EFFECTS OF VARIOUS MANAGEMENT PRACTICES ON BEEF-EATING QUALITY

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INTRODUCTION

Raising cattle to produce safe, high quality protein for the human diet is an important element in the nutritional well-being of the world. Therefore, production practices that optimize the wholesomeness, nutritional quality and palatability of beef are all critical to consumer satisfaction. This report will focus on palatability (beef-eating quality) and those management practices that influence this outcome.

WHAT CONSUMERS WANT IN THEIR BEEF

Americans love the taste and enjoy the satisfaction of eating beef. Many Americans view eating beef, especially steak, as something they earn, and it makes them feel accomplished when they are able to purchase steak. Unfortunately, Americans also realize that not every steak they have is as tender, juicy and flavorful as the next. According to Schroeder (2000), consumers want beef that is tender, consistently high quality, convenient to prepare, healthy and nutritious, safe and competitively priced. Therefore, it is each beef producer's responsibility to do their part to produce the safest beef with the most consistent and acceptable palatability possible.

WHAT IS BEEF QUALITY?

Beef quality can be defined and interpreted many different ways. There are three main factors that make up beef quality: safety (wholesomeness), nutritional quality and palatability. There are numerous pre- and post-harvest management practices and technologies that positively affect all three of these factors. For the purpose of this report, beef quality will refer to one factor, palatability.

Palatability refers to the overall beef-eating experience which is determined by the tenderness, juiciness and flavor of the beef. While tenderness, juiciness and flavor are all important in creating the best overall eating experience, there is some controversy among meat scientists as to which factor is the most important and detectable by the consumer.

Tenderness

A strong case can be made for the importance of tenderness as it is often thought to be the key beef palatability factor and is easily evaluated by consumers. Retail price of various beef cuts is often related to differences in tenderness. For instance, muscles such as the tenderloin and loin which are known to be significantly more tender than the muscles in the round are priced higher per pound. The more tender the cut, the higher the price per pound. Ruhland (2004) and Moeller (1997) indicated that consumers would choose to eat whole muscle beef cuts more often if they knew they were tender and had a more consistent eating quality. Boleman et al. (1997) found that consumers can differentiate between different degrees of tenderness and are willing to pay for increased tenderness. However, Mintert et al. (2000) observed that, while some consumers were willing to pay a “large premium” for a “guaranteed tender steak” instead of a steak that may be tough, not all consumers who preferred a tender steak were willing to pay a premium for a more tender eating experience. Nevertheless, because tenderness among animals and beef cuts can be quite variable, it is important to be aware of the impact of management practices upon the ultimate tenderness of the final product.

Factors that affect tenderness include: the degree of muscle contraction at the time of rigor mortis, the amount of connective tissue and the activity of the muscle’s inherent enzyme systems. These factors can be overcome by postmortem aging and other chemical and mechanical treatments.

Juiciness

Juiciness is a critical trait in determining overall beef palatability. The juiciness of the beef can dictate the perception of tenderness by the consumer. In other words, higher levels of juice in a cut of beef can mask tenderness levels that are less desirable. Likewise, a tender cut of beef that lacks natural juiciness may be perceived to be less tender than it actually is. Juiciness can vary greatly. Factors that have the greatest effect on beef juiciness include: ultimate pH, fat content, marination, cooking method and degree of doneness.

Flavor

Flavor is also an important component of beef palatability. The National Beef Customer Satisfaction Survey II (NCBA, 1998) concluded that flavor is the most important palatability characteristic to consumers. Beef flavor can vary greatly due to a number of factors ranging from breed type, to cattle diets or even meat processing / aging techniques.

MEASURING VARIABILITY IN PALATABILITY

Tenderness, juiciness and flavor can vary greatly among and within beef because of the several biochemical properties that affect these traits. Tenderness is the most easily measured factor of beef palatability. There are two primary methods utilized to assess tenderness: 1) Warner-Bratzler shear force (WBSF) and 2) sensory analysis.

Warner-Bratzler shear force is an objective measure of the peak force (measured in pounds or kilograms) needed to cut through the muscle fibers. Sensory analysis is often used as a measure of tenderness, and may be conducted using either a trained panel or a consumer panel. A third method, “Slice Shear Force,” has been developed and has been cited as being more rapid and technically less-difficult to conduct than WBSF (Shackelford et al. 1999).

PRE-FEEDLOT MANAGEMENT

Breed selection

Perhaps the most important producer decision influencing meat quality is the genetic inputs of cattle. There is a large body of research which indicates this decision carries a great deal of impact in determining ultimate meat quality. While several specific breeds have desirable traits, most commercial cattle are crosses of pure breeds. Crossbreeding to positively influence several production traits is now almost universally practiced in commercial cattle breeding. Classical examples of some of the more successful beef-cattle crosses are those utilizing *Bos taurus* (English and Continental Breeds) and *Bos indicus* breeds. The improvement in production traits from these crosses, however, may have a negative impact on beef tenderness. The early work of Ramsey et al. (1963) demonstrated a tenderness advantage for the *Bos taurus* breeds over the *Bos indicus* breeds. This work has subsequently been validated (Crouse et al. 1989). While the infusion of *Bos indicus* has increased productivity and profitability, its practice among many commercial cattle raisers in the southern United States has resulted in the general decline of beef tenderness.

Scientists have determined that the major reason for the differences in tenderness is the suppression of the inherent tenderizing enzyme systems among *Bos indicus* cattle. This suppressing protein, calpastatin, is found at higher levels in *Bos indicus* cattle and results in higher shear force values and lower tenderness scores for beef cuts from these cattle. While aging beef seven days or more postmortem will reduce this effect, it was observed by Whipple et al. (1990) that net results tend to favor cattle that have a lower percentage of *Bos indicus* breeding. Some experts recommend the level of *Bos indicus* breeding be restricted to three-eighths or less to balance the positive effects of heterosis with the negative effect on tenderness.

There is also some evidence that *Bos taurus* cattle of Continental European breeding may also be less tender. The NCBA Strategic Alliances study found that British breed types had more desirable flavor, tenderness and palatability ratings than Continental breeds. The same was true for WBSF values, with the Continental breeds having higher shear values, particularly within the USDA Select grade.

