



EXECUTIVE SUMMARY

Post-Harvest Practices for Enhancing Beef Tenderness



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POST-HARVEST
PRACTICES
FOR ENHANCING
BEEF TENDERNESS



*Prepared for the
National Cattlemen's Beef Association*

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The components of “taste” that determine the “overall palatability” of beef (i.e., the satisfaction gained from eating beef) are flavor, juiciness and tenderness. Tenderness has been identified as the primary determinant^{60,108,125} of eating satisfaction among U.S. beef consumers, or equal to that of flavor⁹⁹.

Consumers realize that cuts from some areas of the carcass are inherently more tender than cuts from other areas, and are willing to pay more money for them. That is why—in supermarkets—there is a continuum of prices starting, for example, at \$3/lb for a chuck steak and progressively increasing for steaks from the bottom round, top round, top sirloin, ribeye and striploin to, for example, \$14/lb for a tenderloin steak. Some consumers are willing to pay a premium for one cut versus another when both are from the same area of the carcass, or when one cut is of “superior” tenderness^{79,107} or “guaranteed” tenderness^{11,78,91,125}. A single beef carcass can yield 294 steaks and roasts; if all cuts from that carcass are “tender” (or “tough”), approximately 542 consumers will be “delighted” (or “disappointed”).

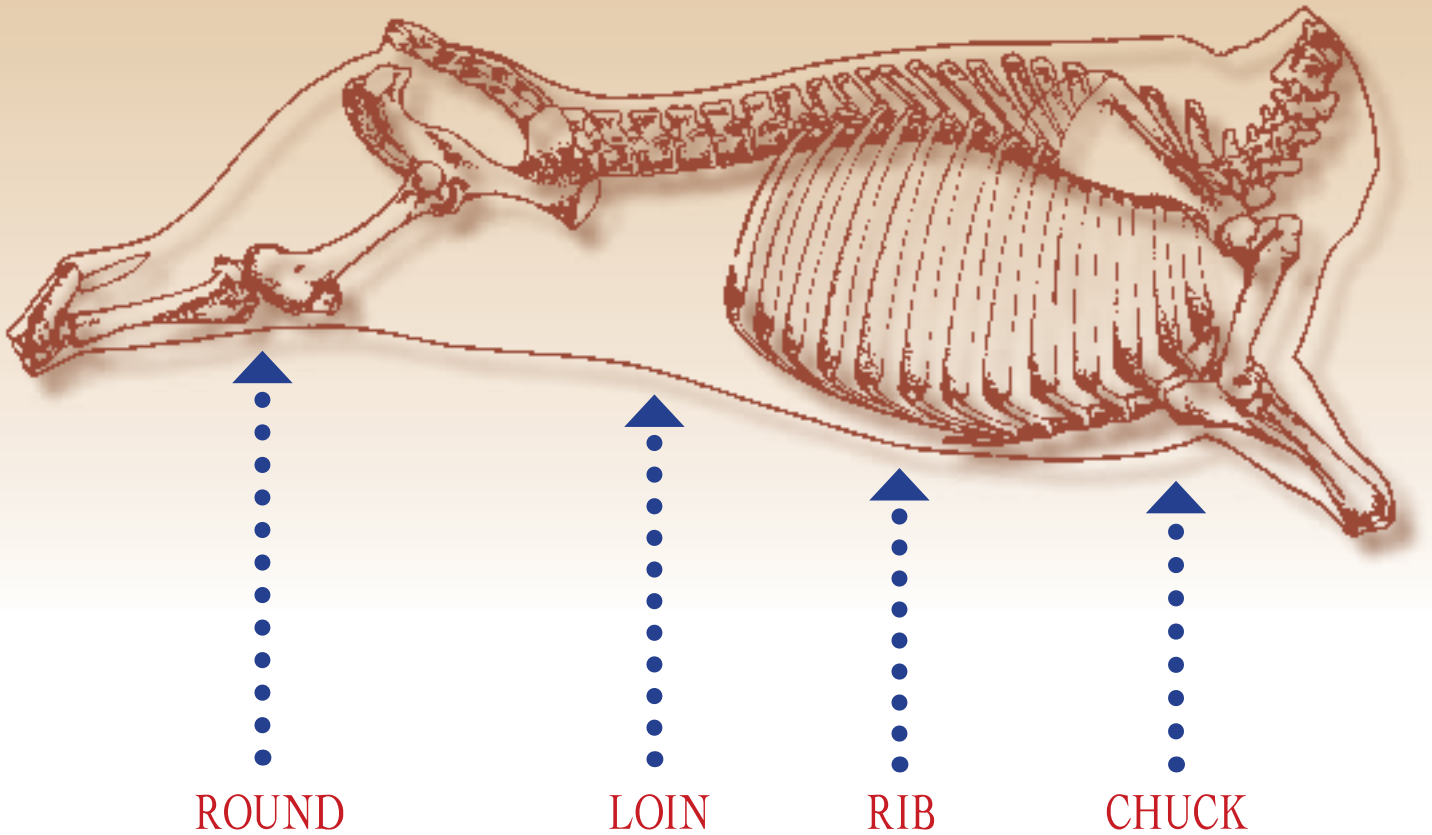
As an indication of its importance to those in all sectors of the U.S. beef industry, tenderness ranked 4th, 4th, 3rd and 9th among the Top Ten Beef Quality Challenges in the National Beef Quality Audits (NBQAs) in 1991, 1995, 2000 and 2005¹⁵⁰. In the International Beef Quality Audit—1994-96, the Number 2 “most important reason that foreign meat importers purchase U.S. beef,” was “its exemplary tenderness and flavor.” And, included in “Industry Goals to Stay on Track” in NBQA—2005¹⁵⁰ is “consider tenderness in genetic and management decisions.” Economic analyses demonstrate that a 10% increase in tenderness of beef produced in the U.S. would add \$150 million to \$170 million, annually, to the income of the U.S. beef industry^{107,115}.

