Meat Science 101

Meat is a very complex product that can be affected by antemortem and postmortem factors. Components of the muscle itself, like contractile proteins and connective tissue affect the characteristics of the final product whether it is a steak or a hot dog. Knowledge of the structure of the muscle and how muscle is converted into meat helps us to understand what affects the tenderness and processing characteristics of the meat.

Many factors influence the tenderness of meat. The development of rigor mortis greatly affects meat tenderness. Muscle, if obtained very soon after death, would be more tender than if the meat were allowed to go into rigor mortis. Many factors affecting the extent of rigor and the speed at which rigor develops also influence tenderness.

Muscle Structure

Intact muscle contains several structural systems with connective tissue and myofibrillar proteins being the most important to tenderness. The structure of muscle resembles wires in a cable. Strands of fibers are grouped together in systems with connective tissue holding the system together. The connective tissue network is designed to combine and transmit the force of contraction to accomplish movement. As a result, there is an intricate network in muscle beginning with an exterior muscle cover termed the epimysium. A subdivision of the epimysium divides the muscle into sections referred to as bundles and the connective tissue around each bundle is referred to as the perimysium. Finally, within each bundle are several muscle fibers each surrounded by connective tissue called endomysium. Obviously, such a network contributes significantly to shear resistance and toughness of muscle cuts. Muscles have variable amounts of connective tissue that affects the overall tenderness of meat.

Within the endomysium lies the individual muscle cells or fibers. Different types of muscle fibers make up individual muscles. The muscle fibers are classified into at least three distinct types, each having a different rate of energy metabolism. The muscle is a mixture of fiber types. The proportion of each fiber type within a muscle influences the rate of postmortem changes that occur in the muscle.

Within the muscle cells are myofibrils, long rod-like aggregates of myofibrillar proteins. Myofibrils are long thin contractile elements inside the cell that give the characteristic striated pattern. The sarcomere is the unit of muscle structure between the two Z lines (Fig. 1). Other bands that can be observed with the light microscope include the A band, I band and Z line (Fig. 1). Areas that appear darkest are the Z line and the regions of the A band where thick and thin filaments overlap. The sarcomere length changes depending on the contractile state of the muscle. The thick and thin filaments do not change length, but the degree of overlap between thick and thin filaments changes.

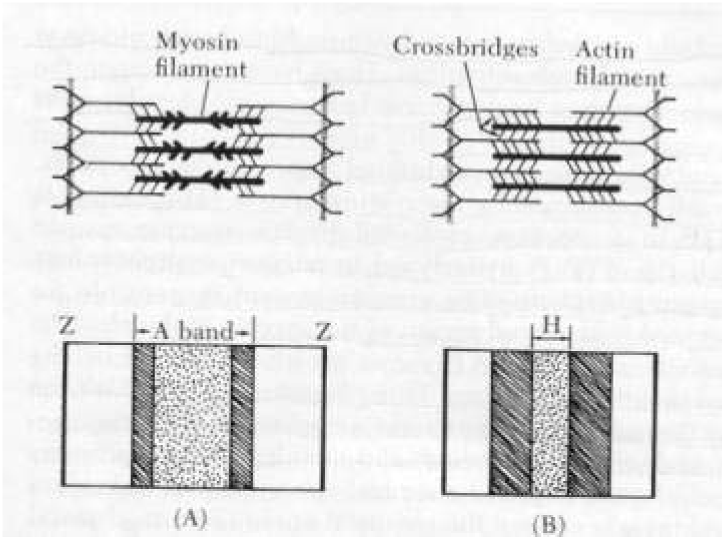

Fig. 1 Myofibril organization

Muscle Contraction

Many events happen during contraction to allow for cooperative action of individual sarcomeres to generate movement. Some of the events are important in the understanding of the conversion of muscle to meat. The first step in contraction is the transfer of the nerve impulse from the brain to the muscle. Through many hormonal and chemical changes an impulse reaches the organelle that stores calcium in the muscle cell. This causes the release of calcium into the sarcoplasm. The calcium interacts with regulatory proteins in the myofibril to allow crossbridges to form between the main contractile proteins, myosin and actin. The calcium also activates enzymes that start energy metabolism. This allows for coordination of energy metabolism with muscle contraction. The high energy phosphate compound, adenosine triphosphate (ATP), is hydrolyzed to create the power stroke of contraction and causes the thick filaments to move past the thin filaments and shorten the sarcomere (Fig 1). Many sarcomeres shortening together are what causes contraction in the muscle. To break the crossbridge formed between myosin and actin, ATP must be present. If energy is depleted and no ATP can be manufactured from glycogen than no relaxation of the muscle occurs.