Table 1. WB shear force values for three-eighths *Bos indicus* vs. full-blooded *Bos taurus* steers harvested at a constant fat thickness (11 mm). [Adapted from Connor et al. (1997)]

Postmortem Aging Time, Days	**Three-eighths *Bos indicus***	***Bos taurus* only**
	Warner-Bratzler Shear Force Values, kg (%>3.85kg)	
1	3.76 (47%)	3.55 (30%)
4	3.37 (35%)	2.77 (6%)
7	3.18 (25%)	2.53 (2%)
14	2.80 (10%)	2.23 (1%)
21	2.49 (2%)	2.13 (0)
35	2.24 (2%)	1.97 (0)

The elimination of *Bos indicus* cattle from a breeding program in the southern United States is not practical, since it would eliminate the desirable breed effects of heterosis and heat resistance. However, to reduce the possibility of less tender meat, *Bos indicus* breeding should not exceed three-eighths of the animal's genetic composition. Moreover, care should be exercised when selecting breeding animals, utilizing those that excel in production traits and may have a positive influence upon carcass traits that influence palatability.

Castration of male calves

Castrating male calves has been shown to have a positive influence on the carcasses from those animals. If the male is left intact until maturity, it will grow more rapidly and be leaner, but it will have a lower quality grade, primarily because of a lower marbling score (Heaton et al., 2006). The timing of the castration also has an impact on tenderness with weaned castrates having higher consumer acceptance than late castrates (Heaton et al., 2006). Furthermore, intact males have a more aggressive disposition which can cause problems in a confined feeding situation. Therefore, the National Cattlemen's Beef Association's Beef Quality Assurance Task Force encourages early castration to enhance beef quality.

Age at weaning

The age of the calf at weaning is important because it influences the age of the animal at the time of harvest. Six to 8 months is generally considered a reasonable age to wean a calf and still have potential grazing productivity and feedlot growth. Postponing weaning beyond 8 months may result in an undernourished calf, if the cow is unable to sustain a lengthy lactation. In fact, there is evidence that pre-weaning gain is reduced after 3 months of age because of reduced lactation (Neville, 1962; Robinson et al. 1978). The calves' advanced age can also result in an eventual lower carcass grade and less tender meat.

Early weaning has shown some promise as a production practice. Research comparing three weaning ages of 90 days (±13 days), 15 days (±13days) and 215 days (±13 days), indicated that early weaning at 90 or 152 days did not reduce carcass factors related to beef palatability (Myers et al., 1999).

Pre-feedlot summary

The assessments of pre-feedlot factors that influence beef palatability are listed in Table 2. Any discussion of the influence of pre-feedlot management upon the ultimate palatability of beef must recognize that the average U.S. cow herd is less than 50 head (USDA, 2002, 2007), reducing the impact a single producer has on beef quality. Therefore, any strategy for attaining the highest beef-eating quality must rely on all segments of the industry doing their very best to make a positive influence

Table 2. Assessment of pre-feedlot factors that influence beef palatability

Factors	***Tenderness***	***Juiciness***	***Flavor***	***Overall Acceptability***
Breed Selection	High	Moderate	Moderate	High
Castration of Male Calves	Moderate	Moderate	Moderate	Moderate
Animal Health (Preconditioning)	Low	Low	Moderate	Low
Age at Weaning	Moderate	Low	Moderate	Moderate
Stocker Management	Moderate	Moderate	Moderate	Moderate
Implant Program	Moderate	Moderate	Moderate	Moderate

FEEDLOT MANAGEMENT

Animal health

The health of the animal is critical to the final beef-eating quality. Animals that have been sick prior to placement in the feedlot have a slower growth rate, lower carcass grades and potentially less palatable beef (Montgomery et al., 1984). Preconditioning calves and yearlings prior to placement in the feedyard reduces feed lot morbidity. Preconditioning includes appropriate vaccinations, parasite control and adequate nutrition. Because of the positive correlation between animal health during the finishing period and carcass quality and palatability, preconditioning is recommended.

It has been well established by Gardner et al. (1999), McNeill et al. (2001, 1996), and Waggoner et al. (2006) that morbidity has a negative impact on feedlot performance and carcass quality. Gardner et al. (1999) observed that morbidity caused lowered daily gains, increased percentage of carcasses that graded USDA Standard and produced tougher steaks. Steers with lung lesions from pasteurellosis produced tougher steaks than did healthy steers according to Warner-Bratzler shear force values (Gardner et al., 1999). McNeill et al. (2001) found that healthy feedlot cattle graded USDA Choice 17 percent more often than did unhealthy cattle. Finally, Waggoner et al. (2006) documented that unhealthy cattle (treated more than once while in the feedlot) had a reduced carcass value of $14.00 per cwt. In short, cattle with poor health grow more slowly, have lower quality grades and possibly have lung lesions that would render the carcass less valuable.

Time on feed and nutrition program

Stocker management. The length of time on pasture and the nutritional level of the pasture play a role in stocker cattle's ability to produce a quality carcass. Researchers have demonstrated that calf-finished steers produce carcasses superior in quality and palatability compared to yearling-finished steers (Brewer et al., 2007). However, Klopfenstein et al. (1999) also found calf-feds to be more tender, but noted that if cattle are fed to a common rib-fat end point, with reasonable rates of summer and winter gains, little effect on marbling or carcass quality grade was realized. Brewer et al. (2007) concluded that growing genetically similar steers for a longer period of time on forage with a short finishing period resulted in heavier carcasses with lower quality grades and initially tougher, less palatable beef. When fed to a common fat thickness end point, steers finished as calves spent more days in the feedlot and produced a more desirable beef product, while yearling steers are more likely to produce less tender beef.

Feedlot nutrition. The amount of time that an animal is fed a high concentrate diet affects the eating quality of the meat. As time on feed increases, marbling, fat thickness, loin muscle area, carcass weight and yield grade increase (Tatum et al., 1980; May et al., 1992). May et al. (1992) found that tenderness increases curvilinearly with days on feed (Figure 1). Tatum et al. (1980) reported that increasing feeding time from 100 to 160 days had a beneficial effect on flavor desirability, but did not significantly affect juiciness, tenderness or overall palatability. Extending time-on-feed beyond 100 days (steers) and 90 days (heifers) provided little additional palatability assurance (Dolezal et al., 1982).