THE STRUCTURE OF MUSCLE

Muscle fibers (comprised largely of myofibrillar proteins), muscle bundles and whole muscles are surrounded by connective tissues (comprised of collagen, elastin and reticulin fibers, in a watery fluid) called endomysium, perimysium and epimysium. These tissues collectivize the activity of the contractile units (i.e., sarcomeres) in the myofibrils of the muscle fibers. The individual unit of a myofibril that allows the muscle (in the living animal) to contract and relax is the “sarcomere.” If the sarcomeres in a muscle are long (because they are fixed in that position during rigor mortis) when a bite of cooked muscle is eaten, it will be tender, while if those sarcomeres are short, the bite will be tough.

Cooking meat makes connective tissue more tender by converting collagen to gelatin, but cooking also coagulates (and makes less tender) the myofibrillar proteins. Both effects depend on time and temperature. Time is more important for the softening of collagen, while temperature is more critical for toughening of the myofibrillar proteins. Beef *longissimus* muscle is tender and *biceps femoris* muscle is tough when both are broiled (dry-heat cookery; high temperature, short time) to 61°C but the converse is true if both muscles are braised (moist-heat cooking; low temperature, long time, steam generation) to 100°C⁷⁵. As beef is heated during cooking, it undergoes a marked decrease in tenderness at 58°C due to the collagen shrinkage reaction, while the muscle fibers begin to shorten at 61°C to 68°C and begin to toughen because of the loss of water and the coagulation of muscle fiber proteins^{53,80,111}.





HOW IS TENDERNESS MEASURED?

The tenderness of cooked beef is measured by mechanically shearing it (shear force value, SFV) or by having people eat it (sensory panel tenderness rating, SPTR). Although its tenderness is an imperfect predictor of the tenderness of some of the other muscles in the carcass, the ribeye muscle (*longissimus*) at the 12th/13th rib is used to characterize the relative tenderness of all the muscles in a specific beef carcass. “Threshold values” for relating specific scores for SPTRs, or amounts (in lb or kg) of SFV, to consumer acceptability have been identified for use in categorizing carcasses, cuts or muscles as “tender,” “intermediate” or “tough.” Tenderness of cooked beef muscle is determined by amounts of connective tissue left unsolubilized after cooking (gristle), amounts of intramuscular moisture and marbling-fat remaining after cooking, and the structural integrity of the sarcomeres, myofibrils and muscle fibers at the time of consumption.

