

# *Beef Quality Systems: Application of TQM Principles to Produce Tender Beef*

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## Introduction

The U.S. beef industry's strategies for stabilizing and increasing consumer demand for beef were recently outlined in the National Cattlemen's Beef Association Long Range Plan (NCBA, 1998). Improving product quality and consistency was identified by NCBA as a critical element in the industry's efforts to arrest the steady decline in beef's market share. This is based on the premise that "meeting and exceeding consumer expectations for quality and consistency will provide the opportunity to increase demand." A primary goal established by NCBA for improving the eating quality and consistency of beef was: "Reduce consumer dissatisfaction due to variability in eating quality (especially tenderness) by 50 percent by the year 2005." To accomplish this goal, it was recommended that the beef industry "develop and implement Total Quality Management-like systems to enhance quality and consistency..." This report summarizes work commissioned by the NCBA and conducted at Colorado State University to develop a TQM approach for improving beef tenderness.

## Rationale for a TQM Approach

Steers and heifers comprising the U.S. "fed" beef supply are highly variable in biological type, age, and management background (most are grain-finished, but they are started on feed at different ages, given different growth promoting implants, fed for differing periods of time, and harvested at different marketing endpoints). The beef industry's current system for ensuring acceptable product tenderness involves "mass inspection" (i.e., USDA Quality Grading) of completed products (carcasses) at the end of the production process. Although this system results in general categorization according to quality and tenderness differences, product value is lost due to imprecision of sorting methodology and because "inferior" products have been

produced and must be sold at discounted prices. Dr. W. Edwards Deming, the originator of a Total Quality Management (TQM) philosophy often cited as the basis for the "quality revolution" that has swept through American industry, recommended that industries "cease dependence on inspection to achieve quality" and "eliminate the need for inspection on a mass basis by building quality into the product in the first place" (Deming, 1986).

An alternative approach for ensuring beef tenderness based on TQM principles was proposed at the 1994 National Beef Tenderness Conference (NCA, 1994). Application of such a system requires identification of causes of non-conformance (in this case, toughness), then focuses on prevention of non-conformance through control of inputs and processes.

## PROTOTYPE QUALITY SYSTEM FOR ASSURING BEEF TENDERNESS

### Identifying "Critical Control Points" and Opportunities for Process Control

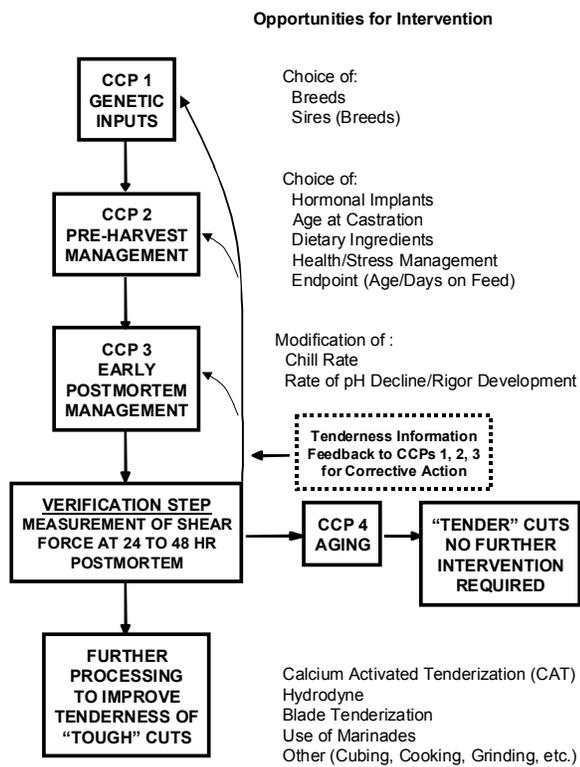
In normal systems of beef production, there are several points at which management decisions are made that can have either positive or negative impacts on subsequent product quality. In keeping with TQM philosophy, these might be considered "critical control points" (CCP) – defined for the purposes of this discussion as points at which process control might impart desired product quality characteristics (in this case, acceptable beef tenderness). Figure 1 outlines a prototype quality system for assuring beef tenderness. This outline is presented simply to illustrate the TQM concept and should not be interpreted as a comprehensive list of all possible CCPs for the improvement of beef tenderness.