ATP is normally regenerated from glycolysis; the tricarboxylic acid cycle and the electron transport chain in the mitochondria. In muscle, another short-term mechanism is in place. ATP is regenerated from adenosine diphosphate (ADP) and creatine phosphate (CP). This allows for rapid restoration of ATP in contracting muscle. If muscle is working slowly, and oxygen is supplied in adequate amounts, aerobic metabolism and CP breakdown can adequately supply most of its energy requirements. However, when muscle is contacting rapidly, its oxygen supply becomes inadequate for support of ATP re-synthesis via aerobic metabolism. Under these conditions of oxygen shortage, a third mechanism, anaerobic metabolism, is able to supply energy for a short time. A major feature of anaerobic metabolism is accumulation of lactic acid. The amount of energy available in this anaerobic route is limited. Lactic acid accumulation in the muscle lowers its pH, and at pH values of less than 6.0 to 6.5, the rate of glycolysis is drastically reduced, with a proportional reduction in ATP re-synthesis. Under these conditions, fatigue develops quite rapidly.

During muscle's recovery from fatigue, lactic acid that has accumulated is transported out of the muscle via the blood stream, and is converted to glucose in the liver or metabolized to carbon dioxide and water by the heart (via a specialized enzyme system). ATP and CP, the energy stores, are replenished by the process of normal aerobic metabolism. The recovery process may occur quite rapidly for a slight fatigue, but may require extended periods if the fatigue is severe.

Conversion of Muscle to Meat

Harvest

Cattle are usually harvested between 1.2-2 years of age depending on the desired carcass composition and management practice used. As animals get older the metabolism shifts from growth to accumulating fat. This fact of life is what feedlot operators take advantage of when feeding animals. The age of the carcass is determined by dentition (teeth) or bone ossification (factor in quality grading). As the animal gets older the cartilaginous tips of the bone turns to bone. Different levels of ossification result in the determination of the carcass age. Also as the animal gets older the number of teeth and wear on the teeth changes. Young animals have fewer teeth with sharper edges than do older animals. Carcass weights vary from 250 -700 kg. This of course depends on the breed-type of the animal and how long it was fed in the feedlot.

The harvest procedure actually starts with the holding pens. Considerable research has been done recently to make the holding pens and handling areas as stress free as possible. The handling pens entering the slaughter plant make the animals enter in single file into the restraining area or knocking pen. In this area, the animal is restrained in a narrow chute to allow for safe stunning. The typical method for stunning in North America is a concussion method using a captive bolt stunner. Stunning is required in the US by the Humane Slaughter Act of 1958 which requires that any meat plants selling meat products to Federal

Agencies to slaughter animals in a humane manner. This has gradually become a requirement for most plants. The major exceptions would be Kosher (Jewish) and Halal (Muslim) plants. Other countries such as Australia and New Zealand use electrical stunning and immobilization. The animal is rendered unconscious with an electrical current. The goal of stunning is to make the animal insensitive to pain, but the heart needs to remain beating to allow for complete exanguination or bleeding.

The next few steps in the slaughter process remove the hooves, horns and hide. The hide is removed mechanically. It is very important that the exterior of the hide does not touch the carcass during removal. The head is removed and the lymph nodes and tongue inspected to ensure that the animal was healthy. The tongue will then be moved to another portion of the plant and packaged for sale. The carcass is then eviscerated. This is one of the most important steps. It is imperative that the intestinal contents not come into contact with the carcass. This is a cause of fecal contamination. The viscera are then inspected to ensure that the carcass is fit for human consumption. Some viscera are recovered for edible uses. The most notable is the recovery of one of the stomachs (tripe) for export to Asian countries. Some plants may use localized steam vacuum for removal of microorganisms at this point and other contamination points along the line. The carcass is then split into two sides and proceeds on to the final wash. Many processing plants use steam cupboards as a final wash to reduce pathogen numbers that may be on the carcass. The carcass is than chilled prior to grading. An alternative to this process that is utilized in New Zealand is hot boning of the meat for cuts or sausage manufacture. The carcasses are normally chilled 24 to 48 hours prior to ribbing and grading.