DIFFERENCES IN TENDERNESS AMONG MUSCLES

The comparative tenderness of individual muscles (e.g., tenderloin vs. top round) differs substantially, depending most upon their amounts of connective tissue (predominantly related to what that muscle does in the live animal), the extent of muscle fiber or sarcomere shortening that has occurred during rigor mortis (i.e. “death stiffening”), the period/conditions of postmortem storage and the method used to cook them. Beef from older animals is less tender than that from younger animals, largely due to the higher quantity and different composition (i.e., greater amounts of collagen cross-linking and, perhaps, of elastin) of its connective tissue. The beef industry has capitalized on identification of “beef value cuts” and is better able to direct certain *muscles*, rather than primal or subprimal *cuts*, to specific end-uses and markets through an improved understanding of the tenderness of individual muscles.

POST-HARVEST PRACTICES FOR ENHANCING BEEF TENDERNESS



Such practices include:

1. Slower Chilling of Carcasses
2. Infusion of Substances into Carcasses
Immediately after Blood Removal
3. Electrical Stimulation of Carcasses
4. Change in Carcass Suspension
5. Severance of the Skeleton
6. Delayed Chilling
7. Very Fast Chilling
8. Sorting of Carcasses by Use of
Physical Characteristics
9. Sorting of Carcasses by Use of
Instrument Assessments
10. Postmortem Aging
11. Mechanical Tenderization
12. Marination or Injection with Organic
Acids, Salt, Phosphates, Calcium Chloride
and/or Ammonium Hydroxide
13. Use of Fungal, Bacterial or Tropical-
Plant Enzymes
14. High Pressure Processing
15. Palatability Assurance Critical Control
Point (PACCP) Systems



Following are descriptions of each of the post-harvest practices that have been proposed for use in enhancing beef tenderness.

1 SLOWER CHILLING OF CARCASSES—Many packers have converted from 24-hour chill cycles to 36- to 48-hour chill cycles in the past 10 years. The percent acceptability in tenderness has been shown to be 20% higher for ribeye and striploin steaks, 40% higher for clod Flat Iron steaks and 10% higher for top round steaks when carcasses are chilled at a slower rate¹.

Rigor mortis has long been associated with physical changes in muscle and, thus, with variability in beef tenderness⁹⁴. A “cold-shortening” phenomenon which accompanies or precedes rigor onset causes appreciable contraction of sarcomeres (and concomitant toughening of muscle fibers), depending upon the temperature of the cold air moving across the surfaces of muscle, the thickness of fat over and around individual areas of the muscle, and skeletal attachments (constraints) on the muscle^{76,85}.

Chilling parameters that minimize cold-shortening are of greatest importance in determining the ultimate quality and palatability of beef. Minimizing cold-shortening can best be accomplished by ensuring that muscle temperatures are not below 10°C before muscle pH reaches 6.2, during the 24- to 48-hour chill cycle¹⁷.

2 INFUSION OF SUBSTANCES INTO CARCASSES IMMEDIATELY AFTER BLOOD REMOVAL—Called “post-exsanguination vascular infusion,” three kinds of solutions have been investigated—one containing only calcium chloride (hereafter called “Calcium Activated Tenderization”), a second comprised of dextrose, maltose, glycerin and polyphosphates (hereafter called “Glycolytic Rate Enhancement”) and a third containing saccharides, sodium chloride, phosphates, vitamins C and/or E (hereafter called “Rinse & ChillTM”).

Early studies of Calcium Activated Tenderization were predicated on the fact that because the enzyme m-calpain does not decline during postmortem storage of carcasses or cuts, it could be activated, postmortem, by calcium chloride, which would tenderize the muscles⁶⁹. Research demonstrated that Calcium Activated Tenderization improved tenderness in some trials^{69,167,169} but could induce bitter and metallic off-flavors⁹⁷. Because numerous subsequent studies confirmed that Calcium Activated Tenderization caused off-flavors in beef, it has not been used in commercial practice.