CCP 1 – Genetic Inputs. Previous research has shown that there are important genetic effects on beef tenderness (Shackelford et al., 1994; Wulf et al., 1996b; O'Connor et al., 1997). Although differences between breeds (particularly *Bos indicus* vs. *Bos taurus* cattle breeds) have been identified (Koch et al., 1976, 1979, 1982; Crouse et al., 1989; Sherbeck et al., 1995; Wheeler et al., 1996), research conducted in the past few years suggests that differences in tenderness among sires within breeds are greater than mean tenderness differences among breeds (Wheeler et

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**Figure 1.**  
**Example of a Quality System for Assuring**  
**Beef Tenderness**



al., 1996; Wulf et al., 1996b; O'Connor et al., 1997). Because tenderness is a moderately heritable trait (Shackelford et al., 1994), sire selection to improve tenderness should be effective, yet the time and expense required to change tenderness via traditional selection methods are frequently cited as impediments to a genetic solution for the beef industry's product tenderness problems (Koochmarai, et al., 1995; Dikeman, 1996). At the present time, seedstock and commercial cattle breeders must still rely on traditional methods such as progeny testing to obtain tenderness information for selection purposes. However, bovine gene mapping studies have detected DNA markers identifying quantitative trait loci associated with differences in beef tenderness (Taylor et al., 1994; Beattie, 1994; Miller et al., 1996) that soon could facilitate marker assisted selection of cattle for improved beef tenderness. Such advances would greatly enhance the efficacy of producer intervention at CCP 1 to increase tenderness of beef.

**CCP 2 – Pre-Harvest Cattle Management.** Management practices that alter the endocrine status of the animal are perhaps the most important pre-harvest processes that may be controlled to influence beef tenderness. The most widely used method of endocrine modification is castration of male cattle (Unruh, 1986). Intact male cattle generally produce less tender beef than do steers (Seideman et al., 1982) be-

cause: (a) elevated serum testosterone levels, coinciding with sexual development at 8 to 14 months of age, are associated with a concomitant increase in intramuscular collagen content (Boccard et al., 1979; Cross et al., 1984) and (b) higher calpastatin activity in the musculature of bulls causes their cuts to age more slowly than do cuts from steers (Morgan et al., 1993). A growing body of evidence suggests that the use of exogenous hormones (implants) to increase growth rate and efficiency of feed utilization may be detrimental to beef tenderness, particularly when very potent anabolic agents are used repeatedly or when they are administered too near the date of harvest (NLSMB, 1995; Morgan, 1997). Other pre-harvest factors that have been shown to affect tenderness include the number of days the animal is fed a high-energy diet (Dolezal et al., 1982; Van Koeveering et al., 1995), health status of the animal during the growing and finishing period (Gardner et al., 1998), intramuscular injection of animal health products (George et al., 1995), temperament and(or) ante-mortem stress (Voisinet et al., 1997), age (Wulf et al., 1996a), and relative fatness (Dikeman, 1996) of the animal at harvest. To encourage U.S. producers to adopt "quality management" practices, the NCBA Beef Palatability Task Force recently established the following pre-harvest management recommendations:

- (1) Eliminate aggressive use of anabolic implants.
- (2) Discourage excessive use of biological types with known, wide variability in tenderness.
- (3) Eliminate intramuscular injections.
- (4) Slaughter all cattle prior to 30 months of age.
- (5) Castrate bull calves as early as possible, and prior to seven months of age.
- (6) Eliminate short (less than 100 days) feeding programs, especially for large biological types of cattle.

**CCP 3 Early-Postmortem Management.** Two early-postmortem rate parameters (rate of cooling and rate of post-mortem glycolysis) interact to affect beef tenderness (Lee, 1986; Marsh et al., 1987; Geesink et al., 1995) and both are subject to process control. Beef processors can (a) manipulate air temperature and velocity to control chill rates and (b) electrically stimulate carcasses to accelerate the rate of postmortem glycolysis (Marsh et al., 1988; Mallikarjunan and Mittal, 1995). Existing research information suggests that management of early postmortem conditions requires simultaneous consideration of both cooling rate and glycolytic rate to produce desired effects on tenderness. For example, when the cooling rate of a carcass is rapid, acceleration of glycolysis and early rigor development resulting from electrical stimulation (high or low voltage) improves tenderness (Savell et al., 1977b; Marsh et al., 1987), but when carcasses are cooled slowly, accelerated glycolysis (resulting from low frequency or low voltage stimulation) can result in appreciable toughening (Takahashi et al., 1984; Unruh et al., 1984; Marsh et al., 1987). Delayed chilling or reducing the chill rate of slow glycolysing beef carcasses improves tenderness (Dutson et