Carcasses are normally fabricated into wholesale cuts at the slaughterhouse. This is where the term boxed beef originated. The beef is packed into boxes and shipped to the customer for further processing. There are several sets of specifications that the company uses to make the products they place in the boxes. The customer defines some of the specifications, while others are industry norms. In the US most companies use IMPS (Institutional Meat Purchasing Specifications) numbers to describe products being sold (www.ams.usda.gov/lsg/stand/st-pubs.htm). The packers' goal is to have carcasses that require a minimum amount of trimming and fit the other specifications of size and weight. This goal is reflected in the pricing schemes that are used to buy live animals.

All animals harvested for human consumption are inspected. That is one of the distinctions between inspection and grading. Animals are inspected live and any animals that appear to be sick will be separated away from the others. Postmortem, the head and viscera are inspected for signs of disease especially lymph nodes, lungs and liver. The carcass is also inspected for dirt and hair or bruises that may be on the carcass. Recently, a risked based system called HACCP - Hazard Analysis Critical Control Points has been introduced into the federal slaughter plants. This system is used to identify points at which microbial, chemical, or physical hazards can be introduced and what can be done to minimize or total prevent the hazards from being introduced onto or into the carcass. The HACCP program is required in all federal plants in the United States. In Montana it is also required in all state inspected plants.

There are several very significant changes that occur in muscle immediately following harvest. The muscle remains functional for some time but because there is no longer a circulating blood supply, oxygen is not conveyed to the muscle and metabolic end-products are not removed. As a result, the muscle utilizes glycogen as an energy source for ATP and in the process generates lactic acid that accumulates. Ordinarily, with oxygen present, the energy sources are more completely broken down and excess lactic acid removed via the blood. Without blood circulation oxygen is unavailable for energy production and lactic acid is not removed from the muscle. The accumulation of lactic acid causes an increase in muscle acidity, from a near neutral pH of 6.8-7.2 to about 5.6 (Fig. 2). The increased acidity causes a loss in water binding ability and causes calcium release that is the trigger for muscle contraction and energy metabolism. As a result, crossbridges are formed between myosin and actin. As the concentration of glycogen stored in the muscle goes down, the energy available to keep muscle relaxed is also depleted. Because the ATP and CP are being used up there comes a point at which the crossbridges become permanent (actomyosin) and rigor mortis develops. The events seen in the development of rigor are the decrease in pH, ATP and CP and a concurrent loss in muscle extensibility. The time required to achieve rigor mortis varies with the type of muscle and animal species. Poultry may require only 1 to 2 hours whereas beef is likely to need 20 to 24 hours. There are several factors that can affect the extent of contraction associated with rigor mortis.

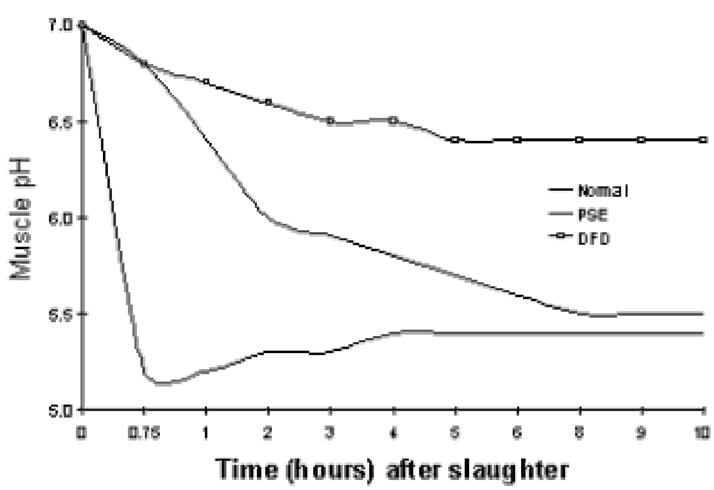

Fig. 3. Examples of the rate and extent of decline in muscle pH for normal muscle and muscles with the DFD or PSE condition.