In addition to the length of time on feed, the type of feed is also critical to meat palatability. Studies have shown that the longer cattle are finished on grain, the more tender their beef becomes (Bennett et al., 1995; Leander et al., 1978). Numerous consumer sensory studies have indicated that the flavor of grass-fed beef is much less desirable than that of grain-fed beef (Dolezal et al., 1982; Larick et al., 1987; Melton et al., 1982a, 1982b; Skelly et al., 1978). The flavor difference has been attributed to the difference in the composition of the fat (Larick et al., 1987; Melton et al., 1982b). The fatty acid composition of the muscle and fat in the animals that are fed a diet high in polyunsaturated fatty acids, such as that of grass and other forages, is different from animals fed a grain diet. Research results have described the flavor of grass-fed beef as having an intense milky-oily, sour and fishy or grassy flavor (Larick et al., 1987).

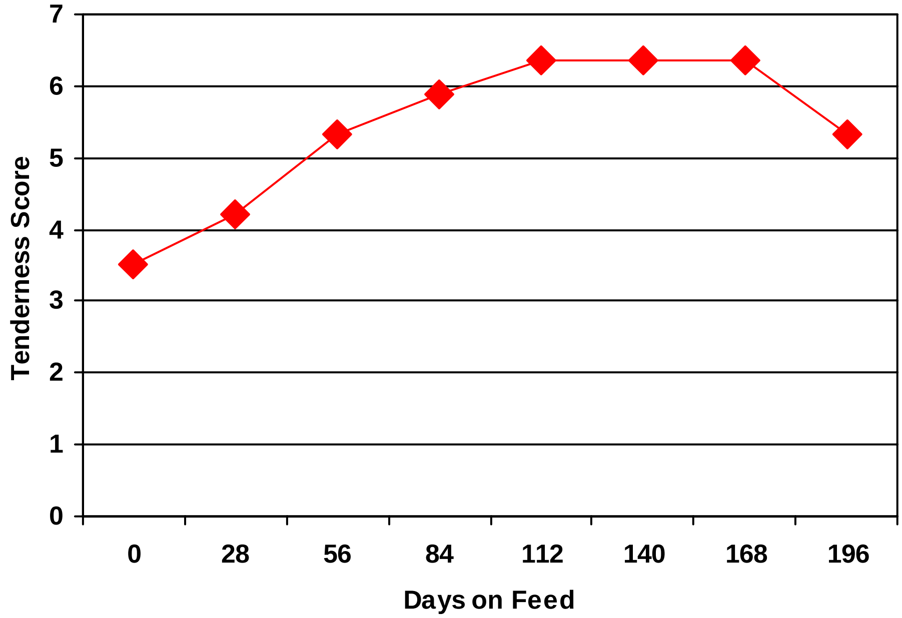

Figure 1. Tenderness according to time on feed (May et al., 1992)

Incorporation of distiller's grains (DG) into cattle diets has increased over the past several years as the milling of corn is on the rise. There has been concern that feeding DG may have an effect on beef quality. According to Roeber et al. (2005), feeding DG at up to 50 percent of the dietary dry matter (DM) did not affect tenderness or sensory traits. It seems to be a viable feed alternative that does not negatively impact sensory attributes.

Research has been conducted to determine if supplementing vitamin D in cattle rations affects beef palatability. The active form of vitamin D (1, 25-dihydroxyvitamin D_3) increases serum calcium concentrations in the body. Calcium is necessary to activate the natural tenderization processes that occur in beef postmortem. Research has been conducted to evaluate the effect of feeding vitamin D to cattle within the last week of life in order to increase calcium concentrations, resulting in the activation of proteolytic enzymes that improve meat tenderness (Morgan, 2007). The effects of vitamin D supplementation to improve meat tenderness have been mixed, making commercial application premature at this time (Morgan, 2007).

Implant programs

Pre-feedlot. The use of anabolic implants prior to entering the feedlot is widely practiced. Implants during the pre-feedlot phase improve weight gain significantly which impacts profitability. However, there is evidence that repeated and multiple implants can result in diminished meat quality (Platter et al., 2003). It would, therefore, be prudent to limit the number of implants in pre-feedyard cattle, especially those destined for a specific branded beef program that places a high premium on quality grade and tenderness.

Feedlot. It is widely recognized that the use of anabolic implants in beef cattle offers the greatest return on investment outside of ensuring the cattle receive adequate nutrition (Montgomery et al., 2001). Since the first use of anabolic implants in 1947, it has been well recognized that anabolic implants improve growth rate, feed conversion, and protein deposition in cattle under both experimental and commercial conditions (Samber et al., 1996; Duckett et al., 1997). Furthermore, the use of anabolic implants results in increased carcass weight (Roeber et al., 2000; Hermesmeyer et al., 2000) and increased longissimus muscle area and carcass muscle yield in cattle (Johnson et al., 1996a,b; Roeber et al., 2000). Despite these positive responses, evidence exists that some eating quality may be sacrificed through the excessive use of anabolic implants. Morgan (1997) concluded that the percentage of carcasses grading USDA Choice was decreased by 5 percent with a mild estrogen implant and by 25 percent with trenbolone acetate containing implants.

There are currently 31 different FDA-approved commercial implants available for use in the U.S. (Table 3). Hormonal implants are approved for use in cattle of all ages and may be used to enhance growth during the suckling, growing and finishing phases of production. Steers and heifers may be implanted several times during their lifetime (Platter, 2003). Implants are classified by the hormones they contain (estrogen, androgens or progestins) and dosage of the active ingredient(s) (Montgomery et al., 2001). Implementation of implant strategies has evolved as beef producers work to maximize returns on investment through all stages of production (Montgomery et al., 2001). From a practical standpoint, implants are used to extend the accelerated portion of the growth curve thus improving the potential for growth (Figure 2). Because the growth curve is extended, it is necessary to feed cattle to heavier weights to achieve the same body composition and USDA grade of non-implanted cattle.

