility due to the depolymerization/unfolding of proteins under high pressure, preferably at high temperatures (Azmi *et al.* 2023) ^[21]. Scientists and technologists have shown considerable interest in applications of HPP in meat processing as a non thermal preservation and post packaging decontamination technology (Scheinberg *et al.*, 2014). According to Shao *et al.* (2018) ^[29], Red swamp crayfish muscle (*Procambarus clarkia*) is treated with 0, 100, 200, 300, 400, and 500 MPa for 5 min (25 to 28°C) and found that hardness of the samples increased with increasing pressure. Morton *et al.* (2017) ^[23] studies on Beef longissimus thoracis muscle and apply pressure 175 MPa for 3 min 250 MPa for 2 min and reported that tenderness increased in treated samples (60% lower shear force than chill aged meat after 1

day).Improvement in the tenderness of beef longissimus dorsi treated at 200 MPa above temperatures of 60°C was reported to be due to accelerated proteolysis after pressure treatment. The final tenderness of analyses the meat largely depends on the heating conditions. During the heating process the changes of myofibrillar proteins have substantial impact on tenderness of meat (Habtu *et al.*, 2019) ^[13].

3.3 Ultrasound processing

Ultrasound is an innovative and emerging technology which has the potential to speed up processes without affecting the quality of foods. It has applications in both the modification and the analysis of foods and is considered as a sustainable “green and innovative” technique which typically involves less energy, water, and time. Several workers have studied the effect of ultrasound on post-rigor meat and have reported an improvement in tenderness, with probable mechanisms of physical disruption in the muscle microstructure by cavitation and/or release and activation of proteolytic enzymes(Bhat *et al.*,2018) ^[4]. Many workers studied the effect of ultrasound on the tenderness of different types of muscles of different animals *i.e.* Zou *et al.* (2018) ^[41], Wang *et al.* (2018) ^[29], Barekat & Soltanizadeh (2017) ^[2], Kang *et al.* (2017) ^[16], Chen *et al.* (2015) ^[8], Sikes *et al.* (2014) ^[31], Ozuna *et al.* (2013) ^[24].According to Kang *et al.* (2017) Beef longissimus dorsi muscle treated with 20 kHz, 150 and 300 W, 30 and 120 min and reported that ultrasound increased tenderness by increasing MFI values and proteolysis of desmin and troponin-T.

3.4 Pulsed electric field

PEF is a novel technology that was first applied commercially to sterilize fruit juice (Clark, 2006) ^[9]. During PEF processing, food is passed through or placed between two electrodes and exposed to electric field pulses of short duration in the range of several nanoseconds to several milliseconds with an electric field strength of 0.1 to 80 kV/cm/m (Barba *et al.*,2018) ^[1]. It is also able to modify several quality characteristics of meat (such as color, texture, and water-holding capacity) and enhance mass transfer processes (such as brining and curing) due to its potential for cell membrane permeabilization (Bhat *et al.*, 2018) ^[4]. Several studies have reported the application of PEF for improving the tenderness and softness of muscles during aging *i.e.* Khan *et al.* (2017) ^[17], Faridnia *et al.* (2016) ^[12], Suwandy *et al.* (2015b) ^[36], Bekhit *et al.* (2014c) ^[3], Suwandyet *al.* (2015d,) etc. Suwandy *et al.* (2015a) ^[36] they studied on *Longissimus lumborum* and semimembranosus (beef) muscle after rigor mortis and treated with 5 kV, 10 kV × 20, 50, 90 Hz and confirmed that Tenderness increased regardless of intensity in longissimus lumborum and with treatment intensity in semimembranosus. And they stated that unlike other methods, such as electrical stimulation or Tenderstretch TM, which do not affect all muscles equally, PEF is a stand-alone technology where process parameters can be optimized for different muscles.