In previous studies, Glycolytic Rate Enhancement improved beef tenderness⁵⁶ but addition of calcium chloride to the process resulted in lamb meat quality problems (toughness and inferior muscle quality)^{35,37} causing the researchers to not recommend its adoption by the meat industry. Rinse & ChillTM has been more thoroughly studied than has Glycolytic Rate Enhancement and apparently has no effect on the tenderness of beef^{27,177,178}. Post-exsanguination vascular infusion does not appear to be efficacious for improving the tenderness of beef.

3 ELECTRICAL STIMULATION (ES) OF CARCASSES—Early studies^{88,89,116,118,120} revealed that beef muscles will be more tender if the carcass—during the harvesting process—is subjected to electrically induced contraction/relaxation cycles (12 or so, induced by about 450 volts of AC, at about 2 amps). High-voltage ES changes the rate of postmortem pH decline in muscle, creates tears and fissures in muscle fibers, speeds up activities of both cathepsins and calpains, and expends energy, thereby lessening sarcomere shortening occasioned by development of rigor mortis. Research study summaries^{154,145} revealed that use of electrical stimulation increased SPTRs by 20 to 26% and decreased SFVs by 22 to 23%.

Electrical stimulation is used quite widely in the U.S. and globally. Some U.S. plants focus upon tenderization of the middle meats while preventing severe contraction of muscles in the round and chuck (to lessen purge loss during subsequent vacuum-packaged storage) using protocols identified first for Swift & Company^{113,114}.

Two recent studies of ES have verified the tenderization effect of ES even at low voltage⁷⁴. The studies show that tenderization is due to prevention of excessive muscle shortening during rigor development (minimizing sarcomere shortening), enhanced proteolysis by release of calcium ions at a higher carcass (and muscle) temperature, and physical disruption of the structure of the muscle fiber⁶².

4 CHANGE IN CARCASS SUSPENSION—The original study of muscles from horizontally placed versus vertically suspended carcass sides demonstrated that when muscles shortened there were corresponding decreases in sarcomere length, increases in muscle fiber diameter and decreases in tenderness⁵². This led to the development of a procedure for carcass suspension from the obturator foramen of the pelvis (i.e., Tenderstretch)⁵⁷. Tenderstretch suspension of carcasses improves the tenderness of muscles of the round because the hind-shanks pull downward, preventing those muscles from shortening (as done in standard Achilles-tendon suspension) and improves the tenderness of the *longissimus* muscle because the forequarter pulls down, straightening and stretching the spine and keeping that muscle from shortening¹⁰². Early studies^{54,55,56}, and a more recent study⁶⁴, demonstrate that Tenderstretch suspension increases the tenderness of the *longissimus* muscle by 24 to 25%.

Use of Tenderstretch suspension changes carcass conformation making commercial handling more difficult, but a novel cutting procedure for preparing supermarket cuts results in a 2.6% yield advantage for Tenderstretch versus conventionally suspended carcasses¹⁰². Pelvic suspension is not practiced in U.S. beef packing plants but is widely used in Australia and the UK, and is also used commercially in Sweden and Norway.

5 SEVERANCE OF THE SKELETON—Severance of the vertebral column in five locations and of the *ligamentum nuchae* of beef carcasses prior to chilling can increase carcass and sarcomere lengths and improve the tenderness of the *longissimus*

muscle¹⁴⁰. Later, the “Tendercut” process was developed to improve the tenderness of beef round and loin muscles by making a prerigor cut through the 12th thoracic vertebra and associated connective tissues²² and severing the shaft of the ischium, the 4th/5th sacral vertebrae and the connective tissue at the round/loin juncture¹⁶⁰. Subsequent studies of various combinations of severance protocols have produced inconsistent tenderization results with regard to round vs. loin muscles, SPTRs vs. SFVs, and zones along the length of the *longissimus* muscle^{5,77,127,159}. Nevertheless, Cargill Meat Solutions uses Tendercut, along with carcass electrical stimulation, as a part of its patented “Snip & Shock” process²⁹.

