EFFECTS OF ELEVATED TEMPERATURE CONDITIONING ON BEEF CARCASSES FROM FOUR NUTRITIONAL REGIMES

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MARY ELIZABETH SMITH

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Approved by:

Curtis L. Kastner
Major Professor

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Chapter I

INTRODUCTION

Due to the rising cost of finishing cattle, alternatives in feeding practices and length of feeding are of economic interest. These may have an effect on shelf life, palatability and resultant consumer acceptance of the finished product. To maximize product acceptance, manipulation of feeding practices and a reevaluation or alteration of handling and processing techniques may be employed.

Tenderness is the most important palatability characteristic. In addition, other palatability characteristics certainly influence consumer acceptance. Modern consumer acceptance of beef produced under management systems utilizing largely roughages is basically unknown. For these reasons, evaluation and appraisal of beef produced under these management systems is of primary importance along with potential problems of processing and marketing beef of this type. Processing procedures which alter the original product and thereby make it more acceptable as a finished meat product warrant investigation.

Chapter II

REVIEW OF LITERATURE

Muscle Structure and Composition

General Composition and Gross Structure

Skeletal muscles constitute 35 to 65% of the carcass weight of meat animals. Specific characteristics of a given muscle are related to its function (Forrest et al., 1975).

Meat is striated, skeletal muscle that is a composite of delicately balanced protein suspensions in dilute salt solutions. Water content (intracellular and extracellular) of muscle varies from 50 to 80%, with most of the variation resulting from a varying amount of neutral lipids (Briskey and Fukazawa, 1971). Muscle lipid content varies quantitatively and qualitatively with maturity, species, muscles and fiber type (Briskey and Fukazawa, 1971). Lipid concentration ranges from approximately 1.5 to 13% (Forrest et al., 1975) and consists primarily of neutral lipids (triglycerides) and phospholipids. Fat cells in muscle are located in the perimysial space either singly or in groups, but the bulk of lipid is present in adipose tissue depots associated with loose connective tissue septa between muscle bundles (Cassens, 1971; Forrest et al., 1975).

Briskey and Fukazawa (1971) stated carbohydrates make up only 1 to 2% of muscle weight and consist primarily of glycogen and mucopolysaccharide (a ground substance associated with connective tissue). Ash, soluble organic extractives and vitamins are approximately 1.0% but vary widely with stage of maturity and chronological development.

Proteins constitute 16 to 22% of the muscle mass and are the principal component of the solid matter. They are generally categorized as sarcoplasmic, myofibrillar, or stromal, based primarily upon their solubility (Forrest et al., 1975).

Sarcoplasmic proteins are readily extractable in water or low ionic strength buffers (below 0.2). They constitute approximately 30 to 34% of total muscle protein in mature mammals and contain 50 to 100 different proteins. Sarcoplasmic protein solubility is highest immediately after death, and either remains unchanged or decreases by some variable amount during post-mortem storage. Their solubility critically depends upon rate of pH decline in post-mortem tissue and the temperature of post-mortem storage. Sarcoplasmic proteins as well as myofibrillar or stroma proteins do not experience extensive post-mortem proteolysis (Goll et al., 1970; Parrish et al., 1973).

Stroma proteins are insoluble in neutral aqueous solvents and constitute 10 to 15% of total muscle protein. Collagen, elastin and reticulin make up the largest portion of the stroma protein fraction. These connective tissues are primarily responsible for the "background" toughness of muscle while the myofibrillar proteins contribute to the "actomyosin" toughness (Goll et al., 1970).

Connective Tissue

Muscle fibers are arranged and held in patterns by a series of connective tissue components that act as wrappings and dividers. An entire muscle is surrounded by a heavy connective tissue sheath, the epimysium, which divides muscle into groups of fibers called bundles (fasciculi). Groups of muscle fibers form primary bundles; several

primary bundles combine to form secondary bundles; and tertiary bundles are formed by the combination of secondary bundles (Bloom and Fawcett, 1962). Nerve bundles and small blood vessels run between bundles of fibers. The perimysium is connective tissue which surrounds primary, secondary and tertiary bundles. It supports vascular elements and nerves. The endomysium is a thin layer of delicate connective tissue surrounding individual muscle cells and contains small collagenous fibrils and numerous reticular fibers (Briskey and Fukazawa, 1971; Cassens, 1971; Partmann, 1973).

Connective tissue proper consists of a structureless mass (ground substance) in which cells and extracellular fibers of reticulin, collagen and elastin are embedded. Collagen, the most abundant protein in the animal body, constitutes 20 to 25% of total muscle protein and influences meat tenderness. Collagen is also the major component of tendons and ligaments with the amount paralleling physical activity (Forrest et al., 1975).

Elastin is a rubbery, easily stretched, extremely insoluble protein present in ligaments, walls of arteries and framework of organs. Reticulin fibers are very thin, highly branched, and often intimately associated with the endomysium of the muscle fiber (Cassens, 1971; Forrest et al., 1975).

Muscle Fibers

The essential structural unit of all muscle is the fiber. Muscle fibers constitute 75 to 92% of the total muscle volume. The muscle fiber consists of a sarcolemma membrane, sarcoplasmic proteins, nuclei,

golgi bodies, mitochondria, sarcoplasmic reticulum, T systems, and contractile elements, the myofibrils (Briskey and Fukazawa, 1971) and lysosomes (Forrest et al., 1975).

Skeletal, striated muscle fibers are multinucleated, elongated and more or less tubular cells. The ends may be conical or tapering, and the diameter of the fiber ranges from 10 to 100 microns. Diameters of fibers vary within a muscle, between muscles, with age and degree of activity of the animal. Fiber length varies greatly and depends on the species and location of the muscle as to whether fibers run the entire length of the muscle or not (Cassens, 1971).

The muscle fiber is encased in the sarcolemma (outer cell membrane), a delicate membrane immediately under the endomysium. The sarcolemma and endomysium are two separate and distinct structures, although both encase the muscle fiber. The sarcolemma is composed of protein and lipid material and is relatively elastic, while the endomysium consists of a protein-polysaccharide ground substance and protein (Cassens, 1971; Forrest et al., 1975).

Cell Components

The cytoplasm of the cell is called the sarcoplasm. Water constitutes about 75 to 80% of the sarcoplasm. The nuclei are located near the surface of the sarcolemma, a distinguishing characteristic of striated, skeletal muscle. Nuclei are distributed fairly regularly along the length of the fiber (Briskey and Fukazawa, 1971), but according to Cassens (1971) the number of nuclei per fiber is not constant. The nucleus contains the genetic material, deoxyribonucleic acid (DNA),

which determines the specificity of cellular behavior and controls its metabolic activities. The principle components of the interphase nucleus are the chromatin (used for DNA), nuclear matrix and the nucleolus. The nucleolus is rich in ribonucleic acid or RNA and plays a key role in nucleic acid metabolism and protein synthesis (Briskey and Fukazawa, 1971).

Mitochondria, the energy-producing organelle in a cell, are located between the myofibrils opposite the I band and straddling the Z band, at the nuclear poles and immediately under the sarcolemma (Briskey and Fukazawa, 1971; Cassens, 1971). The mitochondrial population varies from muscle to muscle, depending upon the intensity of metabolic activity (Edwards et al., 1956). An adequate mitochondrial metabolism guarantees a consistent supply of energy to the contractile units. They are frequently referred to as the "powerhouse of the cell" because they "capture" the energy derived from carbohydrates, lipid and protein metabolism and provide the cell with a source of chemical energy (Briskey and Fukazawa, 1971; Forrest et al., 1975).

These same authors describe the sarcoplasmic reticulum and transverse tubular systems as being located in a regular arrangement in sequence with the myofibril band pattern and serve in the contraction coupling mechanism, even though they are two separate and distinct membrane systems. The T tubules are associated with the sarcolemma while the sarcoplasmic reticulum (SR) is intracellular in nature. The reticulum membranes of the SR are the storage sites of Ca^{++} in resting muscle fibers. The SR comprises 13% and T tubules 0.3% of the total fiber volume.

Lysosomes are small vesicles located in the sarco-tubular system of the cell. They contain several enzymes including ribonuclease (breakdown of RNA), deoxyribonuclease (breakdown of DNA), phosphatase, lipases and cathepsins, which are collectively capable of digesting the cell and its contents. The cathepsins are a group of proteolytic enzymes that affect some of the muscle proteins perhaps contributing to meat tenderization during post-mortem aging (Forrest et al., 1975).

The Golgi complex is located in the sarcoplasm near the nuclei. It functions as the "concentrating" and "packaging" apparatus for the products from the metabolic production line of the cell. The muscle fiber contains numerous Golgi complexes (Forrest et al., 1975).

Proteins of the Myofilaments

Myofibrillar proteins make up 50 to 55% of total muscle protein and are either regulatory or structural in nature. Actin and myosin together constitute approximately 75 to 80% of the myofibrillar protein. Both are necessary for a contractile response. The regulatory proteins are tropomyosin, troponin, two M proteins, α-actinin, C protein and β-actinin (listed in decreasing order of concentration in the myofibril) (Forrest et al., 1975). Goll et al. (1970) noted they apparently have the function of modifying or regulating the actin-myosin interaction in such a way that contraction can be rapidly initiated or stopped in the constant presence of ATP. Thus, the tropomyosin-troponin complex causes the actin-myosin interaction to require Ca^{++}; removal of which results in cessation of contraction (relaxation) and dissociation of the actin-myosin complex. Alpha-actinin has the ability to accelerate or strengthen the contractile response of actomyosin suspensions in in vitro systems.

C protein is present in the myosin filament and composes 2 to 2.5% of myofibrillar proteins; α-actinin, a cementing substance is a component of the Z-line and M proteins are believed to be substances composing the M line. The thin (actin) filament is composed of tropomyosin, troponin, β-actinin and actin, which is present in the largest amount (Goll et al., 1970; Murray and Weber, 1974; Forrest et al., 1975). Actin constitutes about 20 to 25% of the myofibrillar proteins and consists of G-actin (globular), which group together to form F-actin (fibrous). Two strands of F-actin are spirally coiled around one another to form a "super helix", characteristic of the actin filament. Actin molecules are not sperically symmetrical, but each acts as if it had a distinguishable "front" and "back". This directionality is essential to muscular contraction (Murray and Weber, 1974). β-actinin is located at the ends of actin filaments and is believed to regulate their length by maintaining a constant length in each half sarcomere. Troponin is present in the grooves of the actin filament where it lies astride the tropomyosin strands and is present in the same amount as tropomyosin. Tropomyosin strands lie alongside each groove of the actin super helix and comprise 8 to 10% of the myofibrillar protein. In the thin filament one tropomyosin molecule extends over seven actins, with one troponin molecule on each tropomyosin molecule (Goll et al., 1970; Murray and Weber, 1974).

Myosin constitutes approximately 50 to 55% of the myofibrillar proteins (Huxley, 1958) and is a highly charged molecule. Actin, on the other hand, possesses a low charge. The myosin molecule has a thickened end (head region) and a long rod-like portion forming the backbone (tail

region). The portion of the molecule between the head and tail regions is called the neck. The head region of the molecule is double headed and when subjected to trypsin, it is split near the neck into two fractions differing in molecular weight; light and heavy meromyosin (Goll et al., 1970; Murray and Weber, 1974). The sites responsible for its ATPase activity and actin-binding activities are located in its globular head (heavy meromyosin) and the sites responsible for its affinity for other myosin molecules are in its tail. The heads of myosin molecules serve as the crossbridges connecting thick and thin filaments in muscle; explaining a crucial feature of the sliding filament hypothesis (Huxley, 1963; Huxley, 1965).

These same authors noted the formation of crossbridges through this interaction of actin and myosin filaments produces the chemical complex known as actomyosin, a major form of myofibrillar proteins in post-mortem muscle. The rigidity following death (rigor mortis) is largely due to this complex though it is a transient complex in the living animal, being broken during the relaxation phase of the contraction cycle.

Myofibrillar proteins are important in muscle contraction and are primarily responsible for many of the physical changes observed in post-mortem muscle such as loss of Z-line structure and, in some cases, complete removal of both the Z-line and M line; and, modification of actin-myosin interaction resulting in a greater sensitivity to dissociation by ATP (Goll et al., 1970).

Myofibrils

The contractile structure of a muscle fiber is made up of long, thin, intracellular elements called myofibrils that are directly respon-

sible for the characteristic banding or striated pattern of skeletal muscle (Cassens, 1971). Myofibrils are about 1-2um in diameter and extend the length of a muscle fiber (Huxley, 1958; Huxley, 1965; Bendall, 1966).

Myofilaments

There are two kinds of myofilaments: "thick" filaments, composed mainly of the protein myosin, and "thin" filaments, composed primarily of actin. A parallel arrangement of these myofilaments and overlapping of thick and thin filaments in certain regions accounts for the characteristic banding of the myofibril. In turn, the bands of each myofibril are aligned across the entire muscle fiber giving the fiber a striated appearance (Huxley, 1958; Huxley, 1965; Murray and Weber, 1974; Forrest et al., 1975).

Under a powerful light microscope, the striation pattern appears as a regular alteration of dense and light bands along the length of the myofibril. The I band is singly refractive, or isotropic, when viewed with polarized light; the broad, dark, denser A band is doubly refractive, or anisotropic. The I band is bisected by a dark thin structure called the Z line. The unit of the myofibril between two adjacent Z lines is called a sarcomere, the repeating structural unit of the myofibril and site of muscle's contraction-relaxation cycle (Cassens, 1971; Forrest et al., 1975).

The dense A band consists largely of thick (myosin) filaments though it contains a small portion of thin (actin) filaments; the lighter I band, the least dense band of the myofibril, contains thin filaments only (Huxley, 1958; Cassens, 1971). Hanson and Lowy (1963) suggested

each I band filament *in vivo* contains two tropomyosin threads as well as two actin threads all which continue into the Z lines.

Huxley (1958), Huxley (1965) and Forrest *et al.* (1975) noted the H zone is less dense than the rest of the A band because it is the center region between the ends of the opposing actin filaments. The width of the H zone varies with the state of contraction of the muscle. In the center of the H zone and lying on either side of the M line is the "psuedo H zone", a region of even lower density that maintains its width no matter how the length of the muscle changes. The M line is caused by a slight bulge in the center of each thick filament or an overlap of tails, and M proteins serve to cement the tails together.

The actin and myosin filaments are arranged in a hexagonal array so that in mammalian tissue each myosin filament is surrounded by six actin filaments at the point of overlap, and each actin by three myosin filaments (Huxley, 1958; Bendall, 1966). The two kinds of filaments are linked together by an intricate system of crossbridges (actomyosin) which play an important role in muscle contraction. The bridges form a helical pattern which repeats every six bridges. The crossbridges are the only mechanical linkage between the filaments, and they are responsible for the structural and mechanical continuity along the whole length of a muscle. The myosin filament is studded with projections along its entire length except for a bare zone in the middle. The projections appear as minute crossbridges that seem to link the thick and thin filaments. Apparently, each projection is formed from the head region of one myosin molecule. Molecules are arranged within thick filaments with their heads toward the two ends (i.e. tails are oriented

toward the center of the filament), which accounts for the bare zone in the middle or the pseudo H zone. The fact that myosin molecules in one-half of the A-band point in one direction and those in the opposite half of the A-band point in the opposite direction provide a directionality or polarity essential for contraction (Huxley, 1965; Murray and Weber, 1974).

Crossbridges must generate or sustain the tension developed by a muscle. As the sarcomere changes its length, either actively during contraction or passively (stretching or shortening while at rest), the filaments themselves do not perceptively change in length but slide past one another; the thin filaments move into the A bands during shortening and out of them during stretching (Huxley, 1958; Huxley, 1965).

An actin filament on one side of the Z line lies between two actin filaments on the opposite side of the Z line indicating that actin filaments per se do not pass through the Z line. The actin filaments are believed to terminate at the Z line. Ultra-thin filaments (tropomyosin), called Z filaments, primarily constitute the material of the Z line, alpha actinin, and they connect with actin filaments on either side of it (Huxley, 1958; Huxley, 1965; Forrest et al., 1975).

Muscle Contraction

Nerves and the Nature of Stimuli

A muscle contraction is initiated by a stimulus that arrives at the sarcolemma of the muscle fiber. In skeletal muscle, contraction is usually initiated by a nervous stimulus that starts in the brain or spinal cord, and is transmitted to the muscle via a nerve called a motor nerve (Huxley, 1958; Huxley, 1965; Forrest et al., 1975).

In living cells under normal resting conditions an electrical potential exists between the inside and outside of the cell. This membrane potential is positive on the outer surface and negative inside the cell (Huxley, 1958; Forrest et al., 1975).

The membrane potential in nerve and muscle is the result of the active transport of ions through the membrane, the selective permeability characteristics of the membrane to the diffusion of ions and small molecules, and the unique ionic composition of the intracellular and extracellular fluids (Forrest et al., 1975).

Nerve and muscle fibers have the unique capability of transmitting an electrical impulse, called an action potential, along their membrane surfaces. The action potential of muscle is transmitted to each myofibril in the interior of the fiber by the transverse tubule (T tubule) system. Impulses enter the fiber along the T tubules and, at the triad, is transferred to the sarcoplasmic reticulum that surrounds each myofibril (Forrest et al., 1975). When an action potential is transferred from a motor nerve or unit to muscle fibers, via a motor "end-plate", it initiates muscle contractions. The duration of action potentials in muscle differs from the one in nerve fibers. An action potential travels along the membrane surface of the nerve fiber and is actually a wave of reversing electrical polarization resulting from chemical changes in the membrane. In some unknown way this causes a single twitch. When nerve impulses arrive at the motor nerve in rapid succession, the twitches run together, and the muscle maintains its contraction as long as the stimulation continues (or the muscle becomes exhausted). When the nerve stimulation stops, the muscle automatically relaxes. This is the electro-chemical process (Huxley 1958; Huxley, 1965; Forrest et al., 1975).

A separate nerve fiber may activate each muscle fiber for very delicate movement. For nondelicate movement, one nerve fiber may branch and serve one hundred or more muscle fibers. The "all-or-none principle" means a single muscle fiber under sustained nervous stimulation always contracts to the maximum capacity. The ability of a muscle as a whole to contract with different degrees of intensity is dependent not on the ability of individual fibers to contract to different extents, but on the fact that different numbers of fibers in the muscle can be stimulated to contract. Only a small proportion of fibers contract to produce a weak muscular contraction while many fibers respond in strong muscular contraction (Cassens, 1971).

Contraction of Skeletal Muscle

During the resting stage nearly all the calcium in a muscle fiber is bound in the sarcoplasmic reticulum (SR). When the nerve signal to initiate contraction arrives at the muscle cell, it causes the release of calcium from the SR into the sarcoplasmic fluid. The increased free Ca^{++} concentration (10^{-7} M) in the sarcoplasm is the trigger initiating the contractile mechanism and stimulates the splitting of ATP by myosin filaments (Bendall, 1963; Pearson, 1971; Murray and Weber, 1974; Forrest et al., 1975). ATP does not interact with either of the regulatory proteins, troponin or tropomyosin. The released Ca^{++} ions are bound by troponin (Murray and Weber, 1974). This relieves the inhibition that tropomyosin and troponin exert on crossbridge formation between actin and myosin in the relaxed state. Myosin is now free to form crossbridges between the filaments. These crossbridges develop a contractile force, and the actin filaments in each half of the sarcomere are pulled

toward the center of the sarcomere. The protein complex formed when actin and myosin interact at the crossbridge is called actomyosin, which contracts upon exposure to ATP (Huxley, 1958; Forrest et al., 1975). Immediately upon release of Ca^{++}, the "Ca^{++} pump" begins uptake of free Ca^{++} back into the SR and relaxation occurs (Murray and Weber, 1974).

For the power stroke phase, the contraction of skeletal muscle directly involves four of the myofibrillar proteins: actin, myosin, tropomyosin and troponin. Crossbridges formed between the filaments by myosin generate the contractile force during contraction. Crossbridges are composed, presumably, of those parts of myosin molecules which are directly involved in the association with actin. Contraction by bridges results from the ability of bridges to oscillate back and forth and attach with specific sites on the actin filament. They then pull the filament a short distance (approximately 100 Å) and return to their original configuration, ready for another pull. Thus comes the term oscillating bridges or a "ratchet device" meaning that at the molecular level, bridges can reverse direction without reversing the contraction (Huxley, 1958; Huxley, 1965; Pearson, 1971; Forrest et al., 1975). Murray and Weber (1974) describe this as a swiveling motion. Thick filaments attach to the thin filaments at a certain angle and then presumably swivel to a different angle, pulling the thin filaments past the thick. The result of this rowing motion is to pull the filaments into greater overlap, thus decreasing the distance between Z lines and shortening the muscle.