3.5 Smart Stretch™,

Smart Stretch™ is a novel approach have been developed using packaging to improve tenderness of meat. It is designed to reduce the contraction of hot-boned primals during rigor or by stretching these muscles. This process is mainly worked on principle of stretching the muscles. In this technology, the hot-boned muscle is placed in a flexible sheath, this sheath is placed in an airtight chamber, and force is applied

perpendicular to the muscle fibers (Warner *et al.*, 2017) ^[44]. Applying the *SmartStretch™* treatment using a prototype stretching device to hot-boned sheep topsides (semi-membranous) caused a significant reduction in shear compared to non stretched meat (Bhat *et al.*, 2018) ^[4]. SmartStretch™ treatment has the capable to reduce the need of long-processing storage (aging) in pre-rigor sheep muscles to achieve acceptable tenderness (Toohey *et al.*, 2013).

3.6 Pi-Vac Elasto-Pack^R system

The tender bound or *Pi-Vac Elasto-Pack^R* system, other packaging-based approach to tenderness, uses highly elastic wrapping material, like elastic film tubes or sleeves, which are stretched by using a vacuum to enable the introduction of a piece of meat(Bhat *et al.*, 2018) ^[4].A study of the Pi-Vac system applied on beef longissimus muscles chilled at 4 and 14°C air temperatures, showed that Pi-Vac increased the tenderness of the meat at both temperatures, and it was possible to chill these muscles rapidly without detrimental effects on tenderness. Besides improving tenderness and reducing drip loss, other advantages of the system are saving space (no chilling room), energy (not having to chill whole carcass), and time (muscles cool more rapidly), and it is environmentally friendly by reducing the use of packaging materials (Taylor & Hopkins, 2011) ^[38].

3.7 Muscle stretching technology

3.7.1 Tender stretch

Tender stretch tenderizing method for beef carcass suspension from the eye of the aitch bone or obturator foramen, also called Tender stretch. The Tender stretch was most efficient in improving sarcomere lengths and ultimately tenderness, in particular for the massive muscles of the loin and round. The Tender stretch is usually applied within 45 to 90 min after bleeding, while the muscles still are extensible and in the pre-rigor state. If the angle of the hind leg is much less than 90°, it indicates that the muscles have started to contract and that the Tender stretch is applied too late. Methods for stretching or restraining pre-rigor single muscles or muscles in a carcass have been given increasing attention due to their ability to reliably improve tenderness and reduce the variation in tenderness of meat. A number of studies support the positive effects of Tender stretch on meat tenderness of beef, lamb and pork *i.e.* Pen *et al.* 2012, Taylor *et al.*,1995) ^[37, 25] etc.

3.7.2 Tender cut

Tender cut, which implies cutting bones and connective tissue in the mid-loin and round/sirloin junction of carcass sides, is a promising method for increasing tension and tenderness of the muscles. (Sørheim and Hildrum, 2002), Tender cut was introduced by scientists at Virginia Polytechnic Institute and State University. The weight of the carcass below the points of cutting, stretches many of the major loin and round muscles. Bones in the skeleton, connective tissue, adipose tissue and some minor muscles are severed in two selected positions of beef carcass sides. One cut is placed between the 12th and 13th thoracic vertebrae, at or near the normal position for separating the fore- and hindquarter of the side. The other cut is positioned in the junction between the sirloin and the round. Several studies confirm the benefits of tender cut in increasing the tenderness of beef loin and round muscles like (Claus *et al.*, 1997; Sørheim *et al.*, 2001) ^[10] etc. According to Ludwig, Claus, Marriott, Johnson, & Wang, 1997 studied on four different sections along the longissimus

muscle and reported that the tenderness of all sections was improved by tender cut.

3.8 Electric stimulation

Electrical higher than 40°C stimulation speeds up the post-mortem conversion of muscle to meat and thus reduces the ageing time (Habtu *et al.*, 2019) ^[13]. Electrical stimulations (ES) cause intense muscle contractions and speeds up the normal post-mortem processes that is the postmortem pH decline is rapid and sarcomere length is longer resulting in tender meat. Low (up to 100 V) and high (500 V) voltage systems are used for ES. Low voltage systems applied within 5 min of stunning for up to 20 seconds in pulses of 1-2 seconds duration. High voltage systems applied up to 60 min PM for up to 90 seconds in pulses of 1-2 seconds' duration. Calcium released during contraction might stimulate the calpains and cause greater proteolytic break down as the muscle temperature and pH are high. Muhammad *et al.* (2021) ^[22] indicated that ES and suspending showed an effect on meat quality.