Events Affecting Tenderness

Rate of temperature decline

The rate of temperature decline in muscle affects the chemical reactions that occur during the conversion of muscle to meat. Low temperatures (> 10°C) slow down the pH decline and loss of ATP but also cause release of calcium into the sarcoplasm sooner than what happens if the reactions occur at higher temperatures. There is a high correlation between extent of shortening and the ATP content at the onset of rigor. At higher temperatures muscle enters rigor at higher ATP levels than at lower temperatures (Hertzman et al., 1993). It has been suggested that at colder temperatures the calcium accumulating systems works less efficiently and that there is an accelerated release of calcium into the sarcoplasm as well. This results in elevated calcium levels that result in increased shortening of sarcomeres (Olsson et al., 1994).

The rate of carcass chilling postmortem can affect the tenderness of meat. Two condition, cold shortening and thaw rigor, have been well documented in the literature. Cold shortening occurs when muscle is cooled to 4 - 10°C before onset of rigor mortis (Fig. 4). Thaw rigor is similar but more rigorous and occurs if meat is frozen before muscle goes into rigor mortis. These two conditions are the extremes of what can happen with rapid chilling. In cold shortening muscle may shorten 47%, this causes three- to four-fold increase in shear force values. Paradoxically, muscle shortened >60% result in shear force values that are similar to normal rigor mortis development. When muscle that was frozen before onset of rigor is thawed, the muscle shortens to approximately 60% of its original length with an incredible loss of moisture. The contraction in both conditions is caused by a sudden release of calcium into the sarcoplasm, because of loss of enzyme activity in the muscle and calcium binding ability in the mitochondria.

Severe shortening and early onset of rigor mortis may be induced by maintaining muscle at relatively high temperatures >37°C. Heat rigor is thus produced, which is the result of a rapid depletion of ATP stores. Consequently, there appears to be an optimum temperature at which muscle should be held during the onset of rigor mortis to minimize shortening, toughening and other undesirable effects of the rigor process.

It has been suggested that the reported higher tenderness in heavier carcasses is due to differences in chilling rates not any genetic or feeding differences (Lochner et al., 1980). One theory that has been suggested for the variability of beef tenderness is the differences in chilling rates. All slaughter facilities work towards the average carcass weight and size. Therefore, lightweight, thin carcasses are chilled much more rapidly than the heavier ones resulting in large differences in tenderness.

Rate of pH decline

It is well document, in pork, that a rapid pH decline postmortem results in pale soft and watery (PSE) meat. This meat tends to be dry and tough when cooked. In beef this condition is rare. New research has suggested, however, that there is an optimum rate of pH decline. O'Halloran et al. (1995) reported that fast glycolyzing carcasses were more tender than slow glycolyzing carcasses. This information was gathered on carcasses that had not been treated in any way. Wahlgren et al (1997) however showed that with intervention with electrical stimulation glycolytic rates could be reached that were detrimental to tenderness. They reported that a pH of 5.6 within 1 hour postmortem (very similar pH decline to PSE meat) and a pH of 5.6 in 24 hour postmortem resulted in higher shear force values and lower sensory scores than carcasses with intermediate pH declines (Fig. 6). O'Halloran's fast glycolyzing carcasses and Wahlgren's medium glycolyzing carcasses have similar pH declines suggesting that there is an optimum rate of pH decline. These effects are coincident to the effect of ultimate pH.

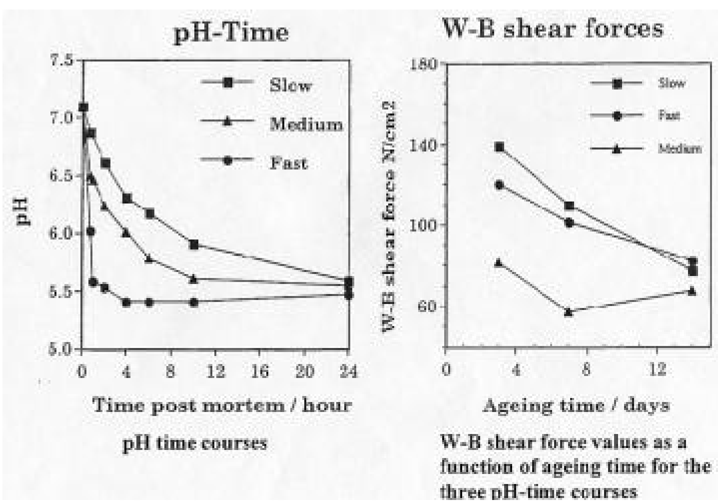

Fig. 5 Effect of different rates of pH decline postmortem on the Warner-Bratzler shear force values of beef (From Wahlgren et al., 1997)