In relaxed muscle there are no crossbridges between actin and myosin filaments, and the interdigitating filaments of each sarcomere slide

freely over one another due to the presence of ATP and the absence of sufficient Ca^{++} in the sarcoplasm to stimulate contraction. The reverse effect such as the formation of permanent links between the actin and myosin filaments in the total absence of ATP explains the rigidity of muscles in rigor mortis, e.g. when the muscles' supply of ATP has been used up, they "lock" like a piston which has been deprived of lubrication (Huxley, 1958). Nauss and Davies (1966) said in the absence of ATP the stiffness characteristic of rigor mortis is maintained by continuous tension exerted by the myosin crossbridges upon the actin (thin) filaments.

The two remaining myofibrillar proteins tropomyosin and troponin, are regulatory and assist in turning the contractile prccess "on" and "off" (Huxley, 1958).

It has been found over a wide range of muscle lengths, during contraction and stretching, the length of individual actin and myosin filaments does not change (Partmann, 1963). When the muscle shortens enough, the ends of filaments will meet; this happens first with the thin filaments and then with the thick. Under such conditions, new bands are observed suggesting the ends of the filaments crumple or overlap. These effects seem to be a result of shortening, not the cause of contraction (Huxley, 1958).

The length of the A band is equal to the length of the thick filaments, both which remain constant in length. The I band and H zone widths vary, being widest when the muscle is stretched and narrower as the muscle shortens. Because the H zone's length corresponds with changes in the I band, the distance from the end of one H zone through

the Z line to the beginning of the next H zone remains approximately the same. This distance is equal to the length of the thin filaments, so they too do not alter their length by any large amount. In severely contracted muscle, the actin filaments meet, or actually overlap, in the center of the A band, and the Z lines may lie against the ends of the myosin filaments (Huxley, 1958; Forrest et al., 1975).

Most ATP is in the form of a magnesium ion (Mg^{++}) complex and its presence prevents interaction of actin and myosin (crossbridge formation). Mg-ATP is the "lubricant" permitting actin and myosin filaments to slide passively over one another (Huxley, 1958; Pearson, 1971; Forrest et al., 1975). Tropomyosin and troponin inhibit crossbridge formation when the sarcoplasmic Ca^{++} concentration is low and Mg-ATP concentration is high (Forrest et al., 1975).

The first step in relaxation is the repolarization of the action potential, which returns the membrane potential to its resting value. Secondly, the Ca^{++} concentration in the sarcoplasm is returned to its original level. As troponin loses this Ca^{++}, it is again able to inhibit the formation of crossbridges. Release of calcium from the terminal cisternae of the triads has a triple effect: allowing contraction while stimulating ATPase activity and activating the processes that pump Ca^{++} back into the terminal cisternae to end the contraction (Murray and Weber, 1974; Forrest et al., 1975).

Sources of Energy for Muscle Contraction and Function

ATP is generally believed to be the direct source of energy for the contractile process, for the pumping of calcium during relaxation, and

for maintaining the sodium and potassium gradients across the sarcolemma (Murray and Weber, 1974; Forrest et al., 1975).

When an animal is slaughtered, muscle does not instantaneously stop living and become meat. ATP continues to provide energy for a period of time. Several pathways attempt to maintain the ATP level after death much as in living muscle. Phosphocreatine is the most immediate source of energy mobilized for ATP synthesis. The reaction: ADP + phosphocreatine = ATP + creatine is catalyzed by the enzyme creatine kinase, and though it is reversible, it lies strongly in the direction of ATP synthesis. This accounts for rapid restoration of ATP during contraction. The concentration (6.2 u mole/gr) of phosphocreatine in resting muscle is about twice that of ATP (Forrest et al., 1975).

The most efficient mechanism for ATP synthesis is aerobic metabolism, where glucose is completely oxidized to CO_2 by converting glucose to pyruvic acid and oxidizing pyruvic acid via the tricarboxylic acid (TCA) cycle and its associated phosphorylations (White et al., 1964). A total of twelve moles of ATP are produced for each mole of acetyl utilized in the cycle (Pearson, 1971).

Whenever energy demand exceeds the ability to provide sufficient oxygen for oxidative resynthesis of ATP, ATP must be resynthesized anaerobically. Virtually all cells can partially oxidize glucose under anaerobic conditions, which results in a net yield of two moles of ATP for each glucose molecule that is converted to lactic acid (Glucose + 2ATP + 2P = 2 lactic acid). Anaerobic metabolism is able to supply energy for only a short time. A major feature of this alternate mechanism is the accumulation of lactic acid which lowers the muscle pH and inhibits further contraction (Pearson, 1971; Forrest et al., 1975).

If pH values are less than 6.0-6.5, the rate of glycolysis is drastically reduced, with a proportional reduction in ATP synthesis. Under these conditions fatigue develops quite rapidly, and muscle is no longer able to contract due to insufficient energy and excess acidity (Forrest et al., 1975).

Glycolysis provides a means for rapidly obtaining ATP under anaerobic conditions, such as occur in normal living muscle in times of stress or after death until glycogen has been dissipated. Although glycolysis results in synthesis of ATP, the process begins by utilizing ATP in the phosphorylation of glucose. Thus, total synthesis of ATP in glycolysis must exceed the amount required by this reaction if there is to be a net gain in energy. Glycolysis is catalyzed by high concentrations of ADP and AMP, whereas a build-up of ATP acts as a control mechanism to block glycolysis (Pearson, 1971).

The same author noted under anaerobic conditions, pyruvic acid is reduced to lactic acid, two moles are produced for each mole of glucose oxidized. Lactic acid formation is favored even though the reaction must be reversed in order to undergo utilization during aerobic conditions. Lactic acid formed in glycolysis is tuilized largely to form muscle glycogen; however, large quantities of lactic acid are found even in resting muscle.

Lactic acid formation supplies energy for the rehabilitation of creatine phosphate, which continues to furnish energy for muscle contraction. Following death, however, there is a decline in pH, the extent depending upon the nature and condition of the muscle at the precise moment circulation ceases. Lactic acid is not required for development of rigor mortis (Pearson, 1971).

According to this author, at death glucose can no longer provide energy for metabolism, so only three sources are available for continuation of glycolysis, namely, ATP, creatine phosphate and glycogen. Neither ATP nor creatine phosphate is present in appreciable quantities in muscle which leaves glycogen as the only major source of energy for glycolysis. Consequently, extent of lactic acid accumulation and resulting pH decline of muscle post-mortem are mainly due to the amount of glycogen present in the tissues at time of slaughter. Normal glucose content in fresh muscle tissue approximates 0.1%.

Glycogen breakdown does not proceed at the same velocity at all stages following death. Where there is rapid equalization of pH throughout the tissues, glycolysis continues at a dimishing rate until either the glycogen stores are completely depleted or the pH is lowered enough to completely inhibit glycolytic enzymes (pH lowering usually occurs first) (Pearson, 1971). According to Bate-Smith (1948), this point occurs at a pH slightly lower than 5.4. Partmann (1963) found that until glycogen reserves are depleted or a pH value of 5.4 in the muscle tissue is reached, both breakdown of ATP and its resynthesis by the glycolytic cycle will take place. These counteracting processes run to the end of rigor development.

Even though ample glycogen may still be present at this pH (5.4), glycogen breakdown ceases. However, the glycolytic enzymes are not irreversibly inactivated; and if the pH is increased, breakdown of glycogen proceeds (Pearson, 1971).

Rigor Mortis

The development of rigor mortis occurs shortly after death and is characterized by stiffness and inextensibility of muscles. All muscle

cells have contracted and the rigor complex becomes firm once the myosin heads firmly attach to actin regardless of the presence of Ca^{++}. Complete examination of the series of events during muscle contraction and those occurring in rigor indicates resemblance between the two processes. Bendall (1951) concluded rigor mortis and muscle contraction are essentially the same process, except rigor is irreversible under normal conditions. The results of several workers (Marsh, 1954; Locker, 1959; Partmann, 1963) have also indicated muscle contraction and rigor develop through the same mechanism. However, Nauss and Davies (1966) noted stimulation is necessary to initiate contraction in normal living tissue, whereas, following death the contractile components develop tension without external stimuli.

Cold Shortening

Locker and Hagyard (1963) described a phenomenon called cold shortening in which bovine muscles in a pre-rigor condition shortened up to 50% or more when exposed to 0C, a common chilling temperature. The extent of cold shortening was inversely related to the degree of rigor onset at the time of cold application, or shortening occurred prior to the development of full rigor. Similar observations were reported by Merkel and Pearson (1975).

Shortening exhibited temperature dependence (Bendall, 1951; Parrish et al., 1969; Newbold and Harris, 1972); however, not all muscles showed the same temperature dependence (Newbold and Harris, 1972). Marsh and Leet (1966) suggested the ultimate tenderness of meat might be affected by temperature during the first few hours post-mortem. Pre-rigor shortening was most severe at 0C (Merkel and Pearson, 1975), and at 0C

to 10C, shortening began rapidly and usually immediately after death and prior to rigor mortis. Shortening was minimal at 15C to 20C but was progressively greater above or below this temperature. At 15C shortening accompanied rigor onset (Locker and Hagyard, 1963; Cassens and Newbold, 1967). Cook and Langsworth (1966a) noted minimum shortening between 5C and 20C. Wilson et al. (1960) found temperature effects on shortening much greater in the lower (0C to 15C) than in the upper (20C to 43C) range; and, in addition, accelerated aging to be expected at the higher temperature range might obscure or eliminate entirely any toughening produced during rigor onset. However, Gothard et al. (1966) found muscle from beef sides initially exposed to 20C showed greater contraction and were ultimately less tender than those held at 1C to 2C. Marsh et al. (1968) noted significant toughness developed from cold shortening in muscle of lamb carcasses exposed to air at -18C.

Tenderness

As muscle length decreased up to about 20%, tenderness remained essentially the same. With 35 to 40% shortening, tenderness rapidly decreased. The regular occurrence of peak toughness in samples shortened 40% suggest possible direct involvement of the rigor process, in addition to shortening, in decreasing tenderness of muscle. At 40 to 60% shortening, tenderness increased and a major rupture of the sarcomere could have resulted in tender meat (Marsh and Leet, 1966; Marsh, 1972; Davey and Gilbert, 1974; Marsh et al., 1974). Clearly shortening was not the single cause since both minimal and maximal shortening resulted only in tender meat. However, the simultaneous occurrence of cold shortening with the formation of "rigor crossbridges" might result in

some degree of internal cohesiveness with a consequent increased resistance to cleavage or chewing. A decrease in tenderness with shortening was due to configurational changes in actin-myosin and apparently would occur only when cold application coincided with the early part of the "rapid phase" of rigor onset (Marsh and Leet, 1966).

Actin-myosin interaction accounts for decreased tenderness induced by early post-mortem chilling or freezing. Connective tissue characteristics determine base-line toughness (Marsh, 1972).

Marsh and Carse (1974) noted no "direct relationship" between shortening and tenderness ratings. Stretching a muscle beyond its initial excised length actually caused a small but significant rise in toughness. Further stretching was responsible for increased tenderness.

Locker (1960), Marsh (1964), Herring et al. (1965b) and Marsh and Leet (1966) noted beef and lamb tenderness was markedly dependent on extent of shortening. Toughening induced by shortening was great if the muscle was excised soon after death, and shortening during rigor onset was encouraged (Marsh and Leet, 1966). Breed, age of animal and lack of aging do not affect muscle shortening although they may cause toughening (McCrae et al., 1971).

State of contraction significantly affected tenderness when connective tissue effects were small (Locker, 1960). Experiments conducted by Locker (1960), Herring et al. (1965a), Gothard et al. (1966) and Marsh and Leet (1966) suggested state of muscle contraction may be related to tenderness, and muscles in a fully or partially contracted state were less tender than those not contracted. Herring et al. (1965b) demonstrated lack of tenderness in beef muscle was correlated with shortening.

Sayre et al. (1964) concluded shear values were higher for muscle where rigor onset occurred at pH values below 6.0 than for those in which rigor commenced at higher pH values. Busch et al. (1967) reported shear force increased as pH declined at 2C but became progressively smaller as Ph declined at 37C. An increase in tenderness for beef muscle held at higher temperatures appeared due to high temperature aging. Fredan et al. (1974) revealed neither individual pH values nor degree of post-mortem pH change were useful predictors of shear value for longissimus muscle from steer and heifer carcasses.

The shear values of unfrozen ovine muscle decreased with increasing incubation temperatures from 0C to 10C, remained constant from 15C to 30C and decreased at 40C (Cook and Langsworth, 1966b). Hostetler et al. (1975) found lower shear force values ($P<0.05$) for beef carcasses subjected to an elevated temperature for 48 hr (16C compared to 2C) immediately following slaughter. Temperature conditioning periods did not result in differences in sarcomere length.

Parrish et al. (1969) found little differences in tenderness of longissimus dorsi and semimembranosus muscles between beef carcasses stored at 2C and 15C. Smith et al. (1971) and Marsh et al. (1968) attributed tenderness increases to storage of lamb carcasses at elevated temperatures during the first 16 to 20 hr after slaughter.

Parrish et al. (1973) concluded post-mortem aging of bovine carcasses immediately post slaughter at 16C for 1 day was effective in improving palatability, especially tenderness of steaks from the longissimus. Warner-Bratzler shear decreased for both aging treatments at 1 day; thereafter, little difference was noted between the two treat-

ments with the steaks from 16C aging having lower values than those aged at 2C. Apparently, sarcomere length and Warner-Bratzler shears were inversely related and amount of shear force may be partially a function of sarcomere length. Aging muscle in the carcass at an elevated temperature seemed important in accelerating tenderness from several aspects. First, muscle remaining attached to the bone while rigor mortis occurred minimized shortening. If minimal muscle shortening occurred, it should eliminate any adverse effect of shortening on tenderness. Furthermore, greater fragmentation of myofibrils and greater loss of Ca^{++} sensitivity occurred.

Fields et al. (1976) reported shear force values were numerically lower for treated sides (12, 16 and 20 hr storage periods at 14C to 19C) versus control sides (0C to 2C for 48 hr) but differences were noted only for cow carcasses (versus steer carcasses) in the 20 hr treatment groups. Sarcomere length for beef sternomandibularis muscle samples from delayed chilling treatments were greater ($P<0.05$) than from control treatments. Muscle samples stored for 16 or 20 hr at 14C to 19C had myofibrils with longer sarcomeres than samples stored for 12 hr, which were in turn longer than those from the controls. Increased tenderness was accomplished by pre-rigor storage of beef carcasses at 14C to 19C with response greatest for cow carcasses. The most improvement in tenderness occurred at 20 hr of storage. Further aging at 2C (up to 7 days) appeared to negate a part of the tenderness advantage for treated versus control sides.

Cooling Rate

Within a few minutes of initiation of cooling, cold shortening

started and was three-quarters or more complete within an hour. Increasing the delay between slaughter and cold temperature application resulted in a diminished rate and extent of cold shortening and a more sluggish change in length (Marsh and Thompson, 1958; Locker and Hagyard, 1963; Marsh and Leet, 1966; Marsh et al., 1968; Dutson et al., 1975). If the delay allowed for formation of rigor cross-linkages before shortening began, little or no cold shortening occurred (Marsh and Leet, 1966).

Rate of cooling a beef carcass affected muscle shortening during storage and consequently tenderness (Parrish et al., 1969; Merkel and Pearson, 1975). Cooling rate was determined by ambient temperature, humidity, air velocity, size of body to be cooled and amount of tissue overlying the muscle. Pattern of rigor onset was determined by species, characteristics of individual muscles within a carcass, ante-mortem treatment of the animal and temperature treatment of the carcass after slaughter (Marsh et al., 1968).

Davey and co-workers (1971) established that a chilling rate exceeding 1.4C per hr in the deep tissue of a beef side during the first 6 hr post-mortem caused cold shortening.

McCrae et al. (1971) reported that lamb carcasses hung in the usual way were greatly toughened by early cold application, especially the semimembranosus, longissimus dorsi and gluteus medius muscles. Shear force for the cooked muscles was on the average three times that of the same muscles of carcasses left until rigor onset before cold exposure. By contrast, other muscles examined (notably the semitendinosus) were invariably tender no matter how early or severe the cooling treatment.

Cold shortening could be prevented and improved tenderness insured if rigor mortis was complete before transferring beef and lamb carcasses to the cold (Marsh and Leet, 1966; McCrae et al., 1971).

Dutson et al. (1975) said carcass temperatures within the first 12 hr were important in determining muscle tenderness. Smith et al. (1971) determined that aging lamb carcasses at 16C for periods from 12 to 20 hr before placing at 0C improved tenderness ($P<0.05$) of many muscles. Unless muscles were subjected to blast freezer temperatures while on the carcass or were excised and exposed to 0C to 2C, cold shortening was not likely to occur in the longissimus dorsi.

Davey and Gilbert (1974) reported low temperatures per se were not the sole reason for cold shortening in beef. The ionic calcium balance was the ultimate trigger for cold shortening and lowering the temperature (15C to 2C) upset the activity of the Ca^{++} pump and resulted in a 30- to 40-fold increase in concentration of ionic calcium in the myofibrillar region. A calcium ion concentration increase commenced with variable delays of up to 3 hr post-mortem and developed until rigor onset at 16 to 24 hr, by which time shortenings of up to 60% of initial muscle length occurred. Therefore, chilling seemed to increase the calcium concentration by creating a new balance between release and adsorption of this ion.

Muscle Attachment

Cold shortening is affected by muscle restraint post-mortem. The strain imposed by carcass hanging determined the final state of contraction of each muscle (Locker, 1960). Merkel and Pearson (1975) concluded some

shortening occurred in all beef muscles during chilling. However, the amount of tension on individual muscles differed because most muscles are attached to bone and adjacent muscles. Suspension by the achilles tendon placed considerable tension on some muscles and greatly slackened others. Marsh (1972) revealed lamb muscles stretched in the normal hanging procedure would remain tender through any post-mortem treatment designed to produce cold shortening. Several major muscles, i.e. longissimus dorsi, are capable of very appreciable shortening despite muscle-skeleton attachments due to the lack of tension.

Skeletal restraint but more specifically the degree of stretch or slack imposed on the muscle by attachments before skeletal restraint is encountered, affected shortening in beef and lamb (Herring et al., 1965b; McCrae et al., 1971).

Marsh (1972) noted the skeleton was effective in preventing cold-induced shortening in only certain muscles of the lamb carcass. McCrae et al. (1971) revealed selected lamb muscles were toughened even though the attachments of these muscles to the skeleton remain completely intact during chilling and freezing. Physical prevention of shortening accounted for tenderness of the "invariably tender" class of muscles. Even though cold shortening was especially severe in unrestrained muscles, it also occurred in localized areas of muscle attached to the skeleton (Forrest et al., 1975).

Inconsistencies in lamb skeletal restraint are due to: (1) the severance of one anchor-point of some muscles during normal carcass dressing (sternomandibularis), (2) the absence of a firm muscle-bone junction at one end of the fibers (longissimus dorsi), (3) the "slack"

introduced by unnatural hanging posture (semimembranosus), and even the differential shortening and lengthening without length change if cooling was more rapid in one sector of a muscle than in another (Marsh and Leet, 1966).

Fat Cover

Cold shortening was more severe in the smaller and leaner carcass as compared to the larger and thicker fat-insulated carcass which chilled at a slower rate (Smith et al., 1974; Marsh, 1972; Merkel and Pearson, 1975). Toughening effects of cold shortening were greatest in cattle with less than ½-inch backfat, becoming more pronounced as fat decreases below this amount. No difference in tenderness was found in cattle with ½-inch or more fat. Major differences in tenderness between "fat" higher grading and "thin" lower grading beef were due to fat, including marbling, on slowing down heat dissipation during carcass chilling (Merkel and Pearson, 1975).

Fat carcasses cool more slowly and are more tender than thin carcasses at normal chilling temperatures but are of essentially the same degree of tenderness when chilled more slowly at 15C for the first 15 to 24 hr after slaughter (Merkel and Pearson, 1975). Smith et al. (1974) noted increasing the quantity of subcutaneous fat partially reduces cold temperature chilling effects and, thus, enhanced lamb tenderness.

In beef carcasses, however, the thicker muscle mass and fat cover may allow internal muscle temperature, even at low ambient temperature, to remain high enough to degrade energy supplies for shortening before

conditions for cold shortening can occur (Marsh et al., 1968; Parrish et al., 1969).