4. Noval chemical methods of meat tenderisation

The use of chemicals as tenderizing agents improves the organoleptic properties such as flavour and aroma to a certain extent. Infusion, marination and injection with Calcium, Magnesium and Phosphate salts (NaCl, CaCl₂^[2], Na₃PO₄ Potassium lactate) organic acids, and commercial preparations, such as amino acids, alginates, and purine nucleotides, among others, are extensively studied or explored for improve the tenderness of meat (Shi *et al.*, 2021) ^[30]. These chemicals improve the tenderness of meat by affecting the structure of the muscle by modifying the protein solubility or mediating it through the action of proteases (Bhat *et al.*, 2018) ^[4]. Significant improvements in water binding ability can be seen by introducing chemical compounds such as Sodium phosphate (Yoon *et al.*, 2013) ^[46].

5. Noval enzymatic methods of meat tenderisation

Introducing exogenous proteolytic enzymes into the muscle is commonly used method of tendrisation of meat. Mainly three methods of inserting proteolytic enzymes into meat have been practiced as dipping in a solution of a particular enzyme, pumping the enzyme solution into the blood vessels and rehydration of freeze-dried meat (Mendiratta, 2000). However, the first two methods were found to be unsatisfactory because of the over tenderizing effect. Enzymes which are capable of hydrolyzing the peptide bonds of proteins in meat are known to be proteolytic in nature. (Madhusankha & Thilakarathna (2021) ^[19]. Plant proteases (Papain, Bromelain, Ficin, Actinidin, Zingibain, Cucumin, etc.), animal based (Trypsin, Pepsin, Pancreatin, and Chymotrypsin, microbial based enzymes (Fungal Amylase, Protease 15, Rhozyme P-11) are mainly used for tenderisation. Papain (Bekhit *et al.*, 2014; Maqsood *et al.*, 2018) ^[3], bromelain (Xu *et al.*, 2020) ^[45], ficin (Maqsood *et al.*, 2018) ^[20], actinidin (Wang *et al.*, 2016) ^[42], and zingibain (Cruzenet *et al.*, 2020; Tsai *et al.*, 2012) ^[40] reported that these improve tenderness of meat. Microbial proteases (fungal or bacterial sources) can eliminate the risk of over-tenderisation with self-limiting activity and have a strong specificity for target proteins. Bromelain, ficin, and papain from plants and the protease from *Bacillus subtilis* have been currently approved by USDA's Food Safety Inspection Service as "generally recognized as safe" (GRAS) for improving tenderness. Compared with plant or microbial protease, few

studies have focused on the application of animal proteases for meat tenderisation, possibly due to their low hydrolytic activity towards myofibrillar protein and high developmental cost, but they manifest higher potential to hydrolyze collagen in connective tissues (Shi *et al.* 2021) ^[30]. For example according to Phillips *et al.* 2000 and Pietrasiket *et al.* 2010 proteases (placental and *pancreatin*) extracted from porcine organs can improve meat tenderness by effectively destroying the Z-disk and H-band to stretch the sarcomere and degrading myosin to loosen the structure of actomyosin (AM). Nowadays, few studies have correlated enzymatic tenderisation with meat nutrition, a subject that deserves further investigation (Zhao *et al.*, 2020) ^[47].

6. Conclusion

Meat tenderness is mainly associated with palatability and consumer satisfaction. The effectiveness of each technique varies depending on the type of muscle, and the technology advancement contributes to the improvement of the methods. Technological interventions like use of blade tenderization, electrical stimulation, and thermal method which are currently applied in the meat industry are effective in improving tenderness. Emerging tenderization techniques like hydrodynamic-pressure processing, HPP, PEF, ultrasound, *SmartStretch*TM, and *Pi-Vac Elasto-Pack*^R system provide some advantages over the applied methods, however, would require initial capital investments and changes in the meat plant design. Technologies such as HPP and PEF are more eco-friendly applications as they produce small amounts of CO₂. The optimal utilization of emerging tenderization technologies requires continuous adjustment for different carcass muscles, different markets (food service industry, fresh products, export products), and different consumer group preferences. Further research and optimization of process parameters are needed to maximize the effect of the emerging coupled tenderization technology. Therefore, Future research in this area should focus on overcoming the challenges posed by the shortcomings of such new technologies.

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