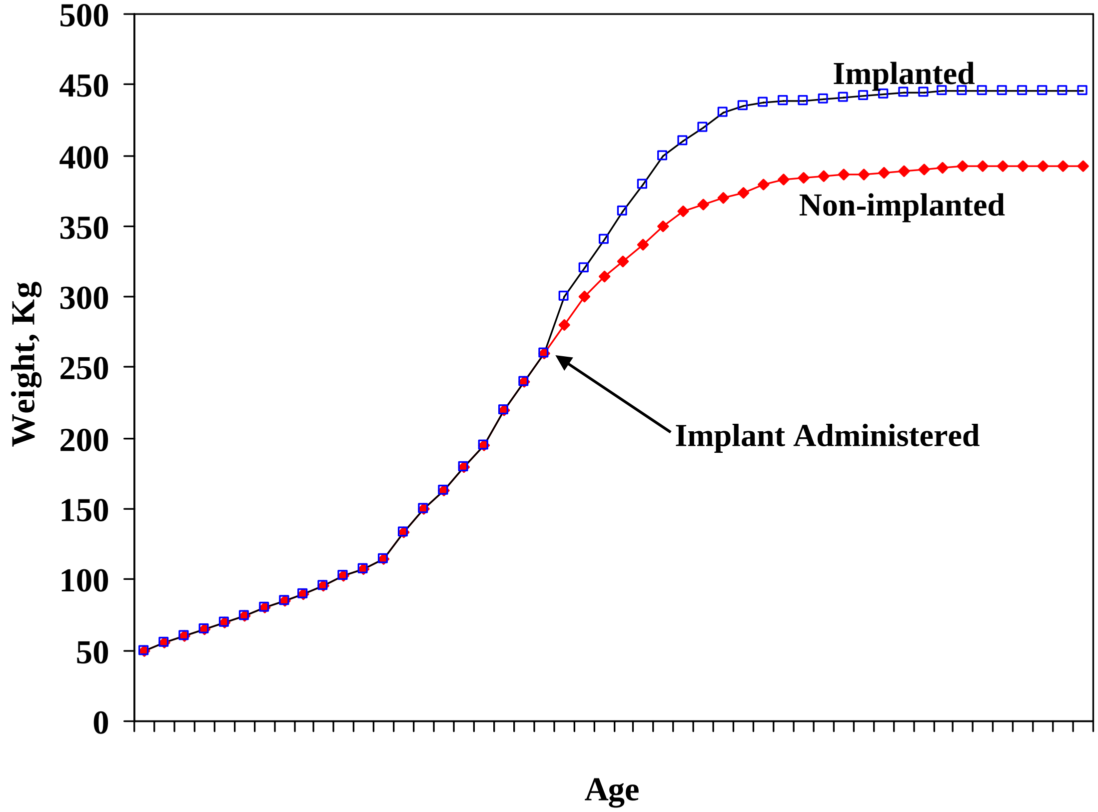

Figure 2. The effect of implanting on the growth curve

Table 3. Hormonal growth promotants currently registered for use in beef cattle in the U.S. by active ingredient, hormone content, registered trade name and type of cattle intended for use.

Ingredient	Hormone content (mg)	Trade Name	Cattle Intended For[a]
SINGLE INGREDIENT IMPLANTS			
Estradiol[1]	43.9	Encore	S/H/SK/PC
Estradiol[1]	25.7	Compudose	S/H/SK/PC
Zeranol[1]	36.0	Ralgro®	ALL
Zeranol[1]	72.0	Ralgro Magnum®	S
Trenbolone Acetate[2]	140	Component® T-S	S
Trenbolone Acetate[2]	200	Finaplix®-H Component® T-H	H
COMBINATION INGREDIENT IMPLANTS			
Estradiol benzoate*[1] Progesterone[3]	10 100	Synovex®-C Component® E-C	C/S/H
Estradiol benzoate*[1] Progesterone[3]	20 200	Synovex®-S Component® E-S	S/SK/PC
Estradiol benzoate*[1] Testosterone Propionate[2]	20 200	Synovex®-H Component® E-H	H/SK/PC
Estradiol[1] Trenbolone Acetate[2]	24 120	Revalor®-S Component® TE-S	S
Estradiol[1] Trenbolone Acetate[2]	14 140	Revalor®-H Component® TE-H	H
Estradiol[1] Trenbolone Acetate[2]	8 40	Revalor®-G Component TE-G	S/H/SK/PC
Estradiol benzoate*[1] Trenbolone acetate[2]	28 200	Synovex® Plus	S/H

Estradiol[1] Trenbolone Acetate[2]	16 80	Component®TE-IS Revalor-IS	S
Estradiol[1] Trenbolone Acetate[2]	8 80	Component® TE-IH Revalor-IH	H
Estradiol[1] Trenbolone Acetate[2]	20 200	Component®TE-200 Revalor 200	S
Estradiol Benzoate* Trenbolone Acetate[2]	14 100	Synovex Choice	S
Estradiol[1] Trenbolone Acetate[2]	40 200	Revalor®- XS	S

[a] S = steers, H = heifers, S/H = steers and heifers, SK = stockers, PC = pasture cattle, C = suckling calves to 182 kg.
*Estradiol benzoate contains 71.4% estradiol
** Zeranol is 31-36% active estrogen
[1]Estrogen group
[2]Androgen group
[3]Progestin group

Producers use a variety of different implant strategies including the number of times the animal receives an implant during its lifetime and at what stages of growth the implant is administered. Numerous research studies suggest that “aggressive” and/or repetitive use of implants may be detrimental to beef carcass quality and tenderness (Tatum, 1993; Morgan, 1997; Roeber et al., 2000; Schoonmaker et al., 2001 – as cited by Platter et al., 2003). However, Schoonmaker et al. (2001) found that implanting cattle two or three times did not affect quality grade compared with cattle that received no implant. These data suggest that implant programs can be managed to minimize the impact of this technology on beef eating quality.

Melengesterol acetate (MGA®, HeifermaX®) is fed to feedlot heifers as a heat suppressant. Melegestrol acetate is a progestin which acts as a growth prompting agent. When it is fed during the finishing period, it enhances endogenous estrogen production and growth (Bloss et al., 1966; Hutcheson et al., 1993). While researchers report varying results depending upon the implant combination used, it appears that carcass grade, dry matter intake (DMI) and average daily gain (ADG) may be positively influenced with the addition of melengestrol acetate to the finishing diet (Macken et al., 2003). It is also effective in reducing the level of dark cutters among feedlot heifers (Montgomery, 1992).

Beta agonists

The introduction and use of beta adrenergic agonists (beta agonists) in the United States offers the possibility of improving the lean muscle yields of beef carcass thus improving beef production efficiency. Currently, two beta agonists are available to cattle feeders: ractopamine hydrochloride (Optaflexx®) and zilpaterol hydrochloride (Zilmax®). Both are effective in improving lean carcass yields. However, improvements in carcass composition have also been associated with a slight decrease in meat sensory parameters and an increase in meat shear force (Schroeder et al., 2003a; Leheska et al., 2007).