Ultimate pH

Ultimate pH of a carcass can vary from 5.3 to 6.8. Carcass surveys have shown that the tenderness of meat is influenced by the ultimate pH (Fig. 6). The greatest effecter of ultimate pH is preslaughter handling. Animals stressed prior to slaughter are more likely to have higher ultimate pH than unstressed animals.

Only the animals with extreme ultimate pH (>5.9) are sorted out in the grading system and reported by statistical agencies. However, as shown in Figure 10, shear force values increase from a pH of 5.5 up to a maximum near 6.0 and then shear force values decrease (Purchas and Aungsupakorn, 1993). The ultimate pH also seems to affect the aging rate of meat. Wanatabe and Devine (1996) reported that a ultimate pH affected the rate of degradation of cytoskeletal proteins. At high pH (7.0) cytoskeletal proteins are breaking down within 12 hr postmortem with decreasing degradation as the pH was reduced.

The ultimate pH of carcasses in North America tends not to vary greatly. Most research report between 5.4 to 5.6, however, in the commercial setting little is known about the variability of the ultimate pH in carcasses. The variation in ultimate pH is a possible source of tenderness variation.

Tenderness is a very complex problem. Many factors can affect tenderness. If consumer induced problems are removed, such as improper use of specific cuts and improper cooking, than one of the largest changes in tenderness occurs in the first 12-18 hours. Many changes occur in this time that has a great impact on tenderness. Some of the changes are totally within the control of the processor (chilling rate) and the animal handlers (ultimate pH). However, others are totally a function of the animal (rate of pH decline, ultimate pH). Control of the animal variation is very difficult. Some of it comes from genetic selection, but some is behavior. Research from New Zealand on animal handling systems suggests that animals react better to transport if they have been handled in some manner prior to transport (Christian Cook, personal communication). Handling the animals prior to transport help to reduce some of the stress related differences in carcasses.

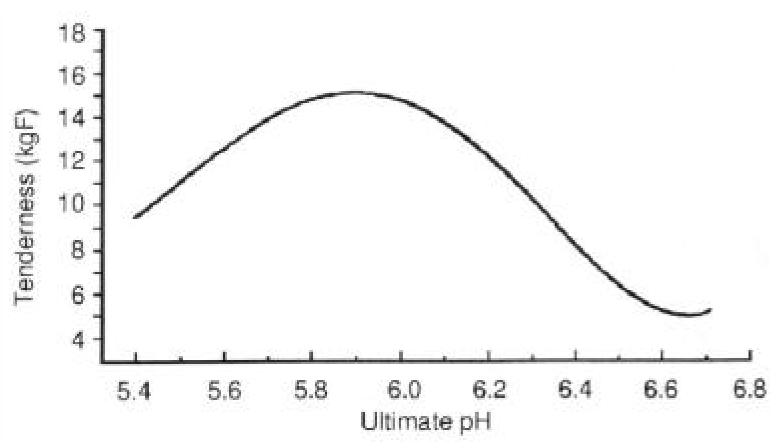

Fig. 7 Relationship between meat tenderness and ultimate pH – the higher the kgF value, the less tender the meat (From MIRINZ Bulletin no. 29).

Some tenderness problems will always be in the system. This is a fact that must be realized. Animals are biological material and thus have expected variation. However, reducing the magnitude of the tenderness problem and reducing the variation among animals is a very important goal for researchers.

Carcass Value

Carcass grading systems are used to describe the value of a beef carcass in terms of lean meat yield and a quality grade that are useful to the meat industry. The grading schemes were developed to aid the buyer and seller to describe carcasses in a common way. It has put the description of the carcass into the hands of an unbiased third party the federal government. The federal grading of carcasses facilitates long distance transactions and allows both parties to have some information about the carcasses prior to delivery. Grading systems were developed as marketing tools. However, some people have come to think quality grades will guarantee eating enjoyment.