6 DELAYED CHILLING—An early study¹⁴⁰ demonstrated that chilling carcasses at 16°C for the initial 16 to 20 hours postmortem, respectively, decreased SFVs by 48 and 32% and increased SPTRs by 40 and 28%. Subsequent studies of delayed chilling of beef carcasses have demonstrated improvements in tenderness^{39,54,84,105,106,136,137,170} of about 7 to 30%. Muscles become more tender when chilling is delayed because of decreased sarcomere shortening and increased proteolysis^{39,105,170}. If performed incorrectly, delayed chilling can result in “heat shortening” which toughens muscles¹⁴¹. Delayed chilling is not practiced commercially in the U.S. because bacteria can proliferate on carcass surfaces under such conditions and—if human pathogens were present—could produce a distinct health threat.

7 VERY FAST CHILLING—There are studies that suggest that a combination of proteolysis and crust freezing can produce tender beef^{15,66}. One such study¹⁵ demonstrated that beef sides chilled at -70°C for 5 hours, at 16°C for 4 hours, and at 1°C for 15 hours (rapid chill), compared to sides chilled at -70°C for 24 hours (conventional chill), produced loin steaks with longer sarcomeres, lower SFVs and higher SPTRs. Subsequent research showed that “very fast chilling” (VFC), the attainment of -1°C in the deep musculature within about 5 hours postmortem, can improve tenderness^{2,3} but another study disagreed¹⁵⁵.

Canadian researchers have combined the use of electrical stimulation with blast chilling in attempts

to accomplish rapid carcass chilling without cold-shortening and resulting meat toughening. One study compared blast chilling (at -20°C, or at -35°C) to achieve -1°C deep muscle temperatures at 5 hours postmortem, with conventional chilling (at 2°C for 24 hours). After 6 days of aging, steaks from blast-chilled sides were more tender but the difference disappeared by 21 days postmortem, causing the researchers to identify the advantage of blast chilling as “a reduction in the aging time necessary to achieve an acceptable product².”

8 SORTING OF CARCASSES BY USE OF PHYSICAL CHARACTERISTICS—There are 63 branded-beef programs that are “Certified” by the USDA and more than 100 company-brand programs that are not. Most of those brands use constraints based on live animal and/or carcass traits. Physical characteristics that are related to the genetics of the animal and/or to the environment to which the animal is exposed, and that help determine the relative tenderness of cooked beef are:

- ◆ biological types of animals^{23,26,128,144}
- ◆ physiological maturity of carcasses^{10,133}
- ◆ amount of marbling in muscles of carcasses^{41,109,132,166}
- ◆ USDA Quality Grade^{107,109,151}
- ◆ external fat thickness on carcasses^{30,65,75,152}
- ◆ muscle pH and color^{65,172,173}
- ◆ gender^{21,70,144}.

In general, a carcass is more likely to produce tender beef if it:

- ◆ is from an animal of British, and not from Brahman, breeding
- ◆ is less mature physiologically
- ◆ has more marbling in its muscles
- ◆ qualifies for a higher USDA Quality Grade
- ◆ has a thicker covering of external (subcutaneous) fat
- ◆ has muscles of pH <5.8 and of lighter color
- ◆ if it comes from a steer or heifer rather than a bullock.

Use of combinations of carcass-trait constraints can segregate carcasses into groups which have higher probabilities of producing tender beef.

9 SORTING OF CARCASSES BY USE OF INSTRUMENT ASSESSMENTS—Instruments can be used to sort carcasses according to categories of physical-appearance traits (e.g., muscle color, marbling score, external fat thickness) or in attempts to predict cooked-beef tenderness. Two image-based instruments are approved to determine marbling score for use in the evaluation of Official USDA Quality Grades for Carcass Beef (www.ams.usda.gov/lsg/ls-st.htm). A number of probe devices have demonstrated limited ability to predict beef tenderness^{6,59,146} and a system was designed to remove, cook and shear a *longissimus* steak from carcasses in the chill cooler¹²⁶ but none of these invasive protocols has been adopted commercially.