The β_1-agonist, ractopamine hydrochloride (Optaflexx®) has been shown (Table 4) to increase beef longissimus muscle Warner-Bratzler shear force and decrease initial and sustained sensory tenderness scores when supplemented at approximately 300 mg/animal/day (Schroeder et al., 2003a). However, this and several additional studies have demonstrated that Optaflexx does not impact beef tenderness when fed at the recommended levels of 200 mg/animal/day (Dunshea et al., 2005; Laudert et al., 2004; Platter et al., 2007).

Table 4. Effects of Optaflexx® on sensory variables and Warner Bratzler shear force tests of strip loin steaks (Schroeder et al., 2003) [a]

Variables	Optaflexx®, mg/hd/day				
	0	**100**	**200**	**300**	**SE**
No. of samples	90	90	90	90	
Cooking loss, % [b]	21.5	21.5	21.0	21.8	0.13
Ultimate pH of fresh muscle	5.56	5.54	5.56	5.56	0.01
Warner-Bratzler shear force, lb	7.8	7.7	8.0	8.7*	0.35
Juiciness [c]	104.6	104.5	106.0	103.3	1.6
Initial tenderness [d]	111.7	110.7	111.5	106.0*	1.18
Sustained tenderness [d]	101.8	100.5	100.3	95.2*	1.8
Flavor	90.3	89.0	90.5	88.7	1.7
Off-flavor [e]	0.252	0.222	0.156	0.157	0.098

a Least Squares Means
b Cooking Loss = [(raw weight-cooked weight)/ raw weight]X 100
c Juiciness evaluation: 0= not juicy, 150 = very juicy
d Tenderness evaluation: 0= not tender, 150 = .very tender
e Flavor/ off flavor evaluation: 0 + none, 150 = intense
* P<.05 compared to controls

Similar studies conducted with zilpaterol hydrochloride have shown increases in beef longissimus muscle shear force and decreases in sensory tenderness scores (Strydom et al., 1998; Strydom and Nel, 1999). However, work reported by Hilton et al. (2007) indicates that aging from 14 to 21 days will reduce differences in tenderness as compared to controls (Table 5). Hilton et al. (2007) reported that there was no difference in consumer acceptability of tenderness between controls and beef from cattle fed Zilpaterol (Table 6).

Table 5. Effects of Zilmax® on Warner-Bratzler shear force (WBSF) of longissimus muscle (LM) at 7, 14 and 21 days postmortem[a]

Item	Control	Zilmax®	SEM	Pr > F[b]
7 days postmortem WBSF, kg	3.66	4.70	0.12	0.001
14 days postmortem WBSF, kg	3.60	4.00	0.07	0.001
21 days postmortem WBSF, kg	3.18	3.45	0.05	0.002

[a]Data source: Hilton et al., 2007.
[b]Probability of an effect of Zilmax®. There was an aging × zilpaterol interaction ($P<0.05$) for WBSF.

Table 6. Effects of Zilmax® on consumer sensory panel scores of longissimus muscle (LM) at 14 days postmortem[a]

Item	Control	Zilmax®	SEM	Pr > F[b]
Overall acceptability, % acceptable [c]	92.4	94.4	1.33	0.41
Tenderness acceptability, % acceptable [c]	89.1	92.8	1.87	0.29
Overall quality [d]	6.37	6.19	0.07	0.07
Beef flavor [d]	6.29	6.22	0.07	0.43
Juiciness [d]	6.02	5.87	0.08	0.17
Tenderness [d]	6.25	6.00	0.08	0.03

[a]Data source: Hilton et al. (2007). There were a total of 564 consumers who participated in the study.
[b]Probability of an effect of Zilmax®
[c]Acceptability scores were acceptable or unacceptable.
[d]Sensory scores were on an 8-point scale: 1 = extremely dislike, uncharacteristic beef flavor, extremely dry, extremely tough; 8 = extremely like, extremely characteristic beef flavor, extremely juicy and extremely tender.

Antemortem stress

The amount of short-term and long-term stress an animal is subjected to prior to harvest can affect meat quality by increasing the animal's body temperature and decreasing the amount of glycogen stored in the muscle. There are several variables that can influence the amount of stress to the animal. Temperament can vary greatly among animals with some being more aggressive than others. More aggressive animals are difficult to handle which increases stress. When an animal is stressed immediately antemortem, their body temperature increases. This increase leads to accelerated metabolism in the muscle postmortem.

The time and distance transporting the animal from the feedyard to the packing plant also has an effect on meat quality. The longer the transport time, the more glycogen the animal will use. Glycogen depletion will also happen if animals are held for an extended time at the packing plant prior to harvest. Animals generally do not have access to feed once they leave the feedyard; therefore, there is no way for them to regain the glycogen they are using from their muscle. Lower levels of glycogen in the muscle reduce postmortem metabolism resulting in higher ultimate pH of the meat which causes darker colored lean tissue with less desirable eating quality (Wulf et al., 2002).

Feedlot summary

The assessment of feedlot practices that influence beef palatability are listed in Table 3. This important phase of cattle production has the potential to greatly influence beef palatability.

Table 7. Feedlot practices that influence beef palatability

Factors	***Tenderness***	***Juiciness***	***Flavor***	***Overall Acceptability***
Time on feed	High	Moderate	Moderate	Moderate
Feedlot health	Moderate	Low	Low	Moderate
Implant program	Moderate**	Moderate	Moderate	Moderate
Beta-agonists* **	High**	Moderate	Moderate	Moderate
Antemortem stress	Moderate	Low	Low	Low

*** High**–Significant impact on final palatability; **Moderate** – intermediate impact; **Low** – little or minor impact
****** Dependent on strategy and compounds used
*** The effect of postmortem aging would reduce this impact to moderate (14 days) or even low (21 days)

POSTMORTEM MANAGEMENT

Early postmortem

The conversion of muscle to meat is a complex biochemical process that occurs soon after harvest. Many factors affecting ultimate meat quality are determined during this process. The conversion of muscle to meat begins when blood circulation ceases during the harvest process. With no circulation, transport of oxygen and other nutrients to the muscles ceases. Even so, metabolism continues in the muscle due to natural physiologic mechanisms in the body. Postmortem metabolism continues to occur as long as there is enough glycogen (carbohydrate stored in muscle) and ATP (energy source) available. After harvest, glycogen and ATP cannot be synthesized in the body and will eventually be depleted causing postmortem metabolism to cease. As postmortem metabolism occurs in the absence of circulating blood, lactic acid builds up in the muscle which causes the pH of the muscle to decline (more acidic).

There are two main factors that determine the extent of postmortem metabolism and the ultimate meat pH: 1) amount of glycogen in the muscle at the time of death (glycolytic potential or GP) and 2) temperature. Both of these factors can be affected by pre-harvest management factors such as breed type and stress level of the animal.