Quality Grading

The US quality grading system is based on the physiological age of the carcass, amount of marbling in the ribeye at the 12^{th} rib, the sex of the carcass and the color of the lean.

The gender of the carcass is determined by the musculature in the shoulder and neck area and by the size and shape of the pizzle eye. There are five maturity classifications in the USDA Quality grading scheme. Only those of A and B maturity are sold in the youthful classification and there are three mature categories labeled C, D, and E. The maturity is determined by the ossification of the tip on the thoracic vertebrae. No ossification is indicative of A maturity while slight ossification is an A/B borderline. Greater than 40% ossification and the carcass is C maturity or greater. As the maturity of the carcass increases, more marbling is necessary to grade in the higher quality grades. The marbling content ranges from practically devoid to abundant. The young animals are the only ones that can be classified as Select, Choice and Prime. Choice and Prime are divided into three levels low, average and high. Federal graders will only distinguish between the Choice and Prime. The packers and some buyers may use the further divisions when filling orders. If more information is needed about the USDA Quality Grading system check the following website:
http://www.ams.usda.gov/lsg/stand/standards/beef-car.pdf

Yield Grading

Yield grading is an estimation of the boneless closely trimmed retail product that will be produced from a carcass. The official U.S.D.A. yield grading standards range from 1.0 to 5.9, but only the whole number yield grade is "rolled" on the carcass by the grader. The yield grade is based on the fat thickness at the 12th rib, ribeye area, hot carcass weight and percent kidney, pelvic and heart fat. Using these factors, regression equations were developed that is used to predict yield grade.

Yield grade = 2.5 + (2.5 x adjusted fat thickness, 12th rib, inches) + (0.0038 x hot carcass wt., pounds) + (0.2 x percentage kidney, pelvic and heart fat) – (0.32 x ribeye area, square inches)

In actual everyday grading of beef carcasses, the regression equation is not used, but two working formulas have been developed to simplify the procedure. The working formula involves the same four factors as the regression equation.

One of the most important things to remember when calculating yield grade is that with increasing fat, the yield grade goes up. Larger yield grade numbers mean a fatter carcass with less expected retail product. Heavy carcasses with small ribeyes also cause the yield grade to increase.

Working Formula

1. Estimate the fat thickness at the 12th rib and adjust, if necessary. Form this estimate determine a preliminary yield grade (PYG).

Adjusted Fat Thickness Estimate (in.)	PYG	Adjusted Fat Thickness Estimate (in.)	PYG
0.1	= 2.25	0.7	= 3.75
0.2	= 2.5	0.8	= 4.0
0.3	= 2.75	0.9	= 4.25
0.4	= 3.0	1.0	= 4.5
0.5	= 3.25	1.1	= 4.75
0.6	= 3.5	1.2	= 5.0

2. For each 1 in2 REA in excess of 11.0 in^2, subtract 0.3 yield grade; and for each 1 in^2 less than 11.0 in^2, add 0.3 yield grade to the PYG.

3. For each 25 lb. Of hot carcass weight (HCW) in excess of 600 lb., add 0.1 yield grade to the PYG; and for each 25 lb. HCW less than 600 lb., subtract 0.1 yield grade from the PYG. (If the chilled carcass weight (CCW) is what is available, multiply the CCW by 102% to convert to HCW).

4. For each 0.5% KPH in excess of 3.5%, add 0.1 yield grade to the PYG; and for each 0.5% KPH less than 3.5% subtract 0.1 yield grade from the PYG.

Weight-Eye Method of Calculating Yield Grade of Beef Carcasses

1. Estimate the fat thickness at the 12th rib and adjust, if necessary. Form this estimate determine a preliminary yield grade (PYG).

Adjusted Fat Thickness Estimate (in.)	PYG	Adjusted Fat Thickness Estimate (in.)	PYG
0.1	= 2.25	0.7	= 3.75
0.2	= 2.5	0.8	= 4.0
0.3	= 2.75	0.9	= 4.25
0.4	= 3.0	1.0	= 4.5
0.5	= 3.25	1.1	= 4.75
0.6	= 3.5	1.2	= 5.0

2.