Nutritional Regime

Considerable work comparing beef produced from different forage-grain feeding systems was conducted from 1930 through the 1950's, but the results were not conclusive. For example, Foster and Miller (1933) reported carcasses from cattle fed roughage were decidely less palatable than grain finished steers.

Pasture feeding of cattle of British and Brahman breeding was reported by Chapman et al. (1961). The beef from pasture fed cattle was rated by a taste panel as less tender than the drylot fed cattle in the first trial but not in the second; however, only small differences were noted. Malphrus et al. (1962) reported no difference in taste, tenderness, and aroma of beef fed grain in drylot and on pasture.

A trained taste panel could detect no differences in tenderness of beef roasts from either low- or high-energy forage rations (Bayne et al., 1969). Dube et al. (1971) fed steers only silage to 409 kg. or only hay to 340 kg. and then silage to 409 kg. Trained taste panel results indicate that feeding corn silage as compared to hay early in the feeding period results in more desirable steak flavor, juiciness and tenderness scores. McCampbell et al. (1972) reported differences in taste panel scores, flavor intensity and desirability indicating beef produced by winter pasture alone or with a short drylot feeding period was less desirable than beef produced by either drylot or self-fed grain on winter pasture. Purchas and Davies (1974) fed Friesian steers either a

predominantly cereal (barley) diet or a pasture diet for at least 160 days. A 15 member taste panel determined the flavor of S.M. inside roasts from cereal fed animals was more acceptable.

Meat from cattle fed limited amounts of concentrates or all-roughage rations produced very acceptable good or low choice carcasses with less external 12th rib fat thickness and less fat in the 9-10-11th rib section than grain fed cattle. Taste panel tests showed very little difference in tenderness, juiciness and overall palatability in meat from the two levels of nutrition (Henrickson et al., 1965).

Trowbridge (1918) noted greater levels of subcutaneous and intramuscular fat in cattle fed supermaintenance levels versus those on maintenance and sub-maintenance levels. Less fat in the 9-10-11th rib section of pasture-fed cattle as compared to grain-fed cattle was noted by Malphrus (1961). Klosterman et al. (1965) reported cattle fed only roughage had less fat trim than those fed only ground-ear corn. Godbey et al. (1959) noted reduced fatness for carcasses from cattle receiving only forage compared to those fed grain in drylot.

Brown (1954) concluded forage-fed cattle had yellow fat and were leaner than grain finished cattle. Meyer and co-workers (1960) pair-fed a group of 16 steers to a common age of approximately 21.5 months. Grain-fed steers had larger carcasses, superior quality grades (Good plus versus Good minus), and were more tender, flavorful and juicy as compared to forage-fed steers. No differences in shear force values were found. Kropf et al. (1975) utilized 30 carcasses, 10 each from 3 groups: grass fed on Flint Hills pasture without supplement until slaughter, short-fed concentrate for 70 days and long-fed concentrate for at least

150 days. Increased length of grain feeding produced larger, higher grading carcasses with a whiter fat and brighter lean color than grass fed steers. The grain fed steers also received higher scores for flavor, juiciness, tenderness and acceptability from a trained taste panel when compared to the grass steers. Warner-Bratzler shear values corresponded with the tenderness scores of the taste panel. Bowling et al. (1976) compared 30 forage fed steers to 30 grain fed steers. Steaks from grain fed carcasses were more tender as measured by Warner-Bratzler shear and received more desirable scores for flavor and over-all satisfaction from a trained taste panel.

Oltjen et al. (1971) fed steers to a constant weight and noted grain fed steers had a higher carcass quality grade and superior dressing percent compared to steers fed pelleted alfalfa hay. Taste panel data revealed samples (original article did not state what was used) from the alfalfa fed steers were more tender, flavorful and over-all more desirable than from grain finished steers.

Huffman (1974) finished two groups of steers on a pasture with combinations of rye, ryegrass and arrowleaf clover. Ninety days before slaughter the second group was placed on a conventional high energy ration. Both groups of steers graded high Good and had the same yield grade. The organoleptic properties were similar for both groups with the grass finished steers being slightly more tender by WB shear and trained taste panel scores than the grain finished group.

Schupp et al. (1976) reported two year old Angus and Angus-Hereford cross steers produced with grass alone or with increasing amounts of grain all had similar quality and yield grades. The beef was evaluated

by three separate panels: a consumer retail panel, a household consumer panel and a trained taste panel. The panels found only small differences in tenderness, juiciness, flavor and over-all acceptability but with some conflicting results. Bidner (1975) noted type of diet had little influence on organoleptic components of steaks if cattle were fed to comparable weights and grades. The same author observed differences in dressing percent, cutability and eating qualities when cattle were fed a constant time or to a constant age. Differences were attributed to wide variation in final weight and quality grade.

Wanderstock and Miller (1948) conducted extensive studies on various feeding systems including drylot (concentrate feeding), pasture plus grain and complete pasture grazing. Grass fed beef was found to have lower quality grades, less external and internal fat, more yellowish color to the fat and lower steak tenderness score than grain fed beef. In a study comparing limited corn feeding over an entire feeding period versus full feeding of corn during the last portion of the feeding period, Young et al. (1962) observed no effect of these treatments on either yield or quality characteristics.

Conflicting results have been presented concerning palatability characteristics of beef derived from animals produced on forage feeding programs. Reddish (1956) and Chapman et al. (1971) indicated forage-fed cattle produced carcasses with less fat and lower quality grades than grain-fed cattle. Also steaks from forage-fed beef were less tender and juicy than steaks from grain-fed beef. Conversely, Bull et al. (1941) and Hunt et al. (1953) observed no differences in palatability attributes between feeding regimes when the carcasses were equal in fatness.

Cover et al. (1957) found no differences in the eating quality of beef rib steaks resulting from feeding steers 35% versus 70% concentrate over 156 days. Cartwright et al. (1958) produced similar results in comparing 60% milo versus 20% milo rations.

Indices of Palatability

Shear

Theoretically, the property of meat tenderness should be determinable by an objective physical method because organoleptic tenderness is evaluated by chewing, a physical process. The principle advantage of an objective method to measure meat tenderness is elimination of human judgment differences and the fatigue experienced by taste panelists which in turn limits the number of samples evaluated at a given time (Bratzler, 1971).

Although shear force as an indication of tenderness is widely used in research and product control tests, the relation of taste panel tenderness and shear force is still a controversial matter. Many investigations of the relation between shear force, as measured by a variety of mechanical devices, and taste panel ratings have yielded varying but significant correlations (Szczesniak and Torgenson, 1965). Other studies have resulted in conflicting or poor correlations between objective and subjective measures of tenderness; and, consequently, the validity of shear force measurements as an indication of meat tenderness has been questioned (Deatherage and Garnatz, 1952; Hurwicz and Tisher, 1954; Wells et al., 1962).

Two major problems in correlating shear force with taste panel scores are the lack of homogenity in muscle and the lack of adequate

training of taste panelists. Within a given muscle, shear force varies from end-to-end (Paul and Bratzler, 1955; Ginger and Wier, 1958) and from location-to-location in a given cross-sectional area (Alsmeyer et al., 1965; Hedrick et al., 1968). Consequently, even by using core samples and taking other customary precautions (Szczesniak and Torgenson, 1965; Khan and Voisey, 1973), samples for shear force measurement do not necessarily have the same tenderness as those submitted to the taste panel, nor are samples submitted to taste panels necessarily uniform in tenderness (Khan et al., 1973).

Khan et al. (1973) noted taste panels discriminated more readily between samples from different muscles than samples from the same or similar muscles. This suggested the mouth became more sensitive to tenderness when there were textural as well as shear force differences. Their results show a very close and definite relation between shear force measurement and taste panel results. Insufficient precision in the sampling and experimental techniques cause conflicting and poor correlations between shear force and taste panel scores reported in the literature. Factors such as use of the same sample for shear force and taste panel assessments and minimization of sample variability for taste panel studies appear importance in obtaining meaningful results.

The instrument most widely used to assess meat tenderness has been the Warner-Bratzler (WB) shear device. Usually this device has been used to determine peak force required to shear through a meat sample of fixed cross-sectional area and of known fiber orientation. Bouton and Harris (1972) and Cross et al. (1973) showed shear force values were more influenced by the muscle fiber properties than by the connective

tissue properties of muscle samples. However, meat toughness was not due solely to muscle fiber properties (Marsh, 1972); and, therefore, variation in reported correlations between shear force and subjective measurements which range from high to low and significant to nonsignificant is to be expected (Szczesniak and Torgenson, 1965). Shear force values correlated poorly with subjective assessment of tenderness when large differences in connective tissue strength occurred (Bouton et al., 1973).

In using a Warner-Bratzler shear device, Bouton et al. (1975) found initial shear values were mainly affected by treatments believed to produce changes in myofibrillar strength. This assumed a deforming force applied to cooked meat structure was borne initially by the myofibrillar structure, which had been coagulated and stiffened by cooking rather than by denatured connective tissue with its rubberlike properties. After initial yield of compression the components of the additional force (e.g. peak force) were related to the increasing strain on the connective tissue structure and to further compression of the myofibrillar structure. In cold-shortened meat the initial shear force and peak force values were nearly the same so that the relative contributions of the connective tissue and myofibrillar structures were more difficult to separate.

Sarcomere Length

The state of bovine muscle contraction as measured by sarcomere length was found to be associated with tenderness. As muscle fibers shortened, muscle tenderness decreased and fiber diameter increased

(Locker, 1960; Herring et al., 1965b; Herring et al., 1967; Marsh and Carse, 1974; Hostetler et al., 1970; Hostetler et al., 1975). Smith et al. (1974) and Herring et al. (1965a,b) found longer sarcomeres were associated with increased beef tenderness. The measurement of sarcomere length of a post-rigor muscle represented a simple, objective method of estimating the degree of contraction and was, therefore, a useful predictor of tenderness (Howard and Judge, 1968).

These same authors noted samples from the medial muscle position were less tender (Allo-Kramer shear), had shorter sarcomeres and higher correlations between sarcomere length and tenderness than from the lateral muscle position. In neither position did sarcomere length account for tenderness variation unaccounted for by combinations of other commonly used carcass variables, indicating a single measure of sarcomere length at a given position was of little value in predicting tenderness if certain carcass parameters were known.

Parrish et al. (1973) reported sarcomeres of myofibrils from 1-, 3-, and 7-day post-mortem longissimus dorsi were similar but all were longer than those from at-death muscle. Sarcomeres of myofibrils from aged semitendinosus, however, increased in length during each post-mortem aging interval. Increased tenderness did not seem to parallel this increased sarcomere length.

Gothard et al. (1966) found considerable lengthening of sarcomeres from beef carcasses during aging for 7 days at 3C. Sarcomere lengths began to increase less than 3 hr after reaching maximum contraction. Fibers were brittle and easily shattered after 6 or 7 days of aging. Shattering always appeared to occur at the levels of the I bands,

suggesting actin protein degradation during aging. This appeared to be associated with tenderization. The degree of contraction after 7 days aging did affect muscle tenderness, particularly in muscles where uninhibited contraction occurred, e.g. no skeletal restraint.

Connective tissue content appears to play a role in the overall tenderness of a muscle at all sarcomere lengths and in the amount of toughening a muscle undergoes as it shortens (Herring et al., 1965b).

Hostetler et al. (1970) concluded equal changes in sarcomere length did not produce equal changes in tenderness. In general, increased sarcomere length was accompanied by an increase in tenderness. In comparing different hanging methods, the muscle with the greatest percent change in sarcomere length was accompanied by the greatest change in tenderness. Individual skeletal muscles had their own characteristic resting sarcomere length. Shortening of sarcomeres to less than resting length increased toughness while stretching of the sarcomere beyond resting length caused little or no change in tenderness. The resting length represented a threshold beyond which increased length had little effect on tenderness. Maximum actomyosin formation theoretically occurred when muscle was fully contracted and the sarcomere was at minimum length. In relaxed muscle, perhaps at resting length, the number of actin-myosin bonds was minimal. When the sarcomere was stretched beyond its normal resting length, some actomyosin formation was still possible; but any accompanying change in tenderness was small. Marsh and Leet (1966) proposed toughness associated with shortened sarcomeres resulted from increased actomyosin formation during rigor.

Sink et al. (1965) found muscles with a long delay phase of rigor had shorter sarcomeres than muscles undergoing a short delay phase, and concluded sarcomere length was dependent upon the time course of rigor.

Cooking Loss

Cook and Langsworth (1966b) reported exudate and cooking losses increased with higher incubation temperatures of lamb carcasses. Fields et al. (1976) reported neither flavor, juiciness nor cooking losses were affected appreciably by pre-rigor storage of beef carcasses at elevated temperatures. Parrish et al. (1973) observed no difference in cooking loss for longissimus steaks held at 0C and 16C and cut 1 day post-mortem.

Cooking loss percentage from steaks prepared by modified broiling to an internal temperature of 66C internally did not differ between short-fed (70 days concentrate) and long-fed (150 days concentrate) cattle, but about 1% more was lost by steaks from grass-fed cattle (Kropf et al., 1975).

Taste Panels

The major purpose of any sensory evaluation study is to provide information regarding the effect (e.g. changes or differences) of experimental treatments upon a particular population (Sidel and Stone, 1976).

Sensory evaluation has been defined as "a scientific discipline used to evoke, measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing" (Prell, 1976).

The reactions by the senses may include:

1. Taste - This includes the basic tastes of sweet, sour, salt and bitter which are sensed on the taste buds, primarily on the tongue.
2. Aroma - The sense of smell perceived directly through the nose and indirectly through the mouth as food is chewed.
3. Muscle sense - Sensation of chewing food by the teeth and through mouth movements (Schultz, 1976).

Experimental Design and Objective

A complete and concise statement of both the project and test objective is essential to design an experiment. The objectives should be classified as major and minor since certain experimental designs give greater precision for some treatment comparisons than for others (Sidel and Stone, 1976; Prell, 1976). Three fundamental types of sensory evaluation are:

1. Discrimination - Measures whether or not samples are different, ability to detect sensory characteristics, or point where a characteristic is first noticed. Paired comparison, duo-trio, triangle and rating difference tests are utilized for this method.
2. Descriptive - Measure qualitative and/or quantitative characteristics (e.g. presence or absence; degree of intensity). Examples of tests employed are quality rating, flavor profile, texture profile, ranking and single samples.

3. Affective - Evaluates preference and/or acceptance and/or opinions of product; the basic like or dislike toward a food product. Methods used as a determination are paired comparison, rank order, single sample and threshold (Schultz, 1976; Prell, 1976).

Testing Conditions

Standardization and control of the physical conditions of the test are essential for reliable results:

1. Testing area - The location of the testing area, presence or absence of distractions and odors, room temperature and humidity, lighting and sound control should be as normal a set of conditions for the consumption of the product as possible.
2. Sample presentation - Decisions regarding the following must be made:
   a. normal serving or a more convenient testing size
   b. serve sample at room temperature, hot, cold or at some characteristic temperature at which it is ordinarily consumed
   c. order or presentation (e.g. normally balanced or randomized)
   d. serve sample alone or in conjunction with a normal product (e.g. hot dog with a bun)
   e. sample code
   f. type of container for samples
   g. utensils for serving
   h. time of day for panels

i. time interval between samples

j. mouth rinsing

k. use of crackers or other materials between samples

l. should samples be swallowed or expectorated (Schultz, 1976; Sidel and Stone, 1976; Prell, 1976).

Panel

These same authors noted selection of judges should depend basically on the purpose of the study. If the study is one in which the consumer is to be represented, then the judges should be selected from the particular target group. Source of the panel must be decided along with panel size, composition (age, sex, etc.) plus methods of selection and training if a trained panel is used. Experienced judges are used in discrimination tests. Either experienced or inexperienced judges qualifying on the basis of acceptance attitudes ("liker" of a product class) are used for effective tests.

Statistical Tests

A primary consideration in the selection of an appropriate statistical test of the experiment's hypothesis is the form of response. Judges' responses may be classified into one or more of the following categories.:

1. Open-end responses - These refer to questions such as "What did you particularly like about sample A?" or "Comments." The experimenter establishes categories of response reflecting statements made by the judges.

2. Selection or choice responses - The judge selects a sample according to criteria such as preference, difference, or a specific attribute.
3. Scaled responses - The judges attach some number or value to each sample or perhaps rank it.

For each response form there are appropriate procedures for statistical analysis such as analysis of variance, balanced-block design, Chi-Square analysis of rank order, t-tests (for paired tests), regression and correlation (Sidel and Stone, 1976).

PH Decline

There is now ample evidence that changes in the myofibrillar component pre-rigor (e.g. during the period between slaughter and the full development of rigor mortis) can markedly influence the tenderness of the resulting meat (Newbold and Harris, 1972).

Usually several hours elapse before rigor mortis is fully developed. During this period glycogen, the carbohydrate reserve in muscle, is converted to lactic acid; and as a reult, the pH of the muscle falls (Newbold and Harris, 1972). The final pH value reached is referred to as the ultimate pH (Callow, 1937). At the same time, the concentration of adenosine triphosphate (ATP), the immediate source of chemical energy for muscle contraction, falls. These two events are closely interrelated (Newbold and Harris, 1972).

Both the rate and extent of the post-mortem fall in pH have been related to the tenderness of the resulting meat. It has been shown with chicken muscle that toughness is increased by treatments which increase the rate of pH (and ATP) fall (deFremery and Pool, 1960; Khan and

Nakamura, 1970). It has also been reported that beef is least tender when the ultimate pH is about 6.0 and increases in tenderness as the ultimate pH increases above or decreases below this value (Bouton et al., 1957). In contrast, the tenderness of rabbit (Miles and Lawrie, 1970), sheep (Bouton et al., 1971) and fish (Kelly et al., 1966) has been shown to be greater with an ultimate pH higher than 6.0.

Factors Affecting Rate and Extent of pH Decline

Fall in muscle pH is a measure of post-mortem glycolysis and, by implication, of the onset of rigor mortis. The rate of pH decline depends on temperature (Bate-Smith and Bendall, 1949; Bendall, 1951; Marsh, 1954; Marsh and Thompson, 1958; Bendall, 1960; deFremery and Pool, 1960; Cook and Langsworth, 1966a; Cassens and Newbold, 1967); but the effect of temperature is not the same with all muscles. For example, with rabbit psoas muscle the lower the temperature in the range 0-37C the more slowly the pH falls (Bendall, 1960). In ox sterno-mandibularis (neck) muscle, however, although the pH falls more slowly the lower the temperature in the range 5-37C, it falls more rapidly at 1C than at 5C during the first few hours post-mortem (Cassens and Newbold, 1967; Newbold and Scopes, 1967).

The rate of pH fall can also vary among different muscles from the same animal and among corresponding muscles from individuals of the same or different species (Lawrie, 1966a). The variability among corresponding muscles is particularly great with pigs (Briskey, 1964) and may be related to the intensity of the nervous stimulus reaching the muscle before and during slaughter (McLoughlin, 1970).

In the living animal the pH of resting muscle is about 7.3. Since the post-mortem fall in pH is the result of the production of lactic acid from glycogen, it is clear that the extent of the pH fall may depend on the amount of glycogen present in the muscle at the time of slaughter. The glycogen content can be reduced by starvation, exhausting exercise, the imposition of pre-slaughter stresses of various sorts, or by struggling at the time of slaughter (Lawrie, 1966b). Ultimate pH values of greater than 7.0 have been obtained by reducing the glycogen reserves before slaughter. Even when there is an adequate supply of glycogen in the muscle at the time of slaughter, the ultimate pH is rarely less than 5.4-5.5; and for reasons which are not yet clear, it is sometimes appreciably higher than this. Abnormally low values, down to 4.8, have been reported in pig muscle (Lawrie et al., 1958).

The rate at which the temperature of the LD decreased was greater for beef carcasses maintained in the 0-2C cooler and pH values for these carcasses evidenced at a slower rate of decline than 14-19C. The ultimate pH (at 48 hr) of the control sides (0-2C) was higher than those held at the elevated temperature (14-19C) (Fields et al., 1976). In contrast, cassens and Newbold (1967) reported temperature at which muscle is stored post-mortem has only a small effect on the ultimate pH.

A relationship between rigor development and cold shortening susceptability exist. Hastening rigor (holding carcass at elevated temperature) enables early loss of cold shortening susceptibility. Immediately after slaughter muscle pH is high (approx. 7.2), and cold shortening susceptibility is maximal but decreases as the muscle approaches rigor. Below pH 6.0 cold shortening is slight (Chrystall,

1976). Delayed chilling (or conditioning) until the muscle pH has fallen below about pH 6.0 ensures only minimal cold shortening will occur. In practice, 21 to 30 hr are required to completely condition lamb at 13C, and 18 to 24 hr at 10C for beef (Locker et al., 1975).