Muscle color characteristics, measured with a Minolta Chromameter (Minolta Corporation, Ramsey, N.J.), were successfully used to sort carcasses into groups with different percentages of “tough” steaks¹⁷³. The Hunter/ CSU BeefCAMTM uses video image analysis to measure the color of muscle and fat in the *longissimus* to sort beef carcasses into expected tenderness groups⁷. It was able to identify sub-populations of carcasses with “tender” steaks in seven trials^{18,19,47,157,174,175,176} but not in one trial¹⁶⁵. Studies of near-infrared, alone or in combination with visible, reflectance spectra, have shown promise in three trials^{101,103,124}, but not in one trial¹⁵⁶, for predicting tenderness of beef from measurements on the *longissimus* muscle. Sorting of carcasses by use of instrument assessments is—at the least—helpful in identifying carcasses with *longissimus* muscle colors indicative of greater probability of toughness. Other instruments are in early stages of development⁴⁵.

10 POSTMORTEM AGING—Individual muscles respond differently, in extent of tenderization improvement, to postmortem aging periods because of differences in rate and extent of pH decline and in activity of calpains⁶⁵ and thus in the extent of proteolytic degradation^{110,154}. Beef can be “wet-aged” (held for periods of time in vacuum packages) or “dry-aged” (held for periods of time with no protection or package) to allow more complete degradation of myofibrils via loss of integrity of sarcomeres at the

Z-lines). One study¹⁰⁴ demonstrated that dry aging improved tenderness more than did wet aging, while another study¹⁶⁵ found no difference in tenderization between the two methods.

Numerous studies have been conducted to identify suggested postmortem aging times for specific primal cuts or muscles^{16,32,46,90,138,164}. One study¹⁶ demonstrated that beef from the USDA Upper Two-Thirds Choice grade does not need to be aged beyond 7 days while beef from the USDA Select grade should be aged at least 14 days. Another study⁴⁶ concluded that muscle-to-muscle tenderness differences depend on USDA Quality Grade and aging time, and that—in general—SFVs of muscles from the Upper Two-Thirds Choice carcasses decreased more rapidly from the 2nd to the 10th days of postmortem aging than did corresponding muscles from USDA Select carcasses. To achieve maximum aging response, all 17 muscles studied required 20 or more days if from USDA Select carcasses while 10 of those 17 muscles required 18 or fewer days if from USDA Upper Two-Thirds Choice carcasses⁴⁶.

11 MECHANICAL TENDERIZATION—Passing beef primal/subprimal cuts through machines that have reciprocating banks/rows of very sharp blades or needles is an effective means for disrupting the structural integrity of myofibrils, muscle fibers and muscle bundles, of severing fibrils of collagen, reticulin and elastin and, thereby, increasing tenderness of muscles. At least some of the blade/needle tenderization effect from a sensory standpoint is from reductions in the amount of perceptible connective tissue^{50,135}. A significant portion of U.S. foodservice beef has been blade/needle tenderized. Middle meats are usually passed through blade/needle tenderizers one or two times while round cuts may be blade/needle tenderized two to eight times⁴⁵.

Research demonstrates that blade/needle tenderization:

- ◆ consistently decreases SFVs^{24,153}
- ◆ further reduces SFVs with successive passes through the machine^{119,123,155}

- ◆ will not (even with two passes) make Select striploins as tender as are those from Choice or Certified Angus Beef striploins⁴²
- ◆ may^{25,44,50}, or may not^{119,122,123,135,153} increase drip loss and/or cooking loss.

There have been recent concerns about blade/needle tenderization taking *E. coli* O157:H7 into the interior of cuts allowing it to survive cooking, but research⁵¹ demonstrated that the risk is minimal and that there are “Good Practices” for mitigating that risk.

12 MARINATION OR INJECTION WITH ORGANIC ACIDS, SALT, PHOSPHATES, CALCIUM CHLORIDE AND/OR AMMONIUM HYDROXIDE—Several processes use marination, infusion or injection of chemical ingredients for purposes of improving real or apparent beef tenderness. The processes work because acetic acid and sodium chloride weaken the sac (i.e., sarcolemma) that surrounds the muscle fiber. Sodium chloride itself has a tenderizing action on meat; phosphates enhance water-holding capacity of muscle; phosphates and ammonium hydroxide raise the pH of muscle; and the calcium ions in calcium chloride activate the calpain enzymes that degrade muscle proteins during postmortem aging.