al., 1977; Lochner et al., 1980; Lee and Ashmore, 1985), but also can result in more rapid proliferation of microorganisms. Any effort to improve tenderness and eating quality must be balanced with efforts to maintain and improve product safety. Therefore, use of slower chill routines is not recommended. However, it is noteworthy that chill routines involving extremely rapid chill rates also have been found to produce more tender beef than conventional chill procedures (Bowling et al., 1987; Joseph, 1996). Koohmaraie (1996) discussed the effects of rapid chilling on beef tenderness and outlined a hypothetical intervention strategy for the early-postmortem period utilizing electrical stimulation, followed by very rapid chilling and conditioning at -5°C to prevent development of toughness. Other practices that might be considered for intervention at CCP 3 to enhance tenderness include, but are not limited to, pelvic suspension of carcasses (Hostetler et al., 1972) and skeletal alteration to permit muscle stretching (Wang et al., 1994; Ludwig et al., 1997).

**CCP 4 – Postmortem Aging.** The length of the postmortem storage/distribution interval for fresh beef cuts affects tenderness and may be considered a “critical control point” for assuring product quality. In today’s beef industry, very few U.S. packers age beef in carcass form. Yet, because of the time required to transport vacuum-packaged, chilled, boxed beef cuts from the point of slaughter and fabrication to the point of purchase, nearly all fresh beef is aged for some period of time before purchase by consumers. However, the time period between packaging and purchase is extremely variable. A recent nation-wide survey conducted by Colorado State University (George, 1998) determined that the time interval between fabrication/packaging and retail display for beef strip loins and top sirloins ranged from 2 to 91 days (average = 20 days). These findings are similar to data for post-fabrication aging time (range: 3 to 90 days; average: 17 days) reported in the National Beef Tenderness Survey (Morgan et al., 1991). At the National Beef Tenderness Conference, it was recommended that beef cuts be aged for at least 10 days to ensure acceptable tenderness (NCA, 1994). Survey results reported by George (1998) suggested that approximately 10% of beef loin steaks were available for purchase in fewer than 10 days from the time of fabrication. Interestingly, nearly 10% of cuts also were offered for sale to consumers more than 35 days post-fabrication. Preventing short-aged products from reaching consumers is a readily attainable goal for quality-driven beef suppliers and meat retailers that could contribute to the reduction of toughness problems. Perhaps a “sell after” date could be placed on packaging to encourage adequate aging of products. Moreover, use of “sell-by” dating on packaging could reduce the incidence of products stored and aged for extremely long periods, which could improve stability of product quality characteristics and extend retail case-life.

## Verification of Conformance to Specifications

A key element of the quality system outlined in Figure 1 is the verification step. Products must be inspected and tested to verify that they conform to specified requirements (i.e., a specified level of tenderness). Scientists at the U.S. Meat Animal Research Center recently designed an automated system for measuring shear force at 1 to 2 days postmortem at commercial beef processing speeds (Shackelford et al., 1995). In this system, a cross-section of the longissimus muscle is obtained from a beef carcass at 1 to 2 days postmortem and cooked using an automated, belt grill. A slice 1 cm thick then is removed from the longissimus sample (parallel to the orientation of the muscle fibers) and used to measure shear force. The slice shear force is used to predict aged longissimus tenderness. Data reported by Shackelford et al., (1997) suggest that longissimus shear force measured at 1 to 2 days postmortem is a reasonably accurate predictor of longissimus shear force after 14 days of aging. Other non-invasive systems for predicting aged beef tenderness have been investigated and, with further development, may also be useful for tenderness verification (Miller et al., 1996; Belk et al., 1997; Wulf et al., 1997).

In the quality system outlined in Figure 1, measurement of longissimus shear force at 24 to 48 hours postmortem has two very important purposes. First, this measurement is used to verify conformance of products to desired tenderness specifications. Secondly, this measurement may be used as a basis for “corrective action” by providing “feedback” of tenderness information to producers for use in genetic improvement of tenderness (at CCP 1) and for correction of management-related tenderness problems (at CCP 2, CCP 3, and CCP 4). Presently, obtaining tenderness data for selection purposes is difficult and expensive. However, if shear force data were collected routinely for sire-identified cattle using an automated system, producers could have continuous access to tenderness information, allowing them to track genetic progress.