Follett et al. (1974) noted initial pH values of post-rigor excised (PE) semimembranosus muscles were within the range 6.80 ± 0.13. The fall in pH was linear, and the value of 5.54 observed at 5 hr was subsequently maintained. The initial pH in the ante-rigor excised (AE) muscles (SM) was similar (6.80 ± 0.16) but then fell more slowly. The spread in pH values recorded at 36 hr (5.60 ± 0.12) appeared to be directly related to the cooling temperatures used.

LITERATURE CITED

Alsmeyer, R. H., J. W. Thornton and R. L. Hiner. 1965. Cross-sectional tenderness variations among six locations of pork longissimus dorsi. J. Food Sci. 30:181.

Bate-Smith, E. C. 1948. The physiology and chemistry of rigor mortis with special references to the aging of beef. Adv. in Food Res. 1:1.

Bate-Smith, E. C. and J. R. Bendall. 1949. Factors determining the time course of rigor mortis. J. Physiol. 110:47.

Bayne, Barbara H., B. H. Meyer, and J. W. Cole. 1969. Response of beef roasts differing in finish, location and size to two rates of heat application. J. Anim. Sci. 29:283-287.

Bendall, J. R. 1951. The shortening of rabbit muscles during rigor mortis: its relation to the breakdown of ATP and creatinine phosphate in muscle contraction. J. Physiol. (London) 114:71.

Bendall, J. R. 1960. Post-mortem changes in muscle. In "The Structure and Function of Muscle," ed. Bourne, G. H. Academic Press, New York. 3:227.

Bendall, J. R. 1963. Physiology and chemistry of muscle. Proc. Campbell Soup Co. Meat Tenderness Symp. Camden, N. J., p. 33.

Bendall, J. R. 1966. Muscle as a contractile machine. IN "The Physiology and Biochemistry of Muscle as a Food." Eds. E. J. Briskey, R. G. Cassens, and J. C. Trautman. University of Wisconsin Press, Madison, Wis., p. 7.

Bidner, T. D. 1975. A comparison of forage-finished and grain-finished beef. 28th Annual Recip. Meat Conf., p. 301.

Bloom, W. and D. W. Fawcett. 1962. A Textbook of Histology. Saunders, Philadelphia.

Bouton, P. E., A. Howard and R. A. Lawrie. 1957. Studies on beef quality, Part 6. Effects on weight losses and eating quality of further pre-slaughter treatments. CSIRO Australian Div. Food Preserv. Tech. Paper No. 6.

Bouton, P. O., P. V. Harris and W. R. Shorthose. 1971. Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. J. Food Sci. 36:425.

Bouton, P. E. and P. V. Harris. 1972. A comparison of some objective methods used to assess meat tenderness. J. Food Sci. 37:218.

Bouton, P. E., A. L. Fisher, P. V. Harris and R. I. Baxter. 1973. A comparison of the effects of some post-slaughter treatments on the tenderness of beef. J. Food Technol. 8:39.

Bouton, P. E., P. V. Harris and W. R. Shorthose. 1975. Changes in shear parameters of meat associated with structural changes produced by aging, cooking and myofibrillar contraction. J. Food Sci. 40:1122-1126.

Bowling, R. A., T. R. Dutson, Z. L. Carpenter, G. C. Smith and W. M. Oliver. 1976. Comparison of beef finished on forage vs grain. J. Anim. Sci. 42:254 (Abstr.).

Bratzler, L. J. 1971. Palatability factors and evaluation. In "The Science of Meat and Meat Products." Eds. J. F. Price and B. S. Schweigert. W. H. Freeman and Co., San Francisco, Calif., p. 328.

Briskey, E. J. 1964. Etiological status and associated studies of pale, soft, exudative porcine musculature. Adv. Food Res. 13:89.

Briskey, E. J. and T. Fukazawa. 1971. Myofibrillar proteins of skeletal muscle. Adv. in Food Res. 19:229-360.

Brown, W. L. 1954. Beef carcass characteristics as influenced by grass and other roughages. Proc. Recip. Meat Conf. 7:199.

Bull, S. L., R. R. Snapp and H. P. Rusk. 1941. Effect of pasture on grade of beef. 111. Agr. Exp. Sta. Bull. 475.

Busch, W. A., F. C. Parrish, Jr. and D. E. Goll. 1967. Molecular properties of post-mortem muscle. 4. Effect of temperature on ATP degradation, isometric tension parameters and shear resistance of bovine muscle. J. Food Sci. 32:390.

Callow, E. H. 1937. The "ultimate pH" of muscular tissue. Ann. Rept. Food Invest. Board London, p. 49.

Cartwright, T. C., O. D. Butler and S. Cover. 1958. The relationship of ration and inheritance to certain production and carcass characteristics of yearling steers. J. Anim. Sci. 17:540.

Cassens, R. G. and R. P. Newbold. 1967. Effect of temperature on the time course of rigor mortis in ox muscle. J. Food Sci. 32:269.

Cassens, R. G. 1971. Microscopic Structure of Animal Tissues. In "The Science of Meat and Meat Products". W. H. Freeman and Co., San Francisco, Calif., 11-49.

Chapman, H. L., Jr., A. Z. Palmer, J. R. Crockett and J. W. Carpenter. 1961. Performance of cattle of British and Brahman breeding when fattened in drylot and on pasture. Everglades Station Mimeo 61-16.

Chapman, H. L., R. L. Shirley, A. Z. Palmer and J. W. Carpenter. 1971. Vitamin A and E in steer fattening rations. Fl. Agri. Exp. Sta. Bull. 748.

Chrystall, B. B. 1976. Accelerated conditioning of meat. Eighteenth Meat Ind. Res. Conf. (Meat Ind. of N.Z.), 5.

Cook, C. F. and R. F. Langsworth. 1966a. The effect of pre-slaughter environment temperature and post-mortem temperature upon some characteristics of ovine muscle. 1. Shortening and pH. J. Food Sci. 31:497.

Cook, C. F. and R. F. Langsworth. 1966b. The effect of pre-slaughter environment temperature and post-mortem temperature upon some characteristics of ovine muscle. 2. Meat quality. J. Food Sci. 31:504.

Cover, S., T. C. Cartwright and O. D. Butler. 1957. The relationship of ration and inheritance to eating quality of the meat from yearling steers. J. Anim. Sci. 16:946.

Cross, H. R., Z. L. Carpenter and G. C. Smith. 1973. Effects of intramuscular collagen and elastin on bovine muscle tenderness. J. Food Sci. 38:998.

Davey, C. L., K. V. Gilbert and C. I. F. Cox. 1971. Prime Beef Processing. Ann. Res. Rep., Meat Ind. Res. Inst. of New Zealand, p. 41.

Davey, C. L. and K. V. Gilbert. 1971. The mechanism of cold-induced shortening in beef muscle. J. Food Technol. 9:51.

Davey, C. L., K. V. Gilbert and W. A. Carse. 1975. Carcass electrical stimulation to prevent cold shortening toughness in beef. New Zealand J. of Agr. Res. 19:13-8.

Deatherage, F. E. and G. Garnatz. 1952. A comparative study of tenderness determination by sensory panel and by shear strength measurements. Food Technol. 6:260.

deFremery, D. and M. F. Pool. 1960. Biochemistry of chicken muscle as related to rigor mortis and tenderization. Food Res. 25:73.

Devine, C. E. 1976. Accelerated conditioning of meat. Eighteenth Meat Ind. Res. Conf. (Meat Ind. of N. Z.), 10.

Dube, G., V. D. Bramblett, R. D. Howard, B. E. Homler, H. R. Johnson, R. B. Harrington, and J. D. Judge. 1971. Dietary effects on beef composition. J. Food Sci. 36:147-154.

Dutson, T. R., G. C. Smith, R. L. Hostetler and Z. L. Carpenter. 1975. Postmortem carcass temperature and beef tenderness. Amer. Soc. of Anim. Sci. Abstr. CSU., p. 289.

Edwards, G. A., H. Ruska, P. De Souza Santos, and A. Vallejo-Freire. 1956. Comparative cytophysiology of striated muscle with special reference to the role of the endoplasmic reticulum. J. Biophys. Biochem. Cytol. 2:143.

Fredan, H. T., A. H. Martin and G. M. Weiss. 1974. Changes in tenderness of beef longissimus dorsi as related to muscle color and pH. J. Food Sci. 39:532-536.

Fields, P. A., Z. L. Carpenter and G. C. Smith. 1976. Effects of elevated temperature conditioning on youthful and mature beef carcasses. J. Anim. Sci. 42:72.

Follett, M. J., G. A. Norman and P. W. Ratcliff. 1974. The anterigor excision and air cooling of beef semimembranosus muscles at temperatures between -5°C and +15°C. J. Fd. Technol. 9:509.

Forrest, J. C., E. D. Aberle, J. B. Hedrick, M. D. Judge and R. A. Merkel. 1975. Principles of Meat Science. W. H. Freeman and Co., San Francisco, Calif., 25-80, 127-142.

Foster, M. T. and J. C. Miller. 1933. The effects of management and sex on carcasses of yearling cattle. University of Missouri Research Bull. 186.

Ginger, B. and C. E. Wier. 1958. Variation in tenderness within three muscles from the beef round. Food Res. 23:662.

Godbey, E. G., R. F. Wheeler, D. H. Kropf, W. C. Godley and L. V. Starkey. 1959. Winter forage for fattening steers. S. Car. Ag. Exp. Sta. Bull. 469.

Goll, D. E., N. Arakawa, M. H. Stromer, W. A. Busch and R. M. Robson. 1970. Chemistry of muscle proteins as a food. In "The Physiology and Biochemistry of Muscle as a Food, 2." The University of Wisconsin Press, Madison, Wis. pp. 775-781.

Gothard, R. J., A. M. Mullins, R. F. Boulware and S. L. Hansard. 1966. Histological studies of post-mortem changes in sarcomere length as related to bovine muscle tenderness. J. Food Sci. 31:825.

Hanson, J. and J. Lowy. 1963. The structure of F-actin and of actin filaments isolated from muscle. J. Mol. Biol. 6:46.

Hedrick, H. B., W. C. Stringer, R. J. Epley, M. A. Alexander and G. K. Krause. 1968. Comparison of factors affecting Warner-Bratzler shear values of beef steaks. J. Anim. Sci. 27:628.

Henrickson, R. L., L. S. Pope and R. F. Hindrickson. 1965. Effect of rate of gain of fattening beef calves on carcass composition. J. Anim. Sci. 24:507.

Herring, H. K., R. G. Cassens and E. J. Briskey. 1965a. Sarcomere length of free and excised bovine muscle at low temperature as related to tenderness. J. Sci. Food Agr. 16:379.

Herring, J. K., R. G. Cassens and E. J. Briskey. 1965b. Further studies on bovine muscle tenderness as influenced by carcass position, sarcomere length and fiber diameter. J. Food Sci. 30:1049.

Herring, H. K., R. G. Cassens, C. G. Suess, V. H. Brungardt and E. J. Briskey. 1967. Tenderness and associated characteristics of stretched and contracted bovine muscle. J. Food Sci. 32:317.

Hostetler, R. L., W. A. Landman, B. A. Link and H. A. Fitzhugh, Jr. 1970. Influence of carcass position during rigor mortis and tenderness of beef muscle. J. Anim. Sci. 31:47.

Hostetler, R. L., Z. L. Carpenter, G. C. Smith and T. R. Dutson. 1975. Comparison of postmortem treatments for improving tenderness of beef. J. Food Sci. 40:223.

Howard, R. D. and M. D. Judge. 1958. Comparison of sarcomere length to other predictors of beef tenderness. J. Food Sci. 33:456.

Huffman, D. L. 1974. Carcass characteristics - current research. Proceedings Alabama Beef Industry Conference, Auburn Univ.

Hunt, R. E., C. M. Kincaid and R. C. Carter. 1953. Grain or grass-fattened cattle. Agric. Exp. Sta. Bull. 458. Va. Polytechnic Inst., Blacksburg, Va.

Hurwicz, H. and R. G. Tischer. 1954. Variation in determination of shear force by means of the Warner-Bratzler shear. Food Technol. 2:391.

Huxley, H. E. 1958. The contraction of muscle. Scientific American 199:66.

Huxley, H. E. 1963. Electron microscope studies on the structure of natural and synthetic protein filaments from striated muscle. J. Mol. Biol. 7:281.

Huxley, H. E. 1965. The mechanism of muscular contraction. In Scientific American. W. H. Freeman & Co., San Francisco, Calif. 213:18.

Kelly, K., N. R. Jones, R. M. Lowe and J. Olley. 1966. Texture and pH in fish muscle related to 'cell fragility' measurements. J. Food Technol. 1:9.

Khan, A. W. and R. Nakamura. 1970. Effects of pre- and post-mortem glycolysis on poultry tenderness. J. Food Sci. 35:266.

Khan, A. W., C. P. Dentz and L. Van den Berg. 1973. A research note. Relation between shear force and tenderness of beef. J. Food Sci. 38:1258.

Khan, A. W. and P. W. Voisey. 1973. Determination of shear force value of major beef muscles. Can. Inst. Food Sci. Technol. J. 6:47.

Klosterman, E. W., P. G. Althouse and V. R. Cahill. 1965. Effect of corn silage or ground ear corn full fed at various stages of growth and fattening upon carcass composition of beef cattle. J. Anim. Sci. 24:454.

Kropf, D. H., D. M. Allen and G. J. Thouvenelle. 1975. Grass-fed, short-fed and long-fed beef compared. Kansas State Cattleman's Day Report 62:78.

Lawrie, R. A., D. P. Gatherum and H. P. Hale. 1958. Abnormally low ultimate pH in pig muscle. Nature 182:807.

Lawrie, R. A. 1966a. "Meat Science", p. 78. Pergamon Press, Oxford.

Lawrie, R. A. 1966b. "Meat Science", p. 117. Pergamon Press, Oxford.

Locker, R. H. 1959. Striation patterns of ox muscle in rigor mortis. J. Biophy. Biochem. Cytol. 6:419.

Locker, R. H. 1960. Degree of muscular contraction as a factor in tenderness of beef. Food Res. 25:304.

Locker, R. H. and C. J. Hagyard. 1963. A cold shortening effect in beef muscles. J. Sci. Food Agri. 14:787.

Locker, R. H., C. L. Davey, P. M. Nottingham, D. P. Haughey and N. H. Law. 1975. New Concepts in Meat Processing. Adv. Food Res., 21:157.

Malphrus, L. D. 1961. Consumer preference for beef fattened on grass and grain. Proc. 13th Res. Conf., Am. Meat Inst. Foundation, Chicago, Ill.

Malphrus, L., R. Edwards, D. Kropf and M. Marbut. 1962. Consumer preference for beef produced on grass and grain or in drylot: a comparison. So. Car. Agr. Exp. Sta. Bull. 499.

Marsh, B. B. 1954. Rigor mortis in beef. J. Sci. Food Agr. 5:70.

Marsh, B. B. and J. F. Thompson. 1958. Rigor mortis and thaw rigor in lamb. J. Sci. Food Agr. 9:417.

Marsh, B. B. 1964. Meat quality and rigor mortis. In "Carcass Composition and Appraisal of Meat Animals." CSIRO, Melbourne, Paper No. 12.

Marsh, B. B. and N. G. Leet. 1966. Studies in meat tenderness. 3. The effects of cold shortening on tenderness. J. Food Sci. 31:450.

Marsh, B. B., P. R. Woodhams and N. G. Leet. 1968. Studies in meat tenderness. 5. The effects on tenderness of carcass cooling and freezing before the completion of rigor mortis. J. Food Sci. 33:12.

Marsh, B. B. 1972. Post-mortem muscle shortening and meat tenderness. Proc. Meat Ind. Res. Conf., p. 109.

Marsh, B. B. and W. A. Carse. 1974. Meat tenderness and the sliding filament hypothesis. J. Food Technol. 9:129.

Marsh, B. B., N. G. Leet and M. R. Dickson. 1974. The ultrastructure and tenderness of highly cold-shortened muscle. J. Food Technol. 9:141.

McCrae, S. E., C. G. Seccombe, B. B. Marsh and W. A. Carse. 1971. Studies in meat tenderness. 9. The tenderness of various lamb muscles in relation to their skeletal restraint and delay before freezing. J. Food Sci. 36:566.

McCampbell, J. C., B. E. Green and R. S. Lowrey. 1972. Cooking and palatability of beef from winter pasture with and without grain and drylot fed cattle. J. Anim. Sci. 35:200 (Abstr.).

McLoughlin, J. V. 1970. Muscle contraction and post-mortem pH changes in pig skeletal muscle. J. Food Sci. 35:717.

Merkel, R. A. and A. M. Pearson. 1975. Slow chilling could produce tender beef from lean carcasses. Meat Ind. 21 (5):27.

Meyer, B., J. Thomas, R. Buckley and J. Cole. 1960. The quality of grain finished and grass finished beef as affected by ripening. Food Technol. 1(1):4.

Miles, C. A. and R. A. Lawrie. 1970. Felation between pH and tenderness in cooked muscle. J. Food Technol. 5:325.

Murray, J. M. and A. Weber. 1974. The cooperative action of muscle proteins. Scientific American. W. H. Freeman & Co., San Francisco, Calif. 230 (2):58-71.

Nauss, K. M. and R. E. Davies. 1966. Changes in phosphate compounds during the development and maintenance of rigor mortis. J. Biol. Chem. 241:2918.

Newbold, R. P. and R. K. Scopes. 1967. Post-mortem glycolysis in ox skeletal muscle. Effect of temperature on the concentration of glycolytic intermediates and cofactors. Biochem. J. 105:127.

Newbold, R. P. and P. V. Harris. 1972. The effect of pre-rigor changes on meat tenderness. J. Food Sci. 37:337.

Oltjen, R. R., T. S. Rumsey and P. A. Putnam. 1971. All-forage diets for finishing beef cattle. J. Anim. Sci. 32:327.

Paul, C. P. and L. J. Bratzler. 1955. Studies on tenderness of beef. II. Varying storage time and conditions. Food Res. 20:626.

Parrish, F. D., Jr., R. E. Rust, G. R. Popenhagen and B. E. Miner. 1969. Effect of postmortem aging time and temperature on beef muscle attributes. J. Anim. Sci. 29:398.

Parrish, F. D., Jr., R. B. Young, B. E. Miner and L. D. Andersen. 1973. Effect of post-mortem conditions on certain chemical, morphological and organoleptic properties of bovine muscle. J. Food Sci. 38:690.

Partmann, W. 1963. Post-mortem changes in chilled and frozen muscle. J. Food Sci. 28:15.

Pearson, A. M. 1971. Muscle function and post-mortem changes. In "The Science of Meat and Meat Products". Eds. J. F. Price and B. S. Schweigert. W. H. Freeman and Co., San Francisco, Calif., 208-226.

Prell, P. A. 1976. Preparation of reports and manuscripts which include sensory data. Food Technol. 11:40.

Purchas, R. W. and H. L. Davies. 1974. Carcass and meat quality of Friesian steers fed on either pasture or barley. Aust. J. Agric. Res. 25:183-192.

Reddish, R. L. 1956. Slaughter and carcass characteristics of Santa Gertrudis steer produced by different management practices. Ph.D. Thesis. Texas A & M University, College Station, Texas.

Sayre, R. N., B. Kiernat and E. J. Briskey. 1964. Processing characteristics of porcine muscle related to pH and temperature during rigor mortis development and to gross morphology 24-hr post-mortem. J. Food Sci. 26:175-181.

Sayre, R. N. 1970. Chicken myofibril fragmentation in relation to factors influencing tenderness. J. Food Sci. 35:7.

Schultz, H. 1976. Sensory evaluation. Meat Industry. 2:59.

Schupp, A., T. Bidner, W. McKnight, D. Smith and J. Carpenter, Jr. 1976. Consumer acceptance of forage finished and limited grain finished beef. Phase one. LSU-D.A.E. Res. Report 503.

Sidel, J. L. and H. Stone. 1976. Experimental design and analysis of sensory tests. Food Technol. 11:32.

Sink, J. D., R. G. Cassens, W. G. Hoekstra and E. J. Briskey. 1965. Rigor mortis pattern of skeletal muscle and sarcomere length of the myofibril. Biochim. et Biophys. Acta 102:309.

Smith, G. C., T. C. Arango and Z. L. Carpenter. 1971. Effects of physical and mechanical treatments on the tenderness of the beef longissimus. J. Food Sci. 36:445.

Smith, G. C., T. R. Dutson, R. L. Hostetler and Z. L. Carpenter. 1974. Subcutaneous fat thickness and tenderness of lamb. J. Anim. Sci. 39:174.