Organic acids have been shown to increase beef tenderness^{8,17}. Salt alone^{121,162}, but especially salt plus phosphates^{4,72,85,121,149,158}, are very effective tenderizers and have been used commercially to “enhance” beef cuts. Calcium chloride improves tenderness^{12,28,168,169} yet has caused bitter and/or metallic off-flavors in some studies^{35,97,121,168} but not in others^{20,71,92}. Solutions containing ammonium hydroxide have recently been demonstrated as effective in tenderizing beef^{54,48,49,171}.

13 USE OF FUNGAL, BACTERIAL OR TROPICAL PLANT ENZYMES—Enzymes of fungal or bacterial origin (e.g., fungal amylase, protease 15) confine their action to muscle fiber protein while those from tropical plants (e.g., papain, bromelain, ficin) contain both collagenase and elastase. Any of these enzyme preparations can tenderize meat, provided the right amount of it can penetrate evenly into the meat

tissue¹⁶². Beef can be tenderized by marinating or injecting it with solutions of papain^{67,86,87,112,161,162}, bromelin^{67,161,162} or ficin^{67,95,161,162}. Papain in solution can be administered to live cattle and beef from treated animals will be tenderized^{61,139}. Bacterial collagenases, for degrading connective tissue in meat, have shown limited usefulness^{9,40} and have not been used commercially for tenderizing beef.

Native forms of collagen, reticulin and elastin, resist attack by proteolytic enzymes of fruit/vegetable origin but, when altered by cooking, are readily susceptible to their action. The tropical plant enzymes (papain, bromelin, ficin—from papaya, pineapple and fig sources) do not reach their optimum temperature of activity until the range of 70 to 85°C is attained⁷³ during cooking. Unless conditions (time/temperature) are carefully controlled, the tropical plant enzymes go too far, over-tenderizing and making the beef mushy and oddly flavored. As a result, those enzymes are not widely used to improve beef tenderness by either the supermarket or foodservice sectors in the U.S. beef industry.

14 HIGH PRESSURE PROCESSING—Research conducted in the early 1970s demonstrated that it was possible to tenderize beef by subjecting the muscles of freshly harvested animals to very high pressures (100 Mpa) for short periods of time (2 to 4 minutes) reducing SFVs for beef cuts by three- to four-fold^{81,82}. Others combined heat and high pressure processing to improve beef tenderness, and reported that such treatment was efficacious because of effects on myofibrillar proteins^{15,14} or on the sarcolemma⁶⁸.

Hydrodynamic pressure (HDP) wave technology uses an underwater detonation of explosives to generate a hydrodynamic shock wave pressure front as a means for tenderizing meat. HDP technology has been shown to improve the tenderness of beef by magnitudes of 30 to 80% and, the tougher the piece of meat, the greater the magnitude of improvement¹⁴². Subsequent studies of the technology have demonstrated tenderness improvements of 14% to 72% for specific beef muscles^{31,143,179}. HDP technology will most likely

be used to control spoilage microorganisms, food-borne pathogens and food allergens rather than for tenderization of beef.

15 PALATABILITY ASSURANCE CRITICAL CONTROL POINT (PACCP) SYSTEMS—The idea of using a PACCP System for improving beef palatability was first proposed during the Strategy Workshop for the NBQA—1991⁹⁵ and was included as the first of the eleven elements of the National Beef Tenderness Plan⁹⁸. The PACCP approach was used to develop a breed association brand of beef⁵⁸, “Genetic Critical Control Points” for improving beef tenderness¹⁰⁰, a program for allowing *Bos indicus* cattle to qualify for a branded beef program^{128,129} and an “Eating Quality Assurance Scheme” in Australia⁵⁸.