## Control of Non-Conforming Product

Once non-conforming products have been identified (Figure 1), one or more of several different postmortem technologies may be employed to improve their tenderness characteristics or to alter their physical or structural characteristics so that tenderness no longer is a primary concern. Technologies that could be applied for this purpose include, but are not limited to:

- (a) Calcium-Activated Tenderization (CAT) which involves infusion of the cut with a solution containing calcium chloride to increase the rate and extent of muscle proteolysis (Koohmaraie et al., 1995);
- (b) Hydrodyne (Solomon et al., 1997; Calkins et al., 1997), which involves the use of an explosion to generate hydrodynamic shock waves in water causing tenderization of meat cuts submerged in the water;
- (c) blade or needle tenderization (Savell et al., 1977a);

- (d) use of marinades (Scanga et al., 1998); or
- (e) further processing (which might involve cubing, cooking, grinding, flaking, etc.).

## Evaluation of the Effectiveness of the Prototype Quality System

The previous section of this manuscript described a prototype quality system for assuring beef tenderness. This section outlines procedures and experimental data used to test the effectiveness of the prototype system for assuring tenderness of loin steaks.

### Baseline Data

English crossbred steers ( $n = 50$ ) of unknown genetic origin and management history were selected randomly at a commercial packing facility. After the steers were processed using conventional procedures (electrical stimulation was not used), strip loins and top sirloin butts were obtained from each carcass, aged at 2°C for 3 and 21 days, and used to provide baseline shear force data. George (1998) determined: (a) that consumers could purchase loin steaks in as few as 2 days following fabrication (which would equate to 3 or 4 days postmortem), and (b) that the average post-fabrication interval was approximately 20 days (i.e., 21 or 22 days postmortem). Correspondingly, we chose to use shear force values of cuts that had been aged for 3 days (“worst-case” scenario) and 21 days (“normal” scenario) as baselines for measuring effectiveness of process control.

### Experimental Application of the Quality System

**Genetic inputs.** Steer progeny ( $n = 144$ ) of 31 genetically diverse sires (2 to 7 calves per sire) mated to crossbred dams were used for the test. Sires included 8 Braford, 7 Charolais, 4 Simmental, 3 Limousin, 3 Red Brangus, 2 Angus, 2 Belgian Blue, and 2 Braunvieh bulls. Initially, only one genetic constraint (a maximum of 3/8 *Bos indicus* inheritance, O'Connor et al, 1997), was imposed.

**Pre-harvest management.** All steers were castrated before 7 months of age. At the beginning of the finishing period, the steers received an implant containing 20 mg estradiol benzoate and 200 mg progesterone. Sixty days later the steers received a second implant containing 24 mg estradiol and 120 mg trenbolone acetate. The steers were fed a high-energy finishing diet for more than 100 days and harvested when they attained 11 mm fat thickness (14 to 17 months old). Any cattle that exhibited severe or chronic health problems during finishing were removed from the system.

**Early-postmortem management.** The cattle were processed at a commercial beef packing facility using conventional methods (plant, processing, and chill methods

were the same as those used for “baseline” cattle). Approximately 40 min post-stunning, the left side of each carcass was electrically stimulated. Stimulated sides received 3 impulses of 175 V (AC), 60 Hz, followed immediately by 17 impulses of 490 V (AC), 60 Hz. Impulse duration was 1.8 s with a 1.8 s delay between each impulse. All carcasses were transferred to a chiller (-3°C air temperature) and were sprayed intermittently (2 min on, 8 min off) with a fine mist of 2°C water for 10 h. At approximately 11 h postmortem, the chiller temperature was increased to 1°C for the remainder of the 24-h chilling period.

**Verification step, aging and control of non-conforming product.** Day-1 longissimus shear force (measured using longissimus core samples 1.3 cm in diameter) was used to verify conformance to tenderness specifications. Strip loins and top sirloin butts from carcasses with a day-1 longissimus shear force less than 5 kg were categorized as “tender” and were aged in vacuum bags at 2°C for 21 d. It was projected that “tender” cuts should meet the shear force specification for finished products of less than 4.54 kg after 21 days of aging. Cuts with a day-1 shear force of 5 kg or greater were categorized as “tough”, injected (5% of weight) with a food-grade calcium chloride solution (200 mM), and aged in vacuum bags at 2°C for 7 days in an effort to meet the finished product tenderness specification.

**“Corrective action”.** Day-1 shear force data collected in the verification step were used as a basis for “corrective action” at CCP1. Sires producing 1 or more calves with a day-1 longissimus shear force of 5 kg or higher were culled. The quality system was applied using the complete data set and, then, reapplied after eliminating data for progeny of 18 sires to simulate culling.