Smith, M. C., Jr., M. D. Judge and W. J. Stadelman. 1969. A "cold shortening" effect in avian muscle. J. Food Sci. 34:42.

Snedecor, G. W. and W. G. Cochran. 1973. Statistical Methods (6th Ed.). The Iowa State University Press, Ames, Iowa.

Szczesniak, A. S. and K. W. Torgeson. 1965. Methods of meat texture measurement viewed from the background of factors affecting tenderness. Adv. Food Res. 14:33.

Trowbridge, P. F., C. R. Moulton and L. D. Haigh. 1918. Effect of limited foods on growth of beef animal. Mo. Agr. Exp. Sta. Res. Bull. 28.

Wanderstock, J. J. and J. I. Miller. 1948. Quality and palatability of beef as affected by method of feeding and carcass grade. Food Res. 13:291.

Wells, G. H., N. K. May and J. J. Power. 1962. Taste panel and shear press evaluation of tenderness of freeze dried chicken as affected by age and preslaughter feeding of ions. Food Technol. 16:137.

White, A., P. Handler and E. L. Smith. 1964. Principles of Biochemistry, 3rd ed. McGraw-Hill, New York, p. 293.

Wilson, G. D., P. D. Brown, C. Pohl, C. E. Weir and W. R. Chesbro. 1960. A method for the rapid tenderization of beef carcasses. Food Technol. 14:86.

Young, L. G., G. A. Brahaman and R. J. Deans. 1962. Influence of rate of grain feeding on gain and carcass characteristics of calves. J. Anim. Sci. 21:621.

Chapter III

EFFECTS OF ELEVATED TEMPERATURE CONDITIONING ON BEEF CARCASSES FROM FOUR NUTRITIONAL REGIMES

Introduction

Different feeding practices are of interest because of economic pressures. Carcasses derived from cattle finished on forage and/or roughage as compared with cattle finished on concentrate have less subcutaneous, intermuscular and intramuscular fat (Trowbridge, 1918; Godbey et al., 1959; Klosterman et al., 1965). As these fat depots decrease, carcass heat dissipates more rapidly upon chilling. Within limits as the cooling rate increases, cold shortening may result and adversely affect tenderness of beef and lamb (Davey et al., 1971; Parrish et al., 1969; Smith et al., 1969; Merkel and Pearson, 1975; Marsh, 1977). Smith et al. (1974) indicated increased subcutaneous fat alleviated, in part, the effect of cold shortening in lamb and improved product tenderness.

Locker (1960), Marsh (1964) and Herring et al. (1965) noted beef and lamb tenderness was markedly dependent on the extent of muscle shortening. Increasing the delay between slaughter and cold temperature application resulted in a diminished rate and extent of cold shortening, e.g. extent of shortening was inversely related to degree of rigor onset at cold application time (Marsh and Thompson, 1958; Locker and Hagyard, 1963; Marsh and Leet, 1966; Marsh et al., 1968; McCrae et al., 1971; Dutson et al., 1975; Merkel and Pearson, 1975). Excision of the *longissimus* muscle prior to rigor and subjection to a cold environment

caused extensive shortening and resultant toughness in lamb (Marsh and Leet, 1966).

Minimum shortening in fresh ox muscle was observed by Locker and Hagyard (1963) when the ambient temperature during the time course of rigor mortis was 14C to 19C. Shortening was progressively greater when the pre-rigor holding temperature was increased or decreased beyond this temperature range.

Smith et al. (1971) determined that aging lamb carcasses at 16C for 12 to 20 hr before chilling at 0C improved tenderness of many muscles. Fields et al. (1976) found a more tender product from beef carcasses held at 14C to 19C for 20 hr versus normally chilled sides (2C). Busch et al. (1967) noted storage temperatures of 2C and 15C for 6 to 12 hr did not affect tenderness of semitendinosus muscles attached to beef carcasses; however, improved tenderness was observed when muscles were excised immediately after death and stored at 16C for 2 days. Post-mortem aging of ovine and bovine carcasses immediately post slaughter at elevated temperature (approximately 16C) for 9, 12 and 16 hr (Marsh et al., 1968), 24 hr (Parrish et al., 1973) and 20 hr (Hostetler et al., 1975) was effective in improving tenderness when compared to conventionally chilled counterparts, 2C.

Considerable work comparing beef produced from different forage-grain feeding systems has been conducted with conflicting results. Oltjen et al. (1971), Huffman (1974) and Schupp et al. (1976) reported forage finished steers were comparable or superior to grain finished steers. Meyer et al. (1960), Kropf et al. (1975), and Bowling et al. (1976) all found forage finished cattle to be less desirable than grain

fed steers. Carcasses from cattle fed roughage had less palatable and less tender cuts than cattle fed grain for varying lengths of time prior to slaughter (Foster and Miller, 1933; Wanderstock and Miller, 1948; Reddish, 1956; Chapman et al., 1961; Chapman et al., 1971; McCampbell et al., 1972; Purchas and Davies, 1974; and Schupp et al., 1976). Bull et al. (1941) and Hunt et al. (1953) observed no differences in palatability attributes between feeding regimes when the carcasses were equal in fatness. No appreciable differences in palatability of cuts from beef produced on roughage versus concentrate ration was found by Hankins and Barbella (1941) and Malphrus et al. (1962).

Therefore, evaluation of the incidence of cold shortening due to selected feeding regimes and the effect of elevated temperatures in elimination of this condition were conducted.

Materials and Methods

Thirty-eight crossbred steers of known background obtained from the U.S.D.A. Meat Animal Research Center at Clay Center, Nebraska were randomly assigned to four nutritional regimes. All animals were initially fed on a brome and bluestem pasture and supplemented with a wintering ration of protein and alfalfa. Ten grass-fed animals were slaughtered directly off pasture at the end of summer. Ten steers were fed an additional 49 days (short-fed) and eight others for 98 days (long-fed) on a 75% cracked corn (4-02-932), 5% supplement and 20% alfalfa haylage (3-08-151) ration, with 10 fed 98 days on a 36% cracked corn (4-02-932), 40% corn silage (3-02-824), 20% alfalfa haylage (3-08-151) and 4% supplement ration (silage-fed). At slaughter steers were approximately 18 months of age. All cattle were slaughtered after fasting overnight (12-15 hr).

Temperature Conditioning

Approximately 1 hr post-mortem the right half of each carcass was conventionally chilled at 3C until 48 hr post-mortem and left halves were conditioned at 13C for 8 hr then chilled at 3C until carcass fabrication at 48 hr post-mortem.

Temperature Decline

Utilizing 5 test animals from each feeding regime and beginning 1 hr post-mortem, temperature readings were taken hourly until 12 hr and at 24 hr post-mortem on each carcass half (unshrouded) in three locations. Calibrated thermometers were inserted through the obturator

foramen into the geometric center of each round, in the geometric center of the loin at the 13th rib and at this point under the subcutaneous fat.

pH Decline

Beginning at 1 hr post-mortem, pH readings were recorded hourly until 8 hr and at 24 hr post-mortem on each carcass half. Samples from the left and right halves (0.64 cm thick) were taken from corresponding locations on each psoas major muscle, beginning at the last lumbar vertebrae and continuing anteriorally. At the appropriate sampling time a .64 cm portion was removed adjacent to the sample location and discarded to allow exposure of fresh muscle. pH readings were taken on the fresh-cut surface using a Corning pH meter equipped with a Markson surface electrode.

Yield and Quality Grades

U.S.D.A. yield and quality grade factors were determined approximately 48 hr post-mortem.

Taste Panel, Shear, and Cooking Loss Analyses

Taste panel responses were obtained only on the longissimus muscle and shear force determinations were on the longissimus (LD), semitendinosus (ST), semimembranosus (SM) and biceps femoris (BF) muscles. Percent total cooking, drip and volatile loss data involved all muscles except the BF.

The BF, ST, SM and LD (through the 13th rib) muscles were excised intact from each carcass half. The midline of each muscle was located by determining the maximum length and dividing by two. Beginning at the midline and continuing anteriorally, a 3.0 cm thick steak was removed for

taste panel, shear force and determination of cooking losses. All steaks were vacuum packaged and stored at -26C until evaluated. Maximum storage time, prior to evaluation, was 34 days for grass- and short-fed, 53 days for long-fed and 73 days for silage-fed samples.

Steaks were thawed at 2C for 24 hr, removed from the vacuum package, rinsed, blotted, weighed and modified oven broiled in a rotary oven at 163C to an internal temperature of 66C. Internal temperature was monitored with a cooking thermometer inserted in the geometric center of each steak. Upon cooking, percent total cooking, drip and volatile loss were determined.

Taste panel evaluations for tenderness, juiciness, desirability of flavor and overall acceptability on the LD muscle were solicited from an 8-member trained panel (6 used at each session) using a 9-point hedonic scale for each response. Panelist selection and training were accomplished by presenting samples of differing degrees of juiciness and tenderness (different quality grades) and evaluating individual sensitivity to discerning differences by use of triangle comparisons (Kramer and Twigg, 1970).

Panelists were positioned randomly in individual booths, served half of a 1.91 cm diameter core (cut perpendicular to the long axis), instructed to expectorate each sample and rinse their mouth with water between samples. Five samples were presented in randomized order, and no more than two panels were held per day. Choice grade LD samples were prepared in the same manner, with one preceding each panel and the other (from the same carcass) incorporated as a "hidden" reference.

Utilizing the LD taste panel steaks and steaks from the ST, SM and BF muscles, six 1.25 cm diameter cores were removed with a drill press unit (Kastner and Henrickson, 1969) and sheared once using a Warner-Bratzler apparatus.

Sarcomere Length

Three 1.25 cm diameter cores were removed from fresh steaks (excised 3.0 cm anterior of original sample) of all four muscles. Medial to central to lateral cores were placed in a polyethylene bag (air removed), heat sealed, frozen and stored at -26C for later analysis.

Cores were thawed at 2C for no longer than 24 hr. The center-third of each core was placed in a Waring Blendor along with 50 ml of cold (2C) .25M sucrose solution, and blended for 1 min at slow speed (rheostat speed 30).

Sarcomere lengths were measured with a Wild phase contrast microscope utilizing 750 X magnification and an eyepiece filar micrometer. The average length of 10 sarcomeres from each of 15 myofibrils was used for each treatment.

Statistical Analysis

The experimental design was completely randomized with respect to assignment of animals to split plot treatments. Data was analyzed using analysis of variance and resultant F-test. To determine differences between means, the least significant difference was utilized (Snedecor and Cochran, 1973).

Results and Discussion

Taste Panel

Taste panel results indicated longissimus steaks from grass-fed cattle had improved tenderness, juiciness and over-all acceptability due to conditioning at 13C vs conventional chilling at 3C (table 1). These results agree with Marsh et al. (1968), Smith et al. (1971), Parrish et al. (1973), Hostetler et al. (1975) and Fields et al. (1976) who reported post-mortem aging of ovine and bovine carcasses immediately post-slaughter at elevated temperatures was effective in improving tenderness. In contrast with this statement, our results indicate no differences ($P>.05$) for short, long and silage regimes in 3C vs 13C comparisons for tenderness, juiciness, desirability of flavor and over-all acceptability. Even though non-significant, the short- and silage-feds followed the same trend for taste panel tenderness as the grass-feds. This agrees with Parrish et al. (1969) who found little differences in tenderness of muscle between beef carcasses stored at 2C and 15C.

Muscles with pH values greater than 6.0 before cold application (Chrystall, 1976) and from beef carcasses with less than 1.27 cm fat cover (Merkel and Pearson, 1975) are susceptible to cold shortening and reduced tenderness if chill rate is sufficiently rapid. In addition, Davey et al. (1971) reported that a chill rate exceeding 1.4C per hr in the deep tissue of beef halves during the first 6 hr post-mortem caused cold shortening in some muscles with the magnitude of cold shortening being greater with faster cooling.

Each nutritional regime in this study yielded carcasses with less than 1.27 cm 12th rib fat thickness (table 2) and pH values greater than

TABLE 1. TASTE PANEL RESPONSES[e] FOR LONGISSIMUS MUSCLE BY NUTRITIONAL REGIME AND TEMPERATURE

Temperature[d] (C)	Nutritional regime: Grass	Short	Long	Silage	Over-all Mean
		Tenderness			
3	4.8^{a}	5.3^{ab}	6.5^{c}	5.9^{bc}	5.6
13	5.4^{a} *	5.8^{ab}	6.0^{ab}	6.3^{b}	5.9 *
		Desirability of flavor			
3	5.9^{a}	6.2^{a}	6.9^{b}	6.9^{b}	6.4
13	5.8^{a}	6.1^{a}	6.8^{b}	6.9^{b}	6.4
		Juiciness			
3	5.8^{a}	6.2^{a}	6.4^{ab}	6.9^{b}	6.3
13	6.5^{ab} *	6.3^{a}	6.5^{ab}	6.9^{b}	6.6
		Over-all acceptability			
3	5.0^{a}	5.7^{b}	6.5^{c}	6.2^{bc}	5.8
13	5.5^{a} *	5.8^{ab}	6.3^{bc}	6.5^{c}	6.0

* Means within same column for each trait are different (P>.05).

abc Means within the same row with the same or no letter superscript are not different (P<.05).

d Conventionally chilled halves held at 3C for 48 hr. Conditioned halves held at 13C until 8 hr post-mortem then 3C for 40 hr.

e Tenderness, flavor, juiciness and over-all acceptability evaluated on 9-point scale (1=extremely tough, dry, or undesirable flavor or acceptability; 5=acceptable; 9=extremely tender, juicy or desirable flavor or acceptability).

TABLE 2. MEAN CARCASS YIELD AND QUALITY GRADES AND YIELD AND QUALITY GRADE TRAITS BY NUTRITIONAL REGIME

Trait	Grass	Short	Long	Silage
Adjusted 12th rib fat thickness (cm)	.53	.51	1.22	1.12
Rib eye Area (sq. cm)	65.8	74.8	72.9	77.4
Hot carcass weight (kg)	262.2	290.8	331.1	332.5
Kidney-pelvic-heart fat (%)	2.7	2.8	3.5	3.3
Yield Grade	2.0	1.8	2.9	2.6
Maturity	A	A	A	A
Marbling[a]	Traces, 83	Slight, 56	Small, 49	Small, 75
Quality Grade[b]	Good, 03	Good, 53	Choice, 03	Choice, 14

[ab] Marbling and Quality Grade: 01-33 = Low, 34-66 = Average, 67-100 = High.

6.0 (figure 1) prior to cold application. Temperature decrease per hr for the first 6 hr in the deep tissue (round location, figure 2) in halves chilled at 3C was 1.3C, 1.1C, 1.0C and 1.0C for carcasses from grass-, short-, long- and silage-fed cattle respectively (figure 2). Considering all conditions (e.g. pH, fat cover and chill rate) the grass-feds appeared to be most susceptible to cold shortening, and even though the chill rate did not exceed 1.4C per hr in the deep tissue for the first 6 hr (as described by Davey et al., 1971) it approached this value. Consequently, taste panel tenderness responses for 3C vs 13C comparisons (table 1) indicates that cold shortening occurred to a limited extent in 3C halves from grass-fed animals. Even though the cold shortening effect was minimal in grass-feds and not observed in the other regimes, these results may indicate that the chill rates observed (figure 2) are just below or at the point at which cold shortening might occur. Chill rates per hr for the first 6 hr post-mortem for 3C fat and loin locations (figure 2) were 4.5C and 3.9C; 4.3C and 3.6C; 4.1C and 3.8C; 3.8C and 3.3C for grass-, short-, long- and silage-feds respectively.

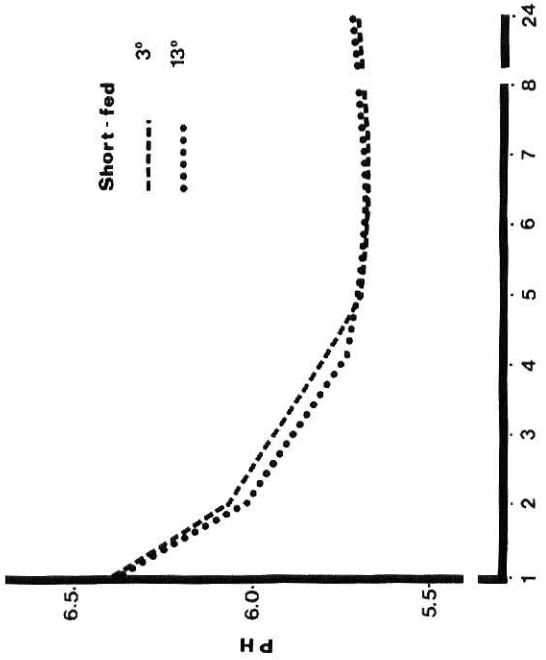
Even though the over-all mean for taste panel tenderness rating was greater ($P<.05$) for 13C vs 3C, this reflects the trend for grass-, short- and silage-feds, the difference of which may not be practically important.

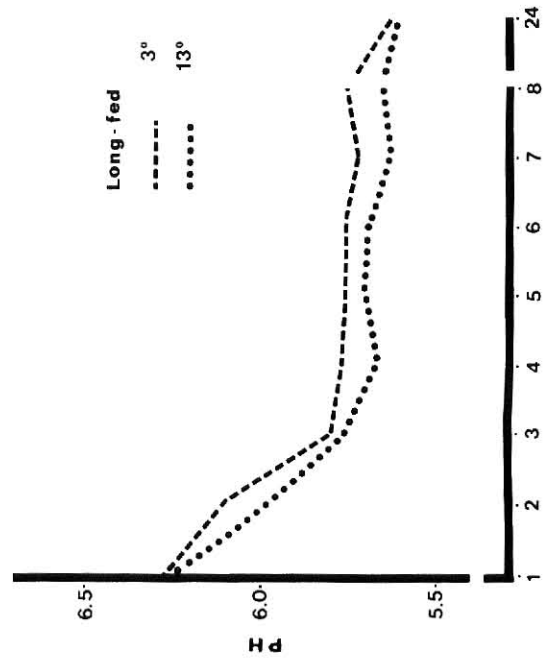
Even though not always statistically different from the other nutritional regimes, the grass-feds were consistently least desirable and acceptable considering each taste panel trait. Silage-finished cattle were the most desirable with short- and long-fed regimes being

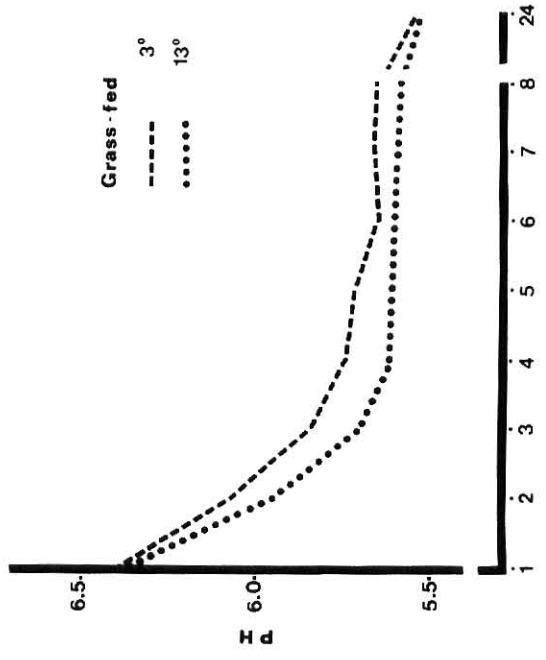
FIGURE 1. POST-MORTEM PH DECLINE BY POST-MORTEM CHILLING (3C) AND CONDITIONING (13C) TEMPERATURES AND NUTRITIONAL REGIME

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.