More recent studies of the PACCP System include a model to reduce the incidence of beef palatability problems¹⁵¹, a Total Quality Management approach for improving beef tenderness¹⁵⁰, quality management practices to reduce the incidence of retail beef tenderness problems¹⁴⁸ and new approaches for improving tenderness, quality and consistency of beef¹⁴⁷. In one of those studies¹⁴⁸, a PACCP program is described that consists of:

- ◆ CCP1—*Genetics* (sire lines)
- ◆ CCP2—*Preharvest Cattle Management* (age, castration, implants, time-on-feed, health, and a subcutaneous fat thickness target)
- ◆ CCP3—*Early Postmortem Management* (high voltage electrical simulation)
- ◆ CCP4—*Late Postmortem Management* (aging for 21 days).

Use of that program reduced nonconformance in tenderness from 1 in 4, to 1 in 8, for top sirloin and striploin steaks.



SUMMARY AND CONCLUSIONS

Of tenderness interventions that can be applied prior to or coincident with chilling of carcasses:

- ◆ postexsanguination vascular infusion cannot be recommended as a means for improving the tenderness of muscles in the beef carcass;
- ◆ electrical stimulation is already used in most fed-beef packing plants and, if applied appropriately, will improve the tenderness of some or most of the major muscles in the beef carcass;
- ◆ suspension of the beef carcass by the aitch bone greatly improves the tenderness of the major muscles in the rib, loin and round;
- ◆ severance of the skeleton has been shown to marginally improve the tenderness of some beef muscles (particularly those muscles or parts of muscle adjacent to sites of severance);
- ◆ chilling carcasses at higher-than-normal temperatures for a few hours immediately postmortem, and then at conventional temperatures, marginally increases tenderness but could increase growth of foodborne pathogens;
- ◆ chilling carcasses in a 48-hour, rather than 24-hour, cycle substantially increases percent acceptability in tenderness of beef muscles; and
- ◆ very fast chilling of beef carcasses is incompletely researched but does not appear to be useful for improvement of beef tenderness.

Of pre-chilling/chilling tenderness interventions that are effective, their efficacy may more often be the result of preventing toughness than from increasing tenderness.

Of practices which can be employed (beyond what is done in government grading) to categorize the tenderness of beef carcasses in the cooler:

- ◆ sorting of carcasses by use of physical characteristics (especially by identifying those with brighter muscle color, higher amounts of

- marbling within the chosen grade range, minimum hump height, more youthful skeleton) can be used to generate populations of products that are more tender; and
- ◆ sorting of carcasses by use of instrument assessments assures that physical-attribute constraints for quality-grade-factor determinants are more objectively monitored. Such assessments are at the least helpful in identifying carcasses with *longissimus* muscle colors indicative of greater probability of toughness.

Of practices that can be applied to primal/subprimal cuts of beef:

- ◆ postmortem aging, for appropriate periods of time and under appropriate storage conditions, greatly improves the tenderness of cuts/muscles that are low in connective tissue and helps improve the tenderness of cuts/muscles with high quantities of connective tissue;
- ◆ mechanical tenderization is widely utilized by foodservice operators and can be used by supermarket operators. With proper control of sanitation, it can be an important tool for tenderizing beef;
- ◆ marination or injection with organic acids, salt, phosphates and/or ammonium hydroxide—but not with calcium chloride—can be used to replace marbling in cuts of beef with insufficient amounts of intramuscular fat (as a means for protecting the palatability of the product if it is overcooked);
- ◆ tropical-plant enzymes, but less often those of fungal or bacterial origin, are used in marinades and are applied by direct contact by consumers (at home), by restaurateurs, and by some supermarket and foodservice operators but must be cautiously applied and carefully managed to assure a successful outcome; and
- ◆ high pressure processing greatly improves tenderness of beef, but logistic and cost concerns are such that its use will likely be limited to use on prepared and/or processed products for which there are food safety concerns.

Of greatest importance to the future of the U.S. beef industry, with respect to providing consistently tender products to our domestic and international customers and consumers, will be widespread application of Palatability Assurance Critical Control Point (PACCP) systems in concert with government certification/verification/validation programs or as essential elements of industry branding programs. Until arriving at that destination, the industry must continue to use the science and apply the technology that is described in this Review of Literature to do all that is possible to assure the tenderness of U.S. beef.



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