Hot Carcass Wt. (lb)	RREA (in^2)	Hot Carcass Wt. (lb)	RREA (in^2)
500	9.8	700	12.2
525	10.1	725	12.5
550	10.4	750	12.8
575	10.7	775	13.1
600	11.0	800	13.4
625	11.3	825	13.7
650	11.6	850	14.0
675	11.9	875	14.3

For each 1 in^2 of estimated ribeye in excess of the RREA, subtract 0.3 of a yield grade from the PYG; and for each 1 in^2 of ribeye area less than the calculated RREA, add 0.3 of a yield grade to the PYG.

3.

Grid Pricing

Many beef processors are using a grid pricing system to determine the value of a carcass. Prices that are quoted for live animal prices are calculated based using an expected dressing percentage and the carcass value. To determine live animal price from the carcass price, the carcass price in multiplied by the dressing percentage. The normal dressing percentage for steers is 63%.

Carcass price $102/cwt

Live price $102 x 0.63 = $62.26/cwt

The grid pricing uses the base price and rewards or discounts carcasses that are outside the product they want. Premiums are paid for quality grades higher than Choice and for yield grades better than 3.0 (Table 1). Deductions from the base price are used when quality grades are less than Choice, yield grades are greater than 3.5, for heavy or light carcasses and any defects like dark cutters, hardbone or bullocks.

Table 1: National Carcass Premiums and Discounts for Slaughter Steers and Heifers (May 8, 2000)

Quality	Average
Prime	5.33
Choice	0.00
Select	-11.59
Standard	-19.93
Certified Programs	
Avg Choice ↑	1.42
Dairy Type/ Bullock	-25.20
Hardbone	-21.83
Dark Cutter	-29.50
Yield Grade	
1.0 – 2.0	2.42
2.0 – 2.5	1.00
2.5 – 3.0	1.00
3.0 – 3.5	-0.17
3.5 – 4.0	-0.33
4.0 – 5.0	-14.93
5.0/up	-19.83
Weight	
400-500 lbs.	-22.33
500-550 lbs.	-17.83
550-950 lbss.	0.00
950-1000 lbs.	-15.50
Over 1000 lbs.	-21.33

Based on individual packer's quality, cutability, and weight buying programs.

Values reflect adjustments to base prices, dollars per cwt., on a carcass basis.

www.ams.usda.gov/mnreports/nw_ls195.txt

Grid Pricing Example

Grid pricing utilizes the base carcass price of the day and adds or subtracts premiums or deductions to determine the value of the carcass.

Example

Quality Grade – Prime

Yield Grade – 4.5

Carcass Wt – 750

Prime carcasses are receiving a $5.33/cwt premium.

Yield Grade 4.5 carcasses are receiving deductions of –$14.83/cwt

750 carcass receives neither a premium nor a deduction.

If the **base price** for the carcass is **$102/cwt**, the described carcass would be receiving

Carcass price = 102 + 5.33 – 14.83 = $92.50/cwt

Live price = $92.50 x 0.63 = $58.27/cwt

Processing

Carcasses are normally cut into wholesale cuts and then into retail cut. In the changing retail market place, few roasts are seen. Approximately 25% of the carcass is used for the high end steaks and roasts. This leaves approximately 75% of the carcass used mostly for hamburger. Hamburger tends to be a low cost product that means that 25% of the carcass must bear most of the cost of the carcass. To counteract this, most companies want to process the product. Further processing of beef is relatively limited. In the past three years many new products have been introduced to the market. Most of these products are utilizing fresh meat in ready meal packets or pre-cooking products that traditionally have taken a long time to prepare to make the beef more convenient. There are still few products in the sausage and sliced meat market. One of the reasons given for not using beef, is the cost of the raw materials. Another, problem that is encountered is that for products that have traditionally been made from pork like bologna, beef does not function the same way in the process. Beef fat has a higher melting point than does pork and this gives products made from all beef a different texture and mouth feel than the traditional pork product. Also, formulations made from all beef will carry flavors differently. This means processors will have to change the formulation to get the same flavor profile of the product.

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