Short-fed
3°
13°
pH
6.5
6.0
5.5
1
2
3
4
5
6
7
8
24
TIME POSTMORTEM (hr)


Long-fed
3°
13°
pH
6.5
6.0
5.5
1
2
3
4
5
6
7
8
24
TIME POSTMORTEM (hr)


Grass-fed
3°
13°
pH
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6.0
5.5
1
2
3
4
5
6
7
8
24
TIME POSTMORTEM (hr)

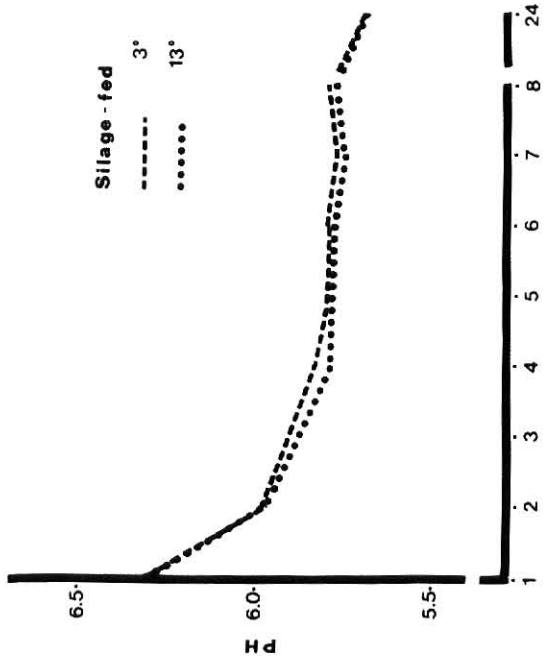
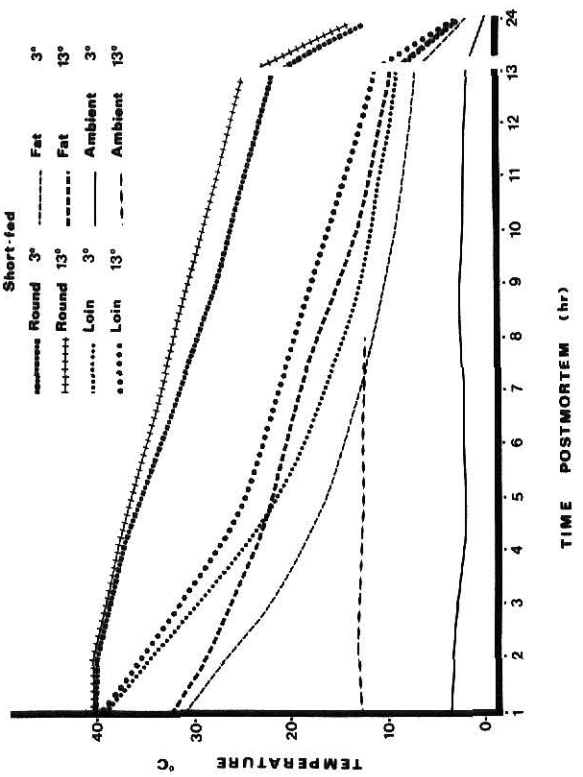
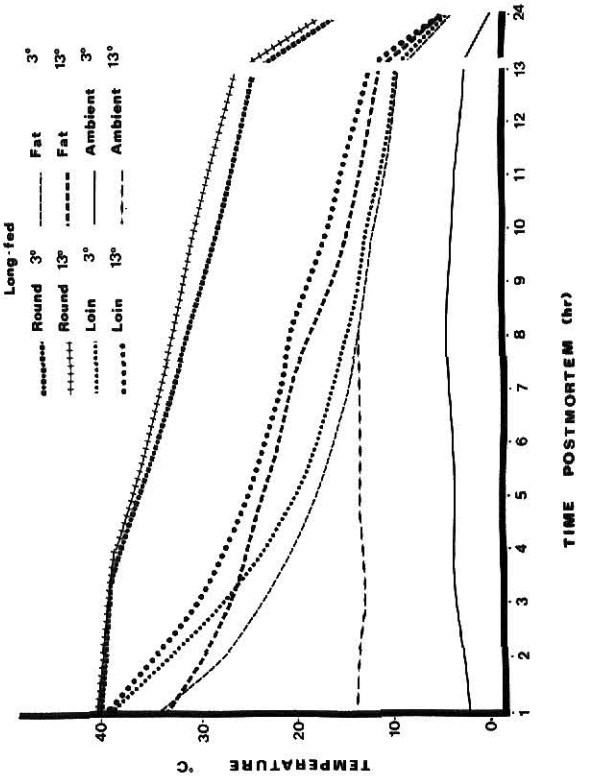
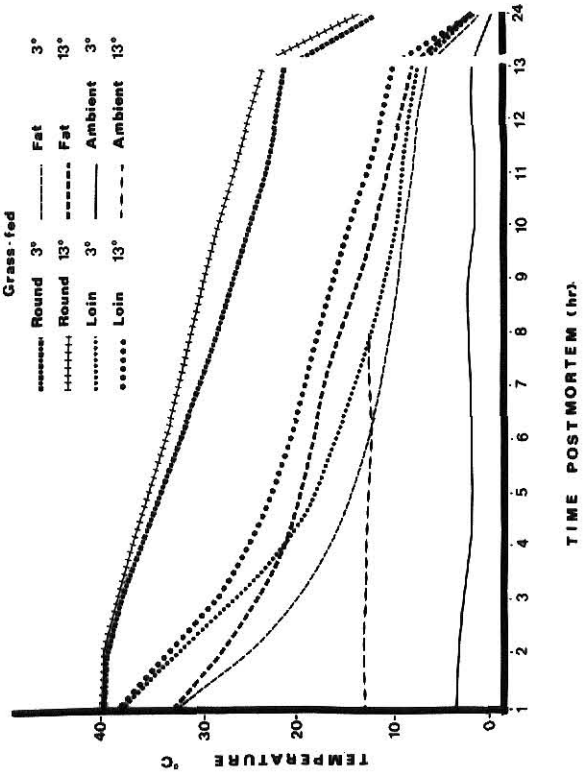
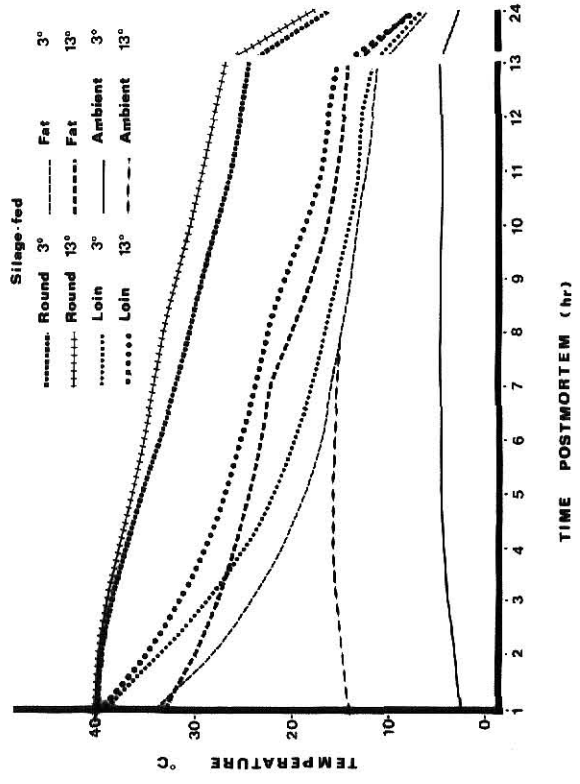

Silage-fed
3°
13°
pH
6.5
6.0
5.5
1
2
3
4
5
6
7
8
24
TIME POSTMORTEM (hr)

FIGURE 2. POST-MORTEM TEMPERATURE DECLINES FOR ROUND, LOIN AND FAT LOCATIONS BY POST-MORTEM CHILLING (3C) AND CONDITIONING (13C) TEMPERATURES AND NUTRITIONAL REGIME


Short-fed
Round 3° Fat 3°
Round 13° Fat 13°
Loin 3° Ambient 3°
Loin 13° Ambient 13°
TEMPERATURE °C
TIME POSTMORTEM (hr)


Long-fed
Round 3° Fat 3°
Round 13° Fat 13°
Loin 3° Ambient 3°
Loin 13° Ambient 13°
TEMPERATURE °C
TIME POSTMORTEM (hr)


Grass-fed
Round 3° Fat 3°
Round 13° Fat 13°
Loin 3° Ambient 3°
Loin 13° Ambient 13°
TEMPERATURE °C
TIME POSTMORTEM (hr)


Silage-fed
Round 3° Fat 3°
Round 13° Fat 13°
Loin 3° Ambient 3°
Loin 13° Ambient 13°
TEMPERATURE °C
TIME POSTMORTEM (hr)

intermediate. The majority of taste panel responses did not indicate that the samples from grass-fed cattle were unacceptable or undesirable.

Shear Force

Shear force means for muscle samples from halves chilled at either 3C or conditioned at 13C exhibited no differences ($P>.05$) regardless of nutritional regime (table 3). These results generally agree with shear force means averaged over muscles, indicating chilling at 3C did not increase shear force, due to cold shortening, as might have been expected. Even though chill rate was sufficient to cause minimal cold shortening in grass-feds as indicated by taste panel results, shear force data does not reflect this effect.

These shear force results disagree with Hostetler et al. (1975), Merkel and Pearson (1975) and Fields et al. (1976) who found lower shear values for samples from beef halves subjected to elevated temperatures (13C to 16C) for various time intervals up to 48 hr post-mortem when compared with samples from control halves conventionally chilled at 0C to 2C. However, elevated temperature conditioning times evaluated by these workers were usually longer than 8 hr and may have, in comparison, facilitated aging (Marsh and Leet, 1966; Marsh et al., 1968; Parrish et al., 1973). In addition, the chill rates for the controls may have been faster than those observed in our study (figure 2) thereby accentuating cold shortening (Davey et al., 1971). Both of these factors could account for our small differences in shear force values when the samples from elevated temperature conditioned halves were compared with samples from conventionally chilled halves.

TABLE 3. MEANS FOR SHEAR FORCE AND SARCOMERE LENGTH BY NUTRITIONAL REGIME, TEMPERATURE AND MUSCLES AND AVERAGED OVER MUSCLES

Temperature[c] (C)	Nutritional regime: Grass	Short	Long	Silage	Over-all Mean
		Shear force (kg)			
		Longissimus dorsi			
3	2.9	3.2	3.4	3.2	3.1
13	3.0	3.0	3.3	3.3	3.1
		Semitendinosus			
3	4.1	4.1	3.9	3.9	4.0
13	4.6	4.1	4.0	3.9	4.2
		Biceps femoris			
3	6.2[a]	6.5[ab]	5.8[a]	6.9[b]	6.4
13	6.6	6.5	6.1	6.5	6.4
		Semimembranosus			
3	4.7	4.4	4.3	4.1	4.4
13	4.9[a]	4.6[ab]	4.1[b]	4.0[b]	4.4
		Averaged over muscles			
3	4.4	4.5	4.4	4.5	4.5
13	4.8	4.5	4.4	4.4	4.5

TABLE 3 (CONTINUED)

Temperature[c] (C)	Nutritional regime: Grass	Short	Long	Silage	Over-all Mean
	Sarcomere length (μm)				
	Longissimus dorsi				
3	2.0	2.1	2.0	2.0	2.0
13	2.0	2.0	2.0	2.1	2.0
	Semitendinosus				
3	2.2	2.3	2.2	2.2	2.2
13	2.2	2.2	2.2	2.2	2.2
	Biceps femoris				
3	1.8[a]	1.9[a]	2.0[b]	1.9[a]	1.9
13	1.8	1.9	1.9	1.9	1.9
	Semimembranosus				
3	1.9	2.0	1.9	2.0	2.0
13	2.0	2.0	1.9	2.0	2.0
	Averaged over muscles				
3	2.0	2.1	2.0	2.0	2.0
13	2.0	2.0	2.0	2.0	2.0

* Means within same column for each trait and muscle are different ($P<.05$).

[ab] Means within same row with the same or no letter superscript are not different ($P>.05$).

[c] Conventionally chilled halves held at 3C for 48 hr. Conditioned halves held at 13C until 8 hr post-mortem then 3C for 40 hr.

It is well established that cold shortening increases shear force (Marsh and Leet, 1966; McCrae et al., 1971). Consequently, shear force comparisons for 3C vs 13C (table 3) are consistent with the observations of Davey et al. (1971) in that chill rates (figure 2) do not appear sufficiently rapid to cause cold shortening.

To the extent that shear force is an index of cold shortening and assuming that conditioning at 13C will deter cold shortening, these results indicate that carcasses of the type shown in table 2 may be chilled at the rates indicated in figure 2 without experiencing cold shortening.

Comparisons between nutritional regimes exhibited no differences ($P>.05$) in shear force for any of the test muscles, regardless of 3C or 13C treatment, except for the 3C BF and 13C SM. When muscle responses were averaged, there were no differences ($P>.05$) in mean shear force values between nutritional regimes for halves chilled at 3C or conditioned for 8 hr at 13C (table 3). This was true even though differences in marbling and quality grades existed (table 2).

Nutritional regime comparisons further indicate that either cold shortening was not a factor under these conditions or shortening was equal across nutritional regimes which would be unlikely due to fat thickness (table 2) and chill rate (figure 2) differences for the grass- and short-feds as compared with long- and silage-feds. The lack of differences in shear force between nutritional regimes agrees with Meyer et al. (1960) and Huffman (1974) but disagrees with Kropf et al. (1975) and Bowling et al. (1976), even though our grass-fed cattle may have been on a higher plane of nutrition as compared to these authors.

Sarcomere Length

Mean sarcomere length for 3C vs 13C treatments indicated no differences ($P>.05$) when individual muscles or muscle averages were compared, regardless of nutritional regime. These results were upheld by over-all means by muscles and averaged over muscles (table 3). These results indicate that conventional chilling of halves at 3C did not decrease sarcomere lengths when compared with 13C conditioning for 8 hr and generally agrees with shear force results. According to Locker (1960) and Herring et al. (1967) the length of the basic myofibrillar subunit, or sarcomere, gives a measure of the contraction state of the muscle. When muscle shortened, there was a corresponding decrease in sarcomere length and decrease in tenderness (Locker, 1960; Herring et al., 1965; Hostetler et al., 1970; Hostetler et al., 1975; Marsh and Carse, 1974). It is widely documented that cold shortening causes sarcomere shortening (Marsh and Thompson, 1958; Locker and Hagyard, 1963; Marsh and Leet, 1966; Davey et al., 1971). Therefore, sarcomere length should be related to shear force.

Comparisons of mean sarcomere lengths between nutritional regimes exhibited no differences ($P>.05$) for LD, ST and SM muscles at either temperature treatment (3C and 13C) or for the BF muscle from halves conditioned at 13C (table 3). There were no differences between nutritional regimes for mean sarcomere lengths averaged over muscles at either 3C or 13C (table 3). This reinforces the discussion presented earlier (see shear force section) regarding the non-occurrence of cold shortening under these conditions due to a slow chill rate even though fat thicknesses (table 2) and chill rate (figure 2) were different for grass- and short-feds vs long- and silage-fed.

In summary, these results are consistent with shear force and indicate that in this study conventional chilling at 3C did not decrease sarcomere lengths due to cold shortening.

Cooking Loss Analyses

Data from Table 4 involving cooking loss analyses show no consistent pattern. Percent total cooking, drip and volatile loss mean responses for LD and ST muscle samples from halves chilled at 3C vs counterparts from halves conditioned at 13C generally indicated no differences ($P>.05$) regardless of nutritional regime (table 4). One exception was the LD muscle from the short-fed regime which exhibited less drip loss at 13C than at the 3C treatment. For the SM muscle for the grass regime only (table 4), the 13C treatment increased total cooking and volatile losses and decreased drip loss ($P<.05$). These results are in agreement with over-all means by muscle (table 4).

Responses for 3C vs 13C averaged over muscles showed no differences ($P>.05$) for total cooking and volatile losses (table 4) regardless of feeding regime. Drip loss mean responses for elevated temperature conditioning (13C) were decreased in the grass- and short-fed regimes.

No differences in total cooking loss ($P>.05$) but significantly more drip and less volatile loss for the 3C treatment were noted in responses for 3C vs 13C averaged over muscles and over-all feeding regimes (table 4). There appeared to be an off-setting effect between drip and volatile loss to ultimately give no difference in total cooking loss. These results are in agreement with Parrish et al. (1973) and Fields et al. (1976) who reported total cooking losses of beef longissimus steaks were not affected appreciably by pre-rigor storage of carcasses at elevated temperatures but disagrees with Cook and Langsworth (1966)

TABLE 4. MEANS FOR PERCENT TOTAL COOKING, DRIP AND VOLATILE LOSS BY NUTRITIONAL REGIME, TEMPERATURE AND MUSCLES AND AVERAGED OVER MUSCLES

Temperature[d] (C)	Nutritional regime: Grass	Short	Long	Silage	Over-all Mean
Total cooking loss (%)					
Longissimus dorsi					
3	17.6[a]	21.2[b]	25.1[c]	23.4[bc]	21.7
13	17.8[a]	19.8[a]	24.3[b]	23.3[b]	21.1
Semitendinosus					
3	22.1[a]	29.7[b]	25.6[a]	25.3[a]	25.7
13	22.8[a]	29.6[b]	28.0[b]	27.1[b]	26.8
Semimembranosus					
3	26.8[a] *	31.6[b]	30.3[ab]	30.2[b]	29.7 *
13	32.7	33.3	31.2	31.2	32.1
Averaged over muscles					
3	23.6[a]	27.5[b]	27.0[b]	26.3[b]	26.1
13	24.4[a]	27.6[b]	27.9[b]	27.2[b]	26.7
Drip loss (%)					
Longissimus dorsi					
3	4.7[a]	6.4[b] *	8.4[c]	8.3[c]	6.9
13	4.0[a]	5.3[b]	8.5[c]	8.1[c]	6.4
Semitendinosus					
3	3.7	3.1	2.1	3.3	3.1
13	3.6	2.4	2.6	3.9	3.1

TABLE 4 (CONTINUED)

Temperature[d] (C)	Nutritional regime: Grass	Short	Long	Silage	Over-all Mean
Drip Loss (%) continued					
Semimembranosus					
3	3.4[ac] *	2.1[b]	3.8[c]	2.7[ab]	3.0 *
13	2.3	2.0	2.8	2.5	2.4
Averaged over muscles					
3	3.9[a] *	3.9[a] *	4.8[b]	4.3	4.3 *
13	3.3[a]	3.2[a]	4.6[b]	4.8[b]	3.9
Volatile loss (%)					
Longissimus dorsi					
3	12.9[a]	14.8[ab]	16.7[b]	15.1[ab]	14.8
13	13.8	14.5	15.8	15.2	14.8
Semitendinosus					
3	18.4[a]	26.6[b]	23.5[bc]	22.0[c]	22.6
13	19.2[a]	27.3[b]	25.4[bc]	23.3[c]	23.7
Semimembranosus					
3	23.3[a] *	29.4[b]	26.5[ab]	27.4[b]	26.7 *
13	30.4	31.3	28.4	28.7	29.8
Averaged over muscles					
3	19.7[a]	23.6[b]	22.3[bc]	21.5[ac]	21.7 *
13	21.2[a]	24.4[bc]	23.2[ac]	22.4[ac]	22.8

* Means within same column for each trait and muscle or averaged over muscles are different ($P<.05$).

abc Means within same row with the same or no letter superscript are not different ($P>.05$).

d Conventionally chilled halves held at 3C for 48 hr. Conditioned halves held at 13C until 8 hr post-mortem then 3C for 40 hr

who found exudate and cooking losses increased with higher conditioning temperatures of lamb carcasses.

Comparisons between nutritional regimes for LD, ST and SM muscles at 3C indicated that the majority of differences involved grass vs short, long and silage regimes plus short vs long and silage fed cattle (table 4). In general, these trends were true for the 13C treatment but in certain cases this treatment reduced differences between feeding regimes. The majority of differences in total cooking, drip and volatile losses exist between feeding regimes and not temperature treatments.

Grass-fed steaks generally had less mean total cooking, drip and volatile loss even though not always statistically different from the other three regimes. Similarly, silage-fed steaks had the second lowest total cooking and volatile losses, but frequently higher drip loss compared to the other feeding regimes. Short- and long-feds were comparable in their total cooking, drip and volatile loss data.

When muscle responses were averaged there was essentially the same pattern for 3C and 13C treatments in mean total cooking, drip and volatile losses between nutritional regimes (table 4).

Summary

Even though taste panel results indicated minimal cold shortening for grass-fed cattle, the other data (e.g. other taste panel responses, shear values, sarcomere length and cooking loss analyses) indicate that carcasses described herein may be chilled at 3C without experiencing significant cold shortening.

LITERATURE CITED

Bowling, R. A., T. R. Dutson, Z. L. Carpenter, G. C. Smith and W. M. Oliver. 1976. Comparison of beef finished on forage vs grain. J. Anim. Sci. 42:254 (Abstr.).

Bull, S. L., R. R. Snapp and H. P. Rusk. 1941. Effect of pasture on grade of beef. 111. Agr. Exp. Sta. Bull. 475.

Busch, W. A., F. C. Parrish, Jr. and D. E. Goll. 1967. Molecular properties of post-mortem muscle. 4. Effect of temperature on ATP degradation, isometric tension parameters and shear resistance of bovine muscle. J. Food Sci. 32:390.

Chapman, H. L. Jr., A. Z. Palmer, J. R. Crockett and J. W. Carpenter. 1961. Performance of cattle of British and Brahman breeding when fattened in drylot and on pasture. Everglades Station Mimeo 61-16.