**Defining non-conformance of finished products.** For the purposes of testing the prototype quality system, we chose a specification for tenderness of 4.54 kg, based on the consensus established at the National Beef Tenderness Conference (NCA, 1994). Specifically, non-conformance was defined as a Warner-Bratzler shear force value (for a core sample 1.3 cm in diameter taken from a steak cooked to 70°C) equal to or greater than 4.54 kg. To evaluate the effectiveness of process control, shear force was assumed to be normally distributed and probability density functions were computed (using means, SD, and the threshold shear force value) for cuts from baseline cattle and for cuts from cattle produced using the quality system. The computed values represented probabilities (expected occurrence) of non-conformance. The purpose of the quality system was to reduce the occurrence of non-conformance.

### Performance of the Quality System

Data showing performance of the quality system are

**Table 1. Comparisons Showing the Effectiveness of the Prototype Quality System for Assuring Tenderness of Loin Steaks**

Item	Top Sirloin Shear Force			Strip Loin Shear Force		
	Mean (kg)	SD	Probability of Non-conformance	Mean (kg)	SD	Probability of Non-conformance
<b>Baseline</b>						
"Worst-Case" Scenario <sup>a</sup>	4.65	0.86	.55	4.96	0.95	.67
"Normal" Scenario <sup>b</sup>	3.96	0.79	.23	4.11	0.67	.26
<b>Quality System</b>						
Applied Without Genetic						
"Corrective Action" at CCP 1 <sup>c</sup>	3.66	0.78	.12	3.44	0.94	.14
Applied With Genetic						
"Corrective Action" at CCP 1 <sup>d</sup>	3.56	0.57	.04	3.05	0.66	.01

<sup>a</sup> Not electrically stimulated, aged for 3 days.

<sup>b</sup> Not electrically stimulated, aged for 21 days.

<sup>c</sup> Electrically stimulated, aged for 21 days, CAT used to improve tenderness of non-conforming cuts.

<sup>d</sup> Electrically stimulated, aged for 21 days, CAT used to improve tenderness of non-conforming cuts, sires that produced progeny with day-1 *longissimus* shear force 8.5 kg were culled.

presented in Table 1. Baseline probabilities indicated an expected rate of non-conformance after 3 days of aging ("worst-case" scenario) of approximately 1 in 2 for top sirloin steaks and 2 in 3 for strip loin steaks. After 21 days of aging ("normal" scenario), the expected failure rate was about 1 in 4 for both cuts.

Application of the quality system, without genetic "corrective action" at CCP1, decreased the probability of non-conformance to .13 for top sirloin steaks and .12 for strip loin steaks. Even after application of high-voltage ES, aging for 21 days, and use of CAT to improve the tenderness of non-conforming product, about 1 out of 8 steaks failed to conform to the desired shear force specification (Table 1), suggesting that application of postmortem technologies did not completely eliminate tenderness problems and that some attention must be given to improving the quality of "raw materials". The following quote (taken from a magazine article by Lowry, 1990) stresses the importance of the quality of raw materials to the quality of a finished product.

*"Once the grapes hit the dock, it's too late for us to correct the fruit. You can make bad wine from good grapes, but you can't make good wine from bad grapes. So we try to help farmers grow premium grapes for our wines." (Bob Reed, Llano Estacado Winery)*

The same principle applies to the production of "quality" beef. It is difficult to produce tender beef using cattle that are inherently "tough". In the quality system outlined

in Figure 1, one way to improve "raw materials" is through genetic intervention at CCP 1. Application of the quality system with genetic "corrective action" at CCP1 was very effective for assuring tenderness (Table 1). The system which involved the combined use of genetic and postmortem interventions improved mean shear force and reduced the expected rate of non-conformance to 1 in 25 for top sirloin steaks and 1 in 100 for strip loin steaks.

## Summary and Conclusions

A quality system for assuring beef tenderness was designed and tested. The test population of cattle was genetically diverse, but was constrained to include youthful steers with no more than 3/8 *Bos indicus* inheritance. Feeding and pre-harvest management of the cattle were consistent with procedures recommended for production of grain-finished beef of an acceptable quality level. Moreover, the target endpoint for harvest (.45 inch external fat thickness) resulted in production of mostly Select and Choice grade carcasses (98% of the resulting carcasses qualified for these two grades). Application of the prototype quality system, which involved control of genetic inputs as well as pre-harvest and post-harvest processes, reduced the expected rate of non-conformance from about 1 in 4 (23% for top sirloins, 26% for strip loins) to 1 in 25 (4%) for top sirloin steaks and 1 in 100 (1%) for strip loin steaks. Use of process control in a quality management system may be an effective approach for assurance of beef tenderness.

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