The ultimate pH of the meat determines the meat color, water-holding capacity and texture, all of which affect the meat quality. The lower the pH falls, the more proteins are denatured causing them to open up and release the water that was bound to them (the natural juices). This leads to paler-colored lean tissue and a drier meat product when cooked. When the ultimate pH is high, little protein denaturation occurs. Therefore, the protein continues to hold on to the water which makes the lean tissue darker color and the meat juicier. Muscle color, ultimate pH and tenderness are interrelated. Dark cutting beef is a serious quality defect which is caused by a high ultimate pH resulting in a very dark color lean and tougher meat. Furthermore, dark cutting beef has a high water activity, thereby increasing the probability for the meat to take on off-flavors from the environment and to harbor and grow bacteria. In general, higher glycolytic potential (GP) is associated with increased tenderness; and lower GP is indicative of DFD (dark, firm and dry or dark cutting) beef which is less palatable (Wulf et al., 2002).

Chilling rate

The rate at which a beef carcass is chilled postmortem affects the ultimate pH which also influences beef quality. Chilling rates that are too fast will result in tougher meat, whereas chill rates that are too slow cause increased protein denaturation resulting in less juicy meat. The optimum chilling rates would create a pH of 6.0 when the muscle is 85° F (Wulf, 2006).

In his classic paper, Locker (1960) demonstrated the negative effect on tenderness when carcasses are subjected to rapid chilling. This phenomenon known as “cold shortening” has since been demonstrated by a number of researchers: Locker and Hagyard (1963); Herring et al. (1965a.b.); Marsh and Leet (1966); Davey et al. (1967); and King et al. (2003). The negative effect of cold shortening can be alleviated with the electrical stimulation of the pre-rigor carcass.

Electrical stimulation

Electrical stimulation involves passing an electric current through the carcass of freshly harvested animals (Jensen et al., 2004). Electrical stimulation of beef carcasses postmortem speeds up pH decline and increases tenderness. The goal should be to lower the pH as rapidly as possible as optimum tenderness occurs when pH is 5.8 to 6.0 at 1.5 hours after death (Wulf, 2006). High voltage has a greater effect than low voltage electrical stimulation which may cause physical tearing of the muscle (Wulf, 2006). The magnitude of reduction in muscle pH is governed by the muscle fiber type, initial glycogen stores within the muscle, the electrical characteristics (current, frequency, pulse shape and stimulation duration), the temperature of muscle, and the time after death at which stimulation is applied (Jensen et al., 2004). There is considerable evidence that electrical stimulation will enhance the quality of beef mainly by improving tenderness (Hwang and Thompson, 2001; White, 2006; Ferguson, 2000). Devine et al. (2004) stated that the improvement of tenderness through electrical stimulation is greatest when the carcass is rapidly chilled to reach temperatures close to 15° C. They also indicate that electrical stimulation does not improve inherently tender meat beyond base line toughness or improve upon tenderness achieved from such procedures as tenderstretch, a technique used to lengthen the pre-rigor muscle to achieve a less contracted, more tender, post-rigor muscle. The mechanism involved in the tenderization is thought to be caused by enzymatic activity or by disruption of the muscle's ultra structure, in addition to the prevention of cold shortening (White et al., 2006).

Postmortem aging

Postmortem aging is the process of holding meat at refrigerated temperatures for an extended time in order to allow natural tenderization processes to occur. There are two types of postmortem aging: 1) dry aging and 2) wet aging. In dry aging, whole carcasses or wholesale cuts (without any covering) are held in a room with controlled temperature, humidity and wind velocity. Wet aging is the process of aging meat in vacuum packages under refrigeration. The natural tenderization effects of dry aging and wet aging are equal, but a flavor difference is possible. Dry aging typically produces beef that has more of a beefy/brothy flavor while wet aging can sometimes produce a livery flavor due to the nature of the packaging.

The majority of the natural meat tenderization process occurs in the first 14 days postmortem. The natural tenderization process that occurs during this stage is due to the proteolytic enzyme, calpain, which degrades the muscle fibers. Calpain requires calcium to be activated and degrade protein. Calpastatin inhibits calpain activity. Therefore, the level of calpastatin present in comparison to calpain determines the ability for protein degradation. Although the majority of protein degradation occurs within the first 14 days postmortem, the breakdown of connective tissues does not occur until after two weeks of aging.

According to the National Beef Tenderness Surveys, the average aging time of retail beef has increased over the years (Table 1). In 1999, 34 percent of retail subprimal cuts were aged less than 14 days, and, according to the 2005 survey, 20 percent of retail subprimals were aged less than 14 days. Figure 3 illustrates the percentage of beef that is tough (WBSF > 3.85 kg, or > 8.64 lbs) as postmortem aging days increase (Wulf et al., 1996). This graph shows the improvement in tenderness as a result of postmortem aging up to and over 14 days postmortem.

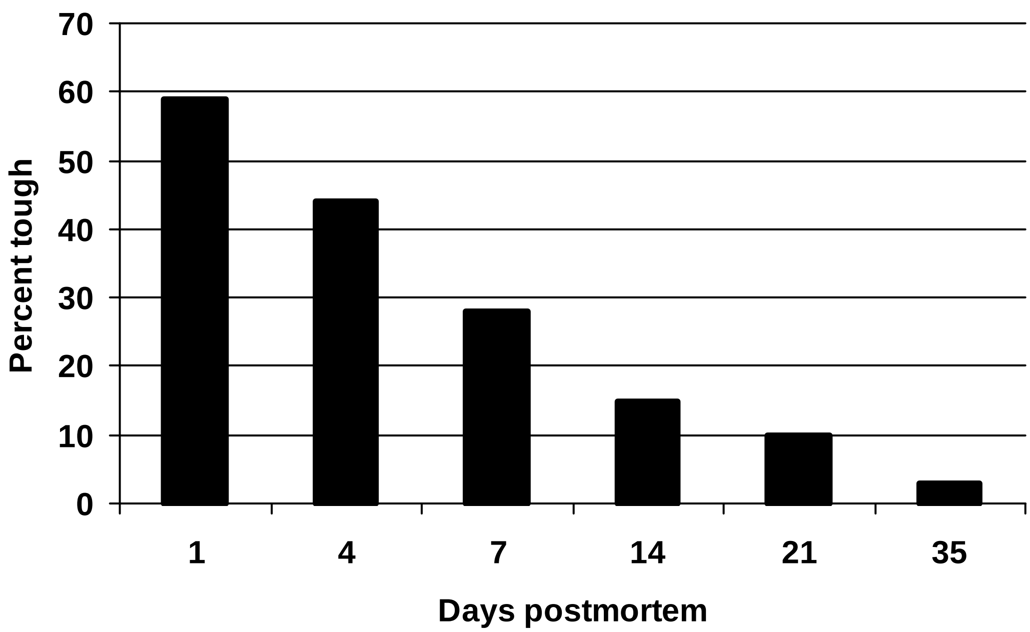

Figure 3. The percentage of beef that is tough (WB Shear Force > 3.85kg; or > 8.64 lbs) as postmortem aging days increase (Wulf et al., 1996).