Chapman, H. L., R. L. Shirley, A. Z. Palmer and J. W. Carpenter. 1971. Vitamin A and E in steer fattening rations. Fl. Agri. Exp. Sta. Bull. 748.

Chrystall, B. B. 1976. Accelerated conditioning of meat. Eighteenth Meat Ind. Res. Conf. (Meat Ind. of N. Z.), 5.

Cook, C. F. and R. F. Langsworth. 1966. The effect of pre-slaughter environment temperature and post-mortem temperature upon some characteristics of ovine muscle. 2. Meat quality. J. Food Sci. 31:504.

Davey, C. L., K. V. Gilbert and C. I. F. Cox. 1971. Prime beef processing. Ann. Res. Rep., Meat Ind. Res. Inst. of New Zealand, p. 41.

Dutson, T. R., G. C. Smith, R. L. Hostetler and Z. L. Carpenter. 1975. Postmortem carcass temperature and beef tenderness. Amer. Soc. of Anim. Sci. Abstr. CSU., p. 289.

Fields, P. A., Z. L. Carpenter and G. C. Smith. 1976. Effects of elevated temperature conditioning on youthful and mature beef carcasses. J. Anim. Sci. 42:72.

Foster, M. T. and J. C. Miller. 1933. The effects of management and sex on carcasses of yearling cattle. University of Missouri Research Bull. 186.

Godbey, E. G., R. F. Wheeler, D. H. Kropf, W. C. Godley and L. V. Starkey. 1959. Winter forage for fattening steers. S. Car. Ag. Exp. Sta. Bull. 469.

Hankins, O. G. and N. G. Barbella. 1941. Quality of beef from grass fed and from grain-fed cattle of equal fatness. National Provisioner. 105(23):16.

Herring, J. K., R. G. Cassens and E. J. Briskey. 1965. Further studies on bovine muscle tenderness as influenced by carcass position, sarcomere length and fiber diameter. J. Food Sci. 30:1045.

Herring, H. K., R. G. Cassens, C. G. Suess, V. H. Brungardt and E. J. Briskey. 1967. Tenderness and associated characteristics of stretched and contracted bovine muscle. J. Food Sci. 32:317.

Hostetler, R. L., W. A. Landman, B. A. Link and H. A. Fitzhugh, Jr. 1970. Influence of carcass position during rigor mortis and tenderness of beef muscle. J. Anim. Sci. 31:47.

Hostetler, R. L., Z. L. Carpenter, G. C. Smith and T. R. Dutson. 1975. Comparison of postmortem treatments for improving tenderness of beef. J. Food Sci. 40:223.

Huffman, D. L. 1974. Carcass characteristics - current research. Proceedings Alabama Beef Industry Conference, Auburn Univ.

Hunt, R. E., C. M. Kincaid and R. C. Carter. 1953. Grain or grass-fattened cattle. Agric. Exp. Sta. Bull. 458. Va. Polytechnic Inst., Blacksburg, VA.

Kastner, C. L. and R. L. Henrickson. 1969. Providing uniform meat cores for mechanical shear force measurement. J. Food Sci. 34:603.

Klosterman, E. W., P. G. Althouse and V. R. Cahill. 1965. Effect of corn silage or ground ear corn full fed at various stages of growth and fattening upon carcass composition of beef cattle. J. Anim. Sci. 24:454.

Kramer, A. and B. A. Twigg. 1970. Taste testing. "Fundamentals of Quality Control for the Food Industry". 3rd ed., AVI Publishing Company, Inc., Westport, Conn., 142.

Kropf, D. H., D. M. Allen and G. J. Thouvenelle. 1975. Grass-fed, short-fed and long-fed beef compared. Kansas State Cattleman's Day Report 62:78.

Locker, R. H. 1960. Degree of muscular contraction as a factor in tenderness of beef. Food Res. 25:304.

Locker, R. H. and C. J. Hagyard. 1963. A cold shortening effect in beef muscles. J. Sci. Food Agri. 14:787.

Malphrus, L., R. Edwards, D. Kropf and M. Marbut. 1962. Consumer preference for beef produced on grass and grain or in drylot: a comparison. So. Car. Agr. Exp. Sta. Bull. 499.

Marsh, B. B. and J. F. Thompson. 1958. Rigor mortis and thaw rigor in lamb. J. Sci. Food Agr. 9:417.

Marsh, B. B. 1964. Meat quality and rigor mortis. IN "Carcass Composition and Appraisal of Meat Animals." CSIRO, Melbourne, Paper No. 12.

Marsh, B. B. and N. G. Leet. 1966. Studies in meat tenderness. 3. The effects of cold shortening on tenderness. J. Food Sci. 31:450.

Marsh, B. B., P. R. Woodhams and N. G. Leet. 1968. Studies in meat tenderness. 5. The effects on tenderness of carcass cooling and freezing before the completion of rigor mortis. J. Food Sci. 33:12.

Marsh, B. B. and W. A. Carse. 1974. Meat tenderness and the sliding filament hypothesis. J. Food Technol. 9:129.

Marsh, B. B. 1977. Temperature and postmortem change: energy use and meat quality. Proc. Meat. Ind. Res. Conf., p. 13.

McCampbell, J. C., B. E. Green and R. S. Lowrey. 1972. Cooking and palatability of beef from winter pasture with and without grain and drylot fed cattle. J. Anim. Sci. 35:200 (Abstr.).

McCrae, S. E., C. G. Seccombe, B. B. Marsh and W. A. Carse. 1971. Studies in meat tenderness. 9. The tenderness of various lamb muscles in relation to their skeletal restraint and delay before freezing. J. Food Sci. 36:566.

Merkel, R. A. and A. M. Pearson. 1975. Slow chilling could produce tender beef from lean carcasses. Meat Ind. 21 (5):27.

Meyer, B., J. Thomas, R. Buckley and J. Cole. 1960. The quality of grain finished and grass finished beef as affected by ripening. Food Technol. 1(1): 4.

Oltjen, R. R., T. S. Rumsey and P. A. Putnam. 1971. All-forage diets for finishing beef cattle. J. Anim. Sci. 32:327.

Parrish, Jr., F. D., R. E. Rust, G. R. Popenhagen and B. E. Miner. 1969. Effect of postmortem aging time and temperature on beef muscle attributes. J. Anim. Sci. 29:398.

Parrish, F. D. Jr., R. B. Young, B. E. Miner and L. D. Andersen. 1973. Effect of post-mortem conditions on certain chemical, morphological and organoleptic properties of bovine muscle. J. Food Sci. 38:690.

Purchas, R. W. and H. L. Davies. 1974. Carcass and meat quality of Friesian steers fed on either pasture or barley. Aust. J. Agric. Res. 25:183-192.

Reddish, R. L. 1956. Slaughter and carcass characteristics of Santa Gertrudis steer produced by different management practices. Ph.D. Thesis. Texas A & M University, College Station, Texas.

Schupp, A., T. Bidner, W. McKnight, D. Smith and J. Carpenter, Jr. 1976. Consumer acceptance of forage finished and limited grain finished beef. Phase one. LSU-D.A.E. Res. Report 503.

Smith, M. C. Jr., M. D. Judge and W. J. Stadelman. 1969. A "cold shortening" effect in avian muscle. J. Food Sci. 34:42.

Smith, G. C., T. C. Arango and Z. L. Carpenter. 1971. Effects of physical and mechanical treatments on the tenderness of the beef longissimus. J. Food Sci. 36:445.

Smith, G. C., T. R. Dutson, R. L. Hostetler and Z. L. Carpenter. 1974. Subcutaneous fat thickness and tenderness of lamb. J. Anim. Sci. 39:174.

Snedecor, G. W. and W. G. Cochran. 1973. Statistical Methods (6th Ed.). The Iowa State University Press, Ames, Iowa.

Trowbridge, P. F., C. R. Moulton and L. D. Haigh. 1918. Effect of limited foods on growth of beef animal. Mo. Agr. Exp. Sta. Res. Bull. 28.

Wanderstock, J. J. and J. I. Miller. 1948. Quality and palatability of beef as affected by method of feeding and carcass grade. Food Res. 13:291.

EFFECTS OF ELEVATED TEMPERATURE CONDITIONING ON BEEF CARCASSES FROM FOUR NUTRITIONAL REGIMES

by

MARY ELIZABETH SMITH

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ABSTRACT

Thirty-eight crossbred steers of known background were randomly assigned to 4 nutritional regimes: grass-, short-, long- and silage-fed. The right half of each carcass was conventionally chilled at 3C until 48 hr post-mortem and left halves were conditioned at 13C for 8 hr then chilled at 3C until fabrication at 48 hr post-mortem. Temperature and pH decline data was obtained hourly until 12 hr (temperature) and 8 hr (pH) and at 24 hr post-mortem. Taste panel responses were obtained on the longissimus (LD) muscle only, whereas shear force and sarcomere length values included the LD, semitendinosus (ST), semimembranosus (SM) and biceps femoris (BF). Percent total cooking, drip and volatile loss data involved all muscles except the BF. Data was analyzed using analysis of variance and resultant F-test. To determine differences between means, the least significant difference was utilized.

Taste panel results indicated longissimus steaks from grass-fed cattle had improved tenderness, juiciness and over-all acceptability due to conditioning at 13C vs conventional chilling at 3C. However, no differences ($P>.05$) for short, long and silage regimes in 3C vs 13C comparisons were noted for tenderness, juiciness, desirability of flavor and over-all acceptability.

Taste panel tenderness responses for 3C vs 13C comparisons indicated that cold shortening occurred to a limited extent in 3C halves from grass-fed animals. Even though the cold shortening effect was minimal in grass-feds and not observed in the other regimes, these results may indicate that chill rates observed in this study were just below or at the point at which cold shortening might occur.

Even though not always statistically different from the other nutritional regimes the grass-feds were consistently least desirable and acceptable considering each taste panel trait. Silage-finished cattle were the most desirable with short- and long-fed regimes being intermediate. The majority of taste panel responses did not indicate that the samples from grass-fed cattle were unacceptable or undesirable.

Mean shear force values and sarcomere length responses from halves chilled at 3C vs counterparts conditioned at 13C generally exhibited no differences ($P>.05$) regardless of nutritional regime when individual muscles or muscle averages were compared. These results were upheld by over-all means by muscles and averaged over muscles. The results indicate that conventional chilling of halves at 3C for 8 hr did not increase shear force values when compared to conditioning at 13C nor did the 3C treatment decrease sarcomere lengths when compared to 13C conditioning as might have been expected.

When muscle responses were averaged, there were no differences ($P>.05$) in mean shear force and sarcomere length values between nutritional regimes for halves chilled at 3C or conditioned for 8 hr at 13C. This was true even though differences in marbling and quality grades existed.

Responses for 3C vs 13C averaged over muscles showed no differences ($P>.05$) for total cooking and volatile losses regardless of feeding regime. Drip loss mean responses for elevated temperature conditioning (13C) were smaller ($P<.05$) in the grass- and short-fed regimes when compared to conventionally chilled counterparts.

Grass-feds generally had less mean total cooking, drip and volatile loss even though not always statistically different from other regimes. Short- and long-feds were comparable in their total cooking, drip and volatile loss data.

Even though taste panel results indicated minimal cold shortening for grass-fed cattle, the other data (e.g. other taste panel responses, shear values, sarcomere length and cooking loss analyses) indicate that carcasses described herein may be chilled at 3C without experiencing significant cold shortening.

APPENDIX

Chapter V

APPENDIX

A. Detailed Materials and Methods

1. Sampling Methods

a. Halves of each carcass assigned to one of the following main treatments within approximately 1 hr post-mortem:

1) conventional chilling at 3C until 48 hr post-mortem

2) conditioning at 13C until 8 hr post-mortem and subsequent chilling at 3C for 40 hr

b. Four muscles were excised at 48 hr post-mortem:

1) biceps femoris (BF)

2) longissimus dorsi (through the 13th rib) (LD)

3) semimembranosus (SM)

4) semitendinosus (ST)

c. The midline of each muscle was determined by measuring its maximum length and dividing by two.

d. Upon dividing muscles at the midline, the anterior half of each muscle was immediately fabricated into test steaks.

e. Test steaks from muscle halves were obtained in the following manner:

1) next to midline, 3.0 cm thick shear force; percent total cooking, drip and volatile loss; and taste panel (LD only) steaks

2) histological, 2.5 cm thick steaks (see Figure 3 for further explanation)

f. Shear force; taste panel; percent total cooking, drip and cooking loss steaks were labeled, vacuum packaged and stored at -26C until evaluated.

g. Cores from fresh histological steaks of all 4 muscles were removed (medial to central to lateral), labeled, placed in polyethylene bag (air removed), heat sealed, frozen and stored at -26C until evaluated for sarcomere length.

2. Taste Panel; Percent Total Cooking, Drip and Volatile Loss

a. Remove steaks from blast freezer (-26C) and thaw in 2C cooler for 24 hr.

b. Label and weigh (to nearest hundredth of a gram) cooking pans (with rack): one per steak.

c. Preheat rotary oven to 163C.

d. Remove steaks from vacuum package, rinse, blot, place on rack and weigh (to nearest hundredth of a gram) on top loading balance.

e. Insert calibrated cooking thermometer (Model MT39, Type 304) in geometric center of each steak.

f. Prepare, identically to test steaks, two Choice LD steaks per taste panel session. Precede each panel with a sample and one as a "hidden" reference.

g. Check to assure correct room environmental conditions.

h. Determine order of presentation to each panelist by drawing from basket containing 5! (120) variations of numbers 1-5 (4 samples plus "hidden" reference).

i. As steaks reach internal temperature of 66C, remove and weigh for total cooking, drip and volatile loss.

1) percent total cooking loss =

$$100 - \frac{\text{cooked steak wt.}}{\text{uncooked steak wt.}} \times 100$$

2) percent drip loss =

$$\frac{\text{drip}}{\text{uncooked steak wt.}} \times 100$$

3) percent volatile loss =

Percent cooking loss - Percent drip loss

j. Remove 3-1.91 cm cores from each steak with drill press unit; cut core in half perpendicular to long axis and place in labeled pyrex pie dishes preheated to 65C in conventional oven. Cover loosely with aluminum foil to hold warmth yet prevent warmed over or steam table flavor.

k. Position panelists randomly in individual booths, instruct to expectorate sample and rinse mouth with water after each sample. Serve immediately.

l. Serve panelists samples 1-5 in predetermined order (see h).

m. Sample size equals half of a 1.91 cm diameter core (cut perpendicular to the long axis).

n. Use a hedonic scale for each response.

o. Hold no more than two panel sessions per day.

p. Taste panel materials:

1) booths and chairs for 6 taste panelists

2) water cups and water

3) cups for expectorated sample and mouth rinsings

4) napkin

5) toothpicks

6) evaluation sheets - Figure 4

7) paper plate with marked divisions for samples; use indelable ink

8) tongs

3. Panelist Selection and Training

Panel training and selection used triangle comparison of samples with differing degrees of juiciness and tenderness (different quality grades) to determine individual sensitivity to discerning differences.

4. Shear

a. Prepare steaks in same manner as steaks for taste panel, percent total cooking, drip, and volatile loss. Use LD taste panel samples for both shear and taste panel analyses.

b. Remove 6-1.25 cm cores with drill press unit, approximately 1 hr after removal from oven.

c. Shear each core once with Warner-Bratzler shear apparatus.

5. Sarcomere Length

a. Initial sampling included in Appendix Sec. A1.

b. Remove polyethylene bag containing 3-1.25 cm cores from blast freezer (-26C) and allow to thaw at 2C for no longer than 24 hr before evaluation. A representative sub sample (e.g. center section) was obtained.

c. Place in glass Waring Blendor; add 50 ml of cold (2C) 0.25M sucrose solution, and blend for 1 min. at slow speed (rheostat speed 30).

d. Pour homogenate into labeled 100 ml beaker. To facilitate ease of transfer to slides, allow solution to settle and air bubbles to disappear (approximately 20 to 30 min.).

e. Place 1 drop of homogenate on slide with a glass rod. Apply cover slip; remove air bubbles; add 1 drop of immersion oil on slip.

f. Measure sarcomere lengths with a Wild phase contrast microscope utilizing 750 X magnification (50 X objective and a 15 X eyepiece equipped with a filar micrometer).

g. Use the average length of 10 sarcomeres from each of 15 myofibrils.

6. Post-mortem Temperature Decline

a. Utilize 5 test animals from each feeding regime.

b. Beginning at 1 hr post-mortem, take readings hourly until 12 hr and at 24 hr post-mortem on each carcass half.

c. Insert calibrated thermometers:

1) through obturator foramen into geometric center of round

2) in geometric center of the loin at the 13th rib

3) at 13th rib location under subcutaneous fat

7. Post-mortem PH Decline

a. Utilize all animals from each feeding regime.

b. Beginning at 1 hr post-mortem, take readings hourly until 8 hr and at 24 hr post-mortem on each carcass half.

c. Extract initial samples prior to placement in cooler.

d. Remove 0.64 cm thick samples from corresponding locations on each psoas major muscle, beginning at last lumbar vertebrae and continuing anteriorally.

e. At appropriate sampling times, remove a 0.64 cm slice adjacent to sample location and discard to allow exposure of fresh muscle.

f. Take pH readings with a Corning pH meter equipped with a Markson surface electrode. Standardize frequently with pH standards 4 and 7.

FIGURE 3. Test Muscle Sampling and Disposition

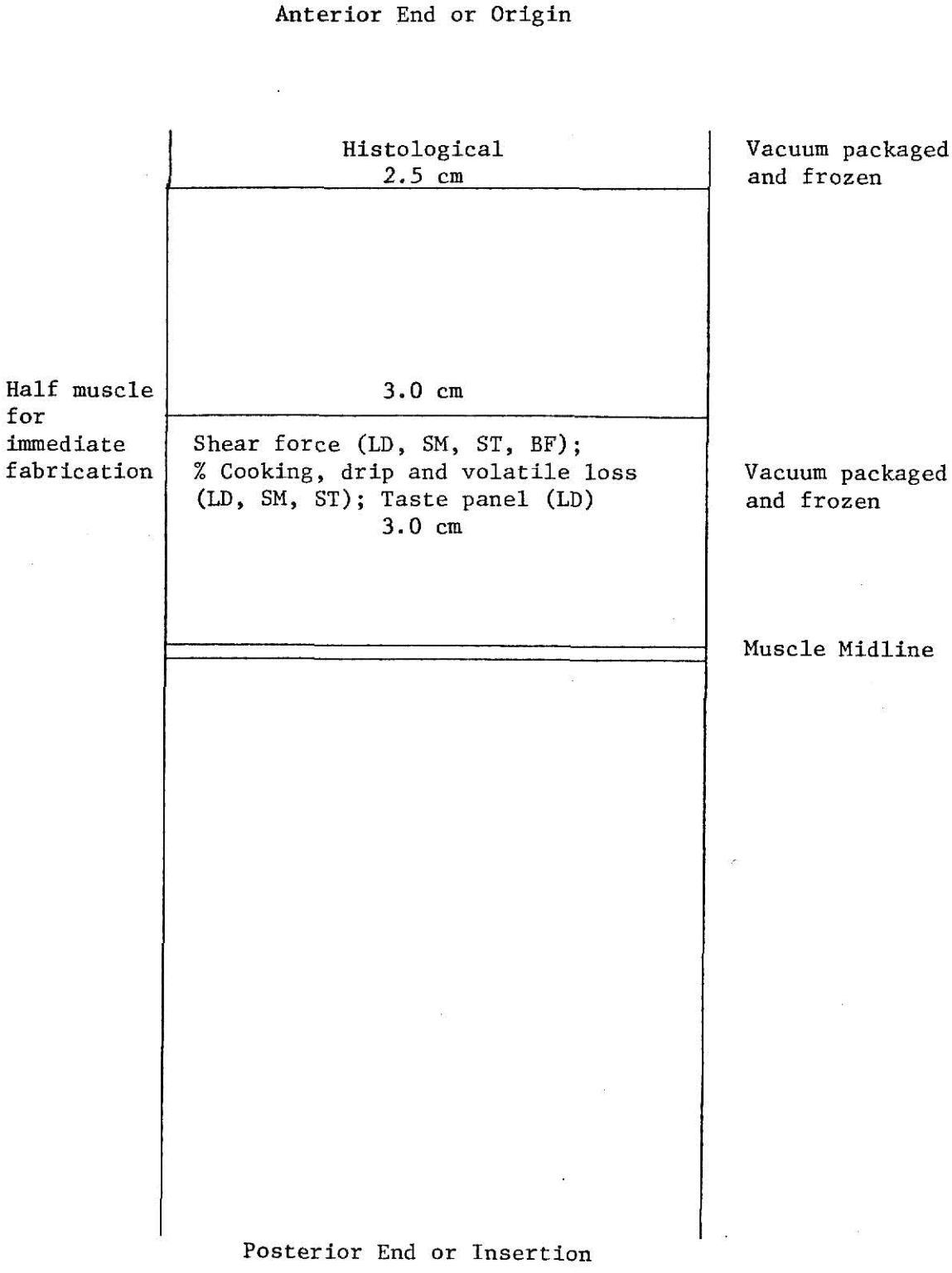

FIGURE 4. SCORE CARD for Evaluating the Palatability of Beef Longissimus

Judge_____ Code_____ Date_____

Sample No.	Desirability of Flavor	Juiciness	Tenderness	Over-all Acceptability	Comments
1					
2					
3					
4					
5					