Product enhancement

There are three main types of product enhancement (mechanical, enzymatic and marinating) utilized by the beef industry to enhance eating quality and consistency and add value to beef cuts.

Mechanical. Two types of mechanical tenderization are utilized in the meat industry: 1) needle tenderization (blade tenderization) and 2) cubing through a rotary steak macerator (Romans et al., 1994). Needle tenderization utilizes many small needles which pierce the meat simultaneously, severing muscle fibers and connective tissue (collagen) making the meat more tender. Jeremiah et al. (1999) found that when the inside round was mechanically tenderized, the desirability of flavor was improved by 16 percent, while the perceived tenderness of the samples initially rated as tough were improved by 32 percent. Similarly, another study showed that mechanically tenderized top sirloin steaks had lower Warner-Bratzler shear force values compared to steaks that were not (George-Evins et al., 2004). Mechanical tenderization can be effectively utilized to reduce the variability and improve the tenderness and palatability of certain muscles, particularly hip muscles (Jeremiah et al., 1999). Needle tenderization is also used to inject solutions into the meat to incorporate enzymatic and chemical tenderization processes.

Enzymatic. Plant, fungal and bacterial enzymes can act as proteolytic enzymes and improve meat tenderness. The most commonly used proteolytic enzymes are papain, bromelain, and ficin which are derived from papaya, pineapple and fig, respectively (Romans et al., 1994). Three types of proteins are degraded in the meat tenderization process: muscle, collagen (heavy connective tissue) and elastin. Degradation of muscle proteins primarily occurs in the first 7 days postmortem, while the degradation of collagen and elastin is a much slower process. Therefore, enzymes which are able to stimulate the degradation of collagen and elastin are important to further enhancing the tenderization process.

Papain is the most widely used of the three enzymes presented, but it has the least degradative effect on collagen (Romans et al., 1994). Bromelain has the ability to degrade collagen (Miyada and Tappel, 1956; Kang and Rice, 1970; Foededing and Larick, 1986), but has the least degradative effect on muscle fibers and elastin (Romans et al., 1994). Ficin is effective at degrading collagen and elastin, and it also has the greatest degradative effect on myofibrillar proteins of the muscle fiber (Romans et al., 1994). Proteolytic emzymes are not widely used because over-tenderization may occur.

Marinating. Marinating meat products has become an efficient and economical way for the industry to enhance beef palatability and consistency and add value. Marinades can be applied by needle injectors or vacuum tumbling.

Vote et al. (2000) found that injecting beef strip loins with solutions containing sodium tripolyphosphate, sodium lactate and sodium chloride offers potential for enhancing tenderness, juiciness and flavor of beef, particularly Select and low Choice steaks cooked to a high degree of doneness.

Marinating with calcium salts is another option as it is known that calcium (Ca^{2+}) improves meat tenderness. Calcium activates the calpain (Ca^{2+} dependent) proteolytic system that hydrolyzes key structural myofibrillar proteins during postmortem aging (Whipple and Koohmaraie, 1992). Scientists have found that calcium chloride ($CaCl_2$) can be injected into the muscle or meat during different periods (within 24 h, after 48 h, or after freezing) postmortem in order to improve tenderness (Wheeler et al., 1992; Whipple and Koohmaraie, 1992; Kerth et al., 1995).

Steaks marinated with $CaCl_2$ were rated higher than control steaks for tenderness, juiciness and flavor by restaurant (Hoover et al., 1995) and retail consumers (Miller et al., 1995). Moreover, Carr et al. (2004) reported that consumers could differentiate tenderness levels and were willing to pay a premium for $CaCl_2$-marinated steaks.

Other calcium salts (calcium ascorbate and calcium lactate) have been found to be just as effective at improving tenderness of beef longissimus muscle as calcium chloride (Lawrence et al., 2003). Lawrence et al. (2003) determined that calcium lactate provided the best overall effect in terms of tenderness, palatability, display color life and microbial inhibition.

Cooking/degree of doneness

Despite all the industry effort toward producing a tender palatable product, there is the very real possibility that the final preparation of a cut will determine ultimate consumer satisfaction. The most common cooking error is over-cooking. It has been demonstrated by several researchers that tenderness decreases as final cooking temperature increases (Cover et al., 1962; Parrish et al., 1973; Cross et al., 1976). Over-cooking also has a negative impact on juiciness and overall acceptability. Wheeler et al. (1999) studied the interaction of tenderness and cooking temperatures and found that final cooking temperature did not interfere with the consumer's ability to distinguish a tender steak, but he noted that as the degree of doneness increased, the consumer's ability to accurately classify a tender steak, was diminished. In the final analysis, it should be noted that even if every effort is made to ensure a cut is tender, if the final cooking is inadequate, all previous efforts may be wasted.

The assessment of post-harvest practices that influence beef palatability are given in Table 4.

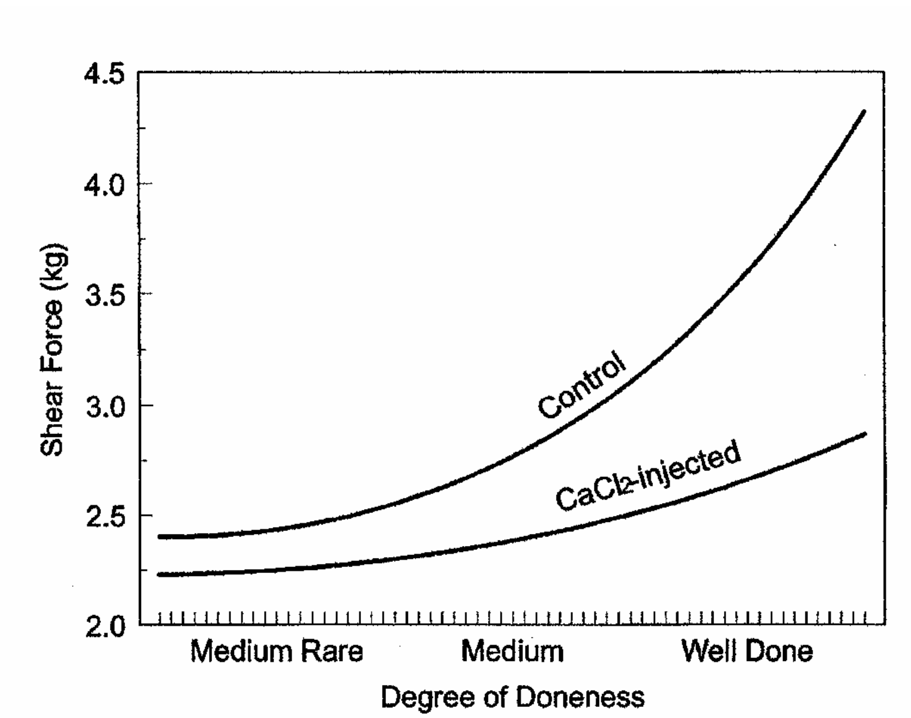

Figure 4. Effects of calcium chloride injection and degree of doneness on shear force of cooked steaks (RSD = 1.58) (Wulf et al., 1996).

Table 8. Assessment of post-harvest practices that influence beef palatability*

Factors	***Tenderness***	***Juiciness***	***Flavor***	***Overall Acceptability***
Electrical Stimulation	Moderate	Moderate	Neutral	Moderate
Chill Rate and Temperature	High	Moderate	Neutral	Moderate
Postmortem Aging Time	High	Low	Moderate	High
Muscle Stretching	High	Neutral	Neutral	High
Enhancement/Marination	Very High	Very High	Low	Very High
Cooking Method	High	Moderate	Very High	Very High
Degree of Doneness	High	Very, Very High	High	Very High

*** High** – Significant impact on final palatability; **Moderate** – intermediate impact; **Low** – little or minor impact; **Neutral** – no impact.

IMPLICATIONS

The impact of management practices from the cow-calf producer through the restaurant or retail supermarket involves the complex interactions of many factors. For example, breed selection and the decision to graze weaned calves until they are yearlings are both management practices which impact ultimate palatability; but the extent of their impact can be significantly altered by other management practices such as poor harvesting techniques or improper cooking. In this paper, the authors have highlighted key management practices and their impact on beef palatability.

Consistent management practices and an appreciation of their impact on beef palatability are important in the production of high-quality beef. The feedlot industry, as the last phase of the production cycle, provides a system to standardize production practices and make a significant contribution to the production of quality beef.

Feedyard managers should consider management practices that will minimize variation in beef palatability. Cattle feeding, with its high level of nutrition, by its very nature is one such practice. Those feeding management practices that result in greater efficiency and monetary returns, but may result in slightly lowered palatability, should be judiciously implemented, but not abandoned.

The harvesting and merchandising of cattle from multiple sources and genetic backgrounds is a daunting task. Processing plants that usually sort carcasses by USDA grade and weight, plant specifications or branded beef program specifications are now attempting to identify carcasses that have the potential for superior palatability. But, in spite of all these efforts, some carcasses still have inferior eating quality. Aging, mechanical and enzymatic tenderization as well a chemical interventions offer the greatest possibility for improving of beef products. However, ultimately, the quality and consistency of beef is the responsibility of the entire production chain. Managers in all segments of production must commit to making decisions that will combine productivity and the highest degree of palatability. The only way to achieve industry-wide improvement of beef's quality and consistency is for every phase of beef production to be managed properly. It is everyone's responsibility. As long as mangers throughout the production chain are continually striving to produce the highest quality beef to meet consumers' demands, then the beef industry will continue to grow and prosper.

RECOMMENDATIONS

Managing cattle for optimum Palatability

Cow-calf

- → Reduce the level of *Bos indicus* breeding to a minimum while still maintaining genetic levels consistent with heat resistance and hybrid vigor. Three-eighths or less is recommended.
- → Castrate male calves at the earliest practical age; prior to weaning is optimal.
- → Maintain an aggressive health program including a timely vaccination and parasite control program. Follow recommended administration procedures and avoid injections in the area of the round, rump, loin and rib.
- → Wean calves at the earliest practical age; 6 to 8 months is recommended.

→ Maintain an adequate level of nutrition.

→ Use no more than one approved pre-weaning implant, following the recommendations on the product label.

Stocker

→ Maintain an adequate level of nutrition consistent with the implant program to sustain growth.

→ Maintain an aggressive health program including a timely vaccination and parasite control programs.

→ Use no more than one approved pasture implant, following the recommendations on the product label. Be sure that the level of nutrition is adequate to support the implant program.

→ Market cattle in a timely manner.

Feedlot

→ Feed cattle to their optimum end-point as determined by in-weight and implant strategy. When possible, sort into outcome groups.

→ Continue to maintain an aggressive health program including vaccinations and parasite controls. Closely monitor cattle health and promptly administer effective treatment for respiratory sickness.

→ Use implants that will optimize the genetic potential of the cattle being fed as determined by their in-weight. Do not use implants within 50 to 60 days of slaughter and follow the recommendations on the product label.

→ Cycling heifers tend to be prone to a high level of dark cutters; therefore, the use of a heat suppressant is recommended.

→ Use beta agonists to improve carcass yields and cutability. Product, dosage level and duration of feeding should be matched to specific marketing targets. Follow label directions with regard to dosage.

→ Avoid situations that increase the potential for antemortem stress and dark cutters; these include, but are not limited to: mixing cattle from different feedlot pens prior to shipping, weighing up cattle more than 2 hours prior to shipping, moving cattle aggressively and standing without water especially in very hot weather.

Post-harvest

→ Use electrical stimulation to hasten the onset of rigor mortis thus preventing cold shortening and improving the appearance, grading and tenderness of the carcass.

→ Chill the carcass at temperatures low enough to diminish bacterial growth but high enough to prevent cold shortening; 32°F to 34°F is optimal.

→ Allow meat to age or mature a reasonable length of time prior to merchandising. This will allow the inherent enzyme systems to tenderize the meat and improve its consistency. Recommended aging times may vary with the cut and quality grade.

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