Desirability of Flavor	Juiciness	Tenderness	Over-all Acceptability
9 Extremely desirable	9 Extremely juicy	9 Extremely tender	9 Extremely desirable
8 Desirable	8 Juicy	8 Tender	8 Desirable
7 Moderately desirable	7 Moderately Juicy	7 Moderately tender	7 Moderately desirable
6 Slightly desirable	6 Slightly Juicy	6 Slightly tender	6 Slightly desirable
5 Acceptable	5 Acceptable	5 Acceptable	5 Acceptable
4 Slightly undesirable	4 Slightly dry	4 Slightly tough	4 Slightly undesirable
3 Moderately undesirable	3 Moderately dry	3 Moderately tough	3 Moderately undesirable
2 Undesirable	2 Dry	2 Tough	2 Undesirable
1 Extremely undesirable	1 Extremely dry	1 Extremely tough	1 Extremely undesirable

TABLE 5. ANALYSIS OF VARIANCE FOR WARNER-BRATZLER SHEAR, PERCENT COOKING, DROP AND VOLATILE LOSS

Variance Source	Shear Force			Cooking Loss			Drip Loss			Volatile Loss		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
Nutritional Regime	3	6.2599	ns	3	425.6685	**	3	30.3383	**	3	369.0645	**
Pooled E(A)	34	5.8594	--	34	55.3778	--	34	6.8577	--	34	50.5405	--
Temperature	1	0.2534	ns	1	40.7290	*	1	2.0293	ns	1	60.9409	**
T x F	3	1.6686	**	3	5.3760	ns	3	5.4645	*	3	2.2835	ns
Pooled E(B)	34	0.2762	--	34	9.4266	--	34	1.4937	--	34	12.1586	--
Muscle	3	445.6168	**	2	8416.2545	**	2	1257.8926	**	2	16151.1431	**
M x F	9	4.6772	**	6	122.6343	**	6	67.3192	**	6	112.5366	**
M x T	3	0.3711	ns	2	10.0379	ns	2	.9468	ns	2	7.5425	ns
M x F x T	9	0.6503	ns	6	9.2553	ns	6	2.0010	ns	6	10.3151	ns
Pooled E(C)	204	0.8026	--	136	14.1184	--	136	2.8264	--	136	14.2810	--
Fabrication	1	85.4152	**	1	1648.9432	**	1	30.4995	**	1	1230.9252	**
Fa x F	3	0.5723	ns	3	27.9619	ns	3	12.2922	**	3	21.0120	ns
Fa x T	1	0.3085	ns	1	2.4047	ns	1	.7864	ns	1	5.9413	ns
Fa x F x T	3	0.5125	ns	3	7.5243	ns	3	.3921	ns	3	11.3706	ns
Fa x M	3	87.5956	**	2	65.3744	**	2	38.5790	*	2	111.5322	**
Fa x M x F	9	0.7058	ns	6	43.0792	**	6	2.0981	ns	6	34.2491	*
Fa x M x T	3	1.1782	*	2	3.3738	ns	2	1.2898	ns	2	8.7710	ns
Fa x M x F x T	9	0.1030	ns	6	9.9679	ns	6	1.5304	ns	6	10.5624	ns
Pooled E(D)	272	0.4023	--	204	13.1780	--	204	1.1851	--	204	12.3782	--

TABLE 5 (CONTINUED)

Variance Source	Shear Force			Cooking Loss			Drip Loss			Volatile Loss		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
Display	1	22.8021	**	1	361.0033	**	1	76.9546	**	1	104.6060	**
D x F	3	0.9107	*	3	11.2567	ns	3	2.5155	*	3	11.3785	ns
D x T	1	0.1206	ns	1	0.5037	ns	1	4.6956	*	1	1.9499	ns
D x F x T	3	0.1078	ns	3	7.6276	ns	3	.3412	ns	3	4.9751	ns
D x M	3	4.8656	**	2	63.9452	**	2	20.5966	**	2	50.8468	**
D x M x F	9	0.4168	ns	6	69.7544	**	6	3.8859	**	6	77.9386	**
D x M x T	3	0.2262	ns	2	1.1114	ns	2	.0602	ns	2	1.6668	ns
D x M x F x T	3	0.0433	ns	6	5.3382	ns	6	.5980	ns	6	4.6272	ns
D x Fa	1	0.0417	ns	1	2.2730	ns	1	3.9368	*	1	12.1927	ns
D x Fa x F	3	1.3855	**	3	16.9598	ns	3	.5329	ns	3	13.3108	*
D x Fa x T	1	0.0487	ns	1	8.0776	ns	1	.6787	ns	1	13.4394	ns
D x Fa x F x T	3	0.2767	ns	3	6.4192	ns	3	.2638	ns	3	7.7452	ns
D x Fa x M	3	8.5320	**	2	100.3036	**	2	2.1490	ns	2	103.0044	**
D x Fa x M x F	9	0.2110	ns	6	22.4344	ns	6	1.1271	ns	6	25.3083	**
D x Fa x M x T	3	0.3084	ns	2	15.8596	ns	2	3.2010	*	2	5.7398	ns
D x Fa x M x F x T	9	0.1617	ns	6	5.0717	ns	6	.7667	ns	6	3.8045	ns
Pooled E(E)	544	0.3167	--	408	11.7603	--	408	.8850	--	408	10.9299	--

D = Display (Before or after 5 days)
F = Nutritional Regime (Grass-, short-, long- and silage-fed)
Fa = Fabrication Time (Before or after vacuum packaging)
M = Muscle (LD, ST, SM, BF)
T = Temperature (3C and 13C)
ns = non-significant
** = P(<.01)
* = P(<.05)

Note: The purpose of this thesis is to report only a part of the results of an over-all study. The analysis of variance tables will, therefore, include more variables than discussed here in, e.g. display and fabrication time.

TABLE 6. ANALYSIS OF VARIANCE FOR SARCOMERE LENGTH

Variance Source	D.F.	M.S.	F
Nutritional Regime	3	.0666	ns
Pooled E(A)	34	.0349	--
Temperature	1	.0015	ns
T x F	3	.0155	ns
Pooled E(B)	34	.0054	--
Muscle	3	10.9112	**
M x F	9	.0581	**
M x T	3	.0073	ns
M x T x F	9	.0039	ns
Pooled E(C)	204	.0116	--
Fabrication	1	1.3652	*
Fa x F	3	.0202	*
Fa x T	1	.0107	ns
Fa x F x T	3	.0017	ns
Fa x M	3	3.0377	**
Fa x M x F	9	.0339	*
Fa x M x T	3	.0041	ns
Fa x M x T x F	9	.0060	ns
Pooled E(D)	272	.0076	--

F = Nutritional Regime (Grass-, short-, long- and silage-fed)
Fa = Fabrication Time (Before or after vacuum packaging)
M = Muscle (LD, ST, SM, BF)
T = Temperature (3C and 13C)
ns = non-significant
** = P(<.01)
* = P(<.05)

TABLE 7. ANALYSIS OF VARIANCE FOR TASTE PANEL TENDERNESS, JUICINESS, FLAVOR AND OVER-ALL ACCEPTABILITY

Variance Source	Tenderness			Juiciness			Desirability of Flavor			Over-all Acceptability		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
Nutritional Regime	3	12.7747	**	3	1.8902	ns	3	8.6189	**	3	8.9556	**
Pooled E(A)	34	2.3222	--	34	1.2108	--	34	.5276	--	34	1.0876	--
Temperature	1	1.2038	ns	1	.0017	ns	1	.0287	ns	1	.5705	ns
T x F	3	.5038	ns	3	.3829	ns	3	.1075	ns	3	.4474	ns
Pooled E(B)	34	.4664	--	34	.2210	--	34	.1557	--	34	.2569	--
Fabrication	1	65.7789	**	1	3.1124	**	1	1.5220	*	1	15.0277	**
Fa x F	3	.9981	*	3	.6117	*	3	1.2973	**	3	.8508	*
Fa x T	1	.1720	ns	1	.2808	ns	1	.1553	ns	1	.0934	ns
Fa x F x T	3	.3539	ns	3	.0764	ns	3	.2739	ns	3	.2209	ns
Pooled E(C)	68	.3500	--	68	.2216	--	68	.2604	--	68	.2897	--
Display	1	13.1350	**	1	.2574	ns	1	6.8026	**	1	.1703	ns
D x F	3	.3528	ns	3	1.3347	*	3	.2415	ns	3	.1226	ns
D x T	1	.6057	ns	1	.4171	ns	1	.0453	ns	1	.4163	ns
D x F x T	3	.2952	ns	3	.1089	ns	3	.2349	ns	3	.0679	ns
D x Fa	1	23.4154	**	1	.1658	ns	1	6.3597	**	1	13.9451	**
D x Fa x F	3	1.6883	**	3	2.7399	**	3	1.2334	**	3	1.6097	**
D x Fa x T	1	.0442	ns	1	.5173	ns	1	.0152	ns	1	.2496	ns
D x Fa x F x T	3	.1943	ns	3	.3060	ns	3	.3375	ns	3	.0525	ns
Pooled E(D)	136	.3520	--	136	.4327	--	136	.2670	--	136	.2974	--

D = Display (Before or after 5 days)
F = Nutritional Regime (Grass-, short-, long- and silage-fed)
Fa = Fabrication Time (Before or after vacuum packaging)
T = Temperature (3C and 13C)
ns = non-significant
** = P(<.01)
* = P(<.05)

TABLE 8. STANDARD ERROR AND EXPECTED MEAN SQUARE FORMULAS

A. 4 Feed, 2 Temperatures, 4 Muscles, 2 Fabrications, 2 Displays
(Variable - Shear force)

$$E(A) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_m + 16\sigma^2_t + 32\sigma^2_f$$

$$E(B) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_m + 16\sigma^2_t$$

$$E(C) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_m$$

$$E(D) = \sigma^2_d + 2\sigma^2_a$$

$$E(E) = \sigma^2_d$$

B. 4 Feed, 2 Temperatures, 3 Muscles, 2 Fabrications, 2 Displays
(Variables - cooking, drip and volatile loss)

$$E(A) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_m + 12\sigma^2_t + 24\sigma^2_f$$

$$E(B) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_m + 12\sigma^2_t$$

$$E(C) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_m$$

$$E(D) = \sigma^2_d + 2\sigma^2_a$$

$$E(E) = \sigma^2_d$$

C. 4 Feed, 2 Temperatures, 1 Muscle, 2 Fabrications, 2 Displays
(Variables - juiciness, tenderness, flavor and over-all acceptability)

$$E(A) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_t + 8\sigma^2_f$$

$$E(B) = \sigma^2_d + 2\sigma^2_a + 4\sigma^2_t$$

$$E(C) = \sigma^2_d + 2\sigma^2_a$$

$$E(D) = \sigma^2_d$$

D. 4 Feed, 2 Temperatures, 4 Muscles, 2 Fabrications
(Variable - sarcomere length)

$$E(A) = \sigma^2_a + 2\sigma^2_m + 4\sigma^2_t + 16\sigma^2_f$$

$$E(B) = \sigma^2_a + 2\sigma^2_m + 4\sigma^2_t$$

$$E(C) = \sigma^2_a + 2\sigma^2_m$$

$$E(D) = \sigma^2_a$$

Compare T/F/D/Fa/M

A. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(B) + 3\,E(C) + 4E(D) + 8\,E(E)}{16}}$

B. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(B) + 2\,E(C) + 3\,E(D) + 6\,E(E)}{12}}$

C. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(B) + E(C) + 2\,E(D)}{4}}$

D. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(B) + E(C) + 2\,E(D)}{4}}$

Compare T/F/D/Fa averaged over M

A. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(B) + E(D) + 2\,E(E)}{4}}$

B. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(B) + E(D) + 2\,E(E)}{4}}$

D. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{E(B) - \tfrac{1}{2}\,E(C) + \tfrac{1}{2}\,E(D)}$

Compare F/T/M/Fa/D

A. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(A) + E(B) + 6\,E(C) + 8\,E(D) + 16\,E(E)}{32}}$

B. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(A) + E(B) + 4\,E(C) + 6\,E(D) + 12\,E(E)}{24}}$

C. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(A) + E(B) + 2\,E(C) + 4\,E(D)}{8}}$

D. Std. Error = $\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{E(A) + 3\,E(B) + 4\,E(C) + 8\,E(D)}{16}}$

Compare F/T/Fa/D averaged over M

A. Std. Error = $\sqrt{\frac{1}{4}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}\ \sqrt{\frac{E(A)+E(B)+2E(D)+4E(E)}{8}}$

B. Std. Error = $\sqrt{\frac{1}{3}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}\ \sqrt{\frac{E(A)+E(B)+2E(D)+4E(E)}{8}}$

D. Std. Error = $\sqrt{\frac{1}{4}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}\ \sqrt{\frac{E(A)+3E(B)-2E(C)+2E(D)}{4}}$

Compare T averaged over F/D/Fa/M

A. Std. Error = $\sqrt{\frac{2}{38}}\ \sqrt{\frac{E(B)+3E(C)+4E(D)+8E(E)}{16}}$

B. Std. Error = $\sqrt{\frac{2}{38}}\ \sqrt{\frac{E(B)+2E(C)+3E(D)+6E(E)}{12}}$

C. Std. Error = $\sqrt{\frac{2}{38}}\ \sqrt{\frac{E(B)+E(C)+2E(D)}{4}}$

D. Std. Error = $\sqrt{\frac{2}{38}}\ \sqrt{\frac{E(B)+E(C)+2E(D)}{4}}$

Compare T averaged over F/D/Fa averaged over M

A. Std. Error = $\sqrt{\frac{1}{4}\cdot\frac{2}{38}}\ \sqrt{\frac{E(B)+E(D)+2E(E)}{4}}$

B. Std. Error = $\sqrt{\frac{1}{3}\cdot\frac{2}{38}}\ \sqrt{\frac{E(B)+E(D)+2E(E)}{4}}$

D. Std. Error = $\sqrt{\frac{1}{4}\cdot\frac{2}{38}}\ \sqrt{E(B)-\tfrac{1}{2}E(C)+\tfrac{1}{2}E(D)}$

LSD = Least Significant Difference
= Std. Error x t*
t* = Calculated t value
= Std. error formula's error term numerator multiplied by appropriate t table values ($P<.05$) for each error term in the numerator divided by std. error formula's error term numerator.

e.g. $\frac{E(B)\ (t\ value)+3E(C)\ (t\ value)+4E(D)\ (t\ value)+8E(E)\ (t\ value}{E(B)+3E(C)+4E(D)+8E(E)}$

The appropriate value for n varies with the nutritional regime.
Grass-, Short- and silage-fed-n=10.
Long-fed - n=8.

A,B,C and D correspond to appropriate variable(s) for each comparison.

D = Display (Before or after 5 days)
F = Nutritional Regime (Grass-, short-, long- and silage-fed)
Fa = Fabrication Time (Before or after vacuum packaging)
M = Muscle (LD, SM, ST, BF)
T = Temperature (3C and 13C)

TABLE 9. LEAST SIGNIFICANT DIFFERENCE AND CALCULATED T VALUES STRATIFIED BY COMPARISON AND VARIABLE

Comparisons	Values	Shear	Total Cooking Loss	Drip Loss	Volatile Loss	Tenderness	Juiciness	Desirability of Flavor	Over-all Acceptability	Sarcomere
T/F/D/Fa/M	t*	0.890	1.843	1.976	1.965	1.989	1.978	1.981	1.984	1.972
	LSD^a	0.573	2.986	1.016	3.039	0.549	0.506	0.432	0.474	0.788
	LSD^b	0.641	3.339	1.136	3.398	0.613	0.566	0.482	0.530	0.088
T/F/D/Fa averaged over M	t*	0.896	1.974	1.983	1.978					2.059
	LSD^a	0.253	1.729	0.539	1.739					0.027
	LSD^b	0.283	1.934	0.601	1.944					0.030
F/T/M/Fa/D	t*	0.899	1.973	1.976	1.973	2.004	1.992	1.989	1.996	1.984
	LSD^a	0.687	3.328	1.103	3.248	0.701	0.598	0.474	0.557	0.088
	LSD^c	0.729	3.721	1.169	3.631	0.743	0.633	0.503	0.591	0.094
F/T/Fa/D averaged over M	t*	0.913	1.993	2.001	1.994					2.042
	LSD^a	0.456	2.138	0.692	2.083					0.048
	LSD^c	0.484	2.390	0.731	2.318					0.051
T averaged over F/D/Fa/M	t*	0.890	1.964	1.967	1.966	1.990	1.976	1.977	1.984	1.969
	LSD^d	0.294	1.581	0.521	1.559	0.281	0.259	0.221	0.244	0.041
T averaged over F/D/Fa averaged over M	t*	0.896	1.974	1.980	1.978					2.059
	LSD^d	0.130	0.887	0.276	0.892					0.014

t* = Calculated t value
LSD^a = n=10/n=10 comparisons
LSD^b = n=8/n=8 comparisons
LSD^c = n=10/n=8 comparisons
LSD^d = n=38/n=38 comparisons
abcd = LSD's for appropriate mean comparisons due to differences in animal numbers per feeding regime
D = Display (Before or after 5 days)
F = Nutritional Regime (Grass-, short-, long- and silage-fed)
Fa = Fabrication Time (Before or after vacuum aging)
M = Muscle (LD, ST, SM, BF)
T = Temperature (3C and 13C)

TABLE 10. RATIONS INGREDIENTS AND APPROXIMATE COMPOSITION

Ingredient	International ref. no.	Ration 1	Ration 2	Ration 3
Corn silage, %	3-02-824	48.0	40.0	0.0
Alfalfa haylage, %	3-08-151	50.0	20.0	20.0
Cracked corn, %	4-02-932	0.0	36.0	75.2
Supplement[a], %		2.0	4.0	4.8
Approximate ration composition, dry matter basis[b]				
Dry matter, %		44.9	60.0	81.2
Crude protein, %		14.6	13.0	13.0
Metabolizable energy, Mcal/kg		2.18	2.84	3.11

[a]Soybean meal (ref. no. 5-04-604) supplement containing calcium, phosphorus, vitamin A and chlortetracycline. Steers also had free choice access to both block salt and a mixture of 1/3 loose salt, 1/3 limestone and 1/3 dicalcium phosphate.

[b]Nutrient composition based on tabular values (N.R.C., 1963) supplemented with limited proximate analyses.

Rations and Slaughter Schedule

Thirty-eight crossbred steers were used. These steers were born in the spring, 1974, at the U.S. Meat Animal Research Center and were castrated at birth. The calves grazed with their dams until weaning at 6 months of age. After weaning, the steers were fed rations which contained approximately 65% corn silage, 15% alfalfa haylage and 20% grain and soybean supplement for 75 days until start of the experiment in mid-December. At that time, each steer was implanted with Ral-Gro (36 mg zeranol).

Subsequently, all steers were fed on a winter growing ration (ration 1) for 134 days, then 133 days of grazing on cool and warm season grasses. Ten grass-fed animals were slaughtered at this time. After a 6 day adjustment period, 10 animals (silage-fed) were fed 98 days on a 60% forage ration (ration 2), 10 animals (short-fed) were fed 49 days on a 20% forage ration (ration 3), and 8 animals (long-fed) were fed 98 days on a 20% forage ration (ration 3). Rations are explained in table 10 (see page 104).

EFFECTS OF ELEVATED TEMPERATURE CONDITIONING ON BEEF CARCASSES FROM FOUR NUTRITIONAL REGIMES

by

MARY ELIZABETH SMITH

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ABSTRACT

Thirty-eight crossbred steers of known background were randomly assigned to 4 nutritional regimes: grass-, short-, long- and silage-fed. The right half of each carcass was conventionally chilled at 3C until 48 hr post-mortem and left halves were conditioned at 13C for 8 hr then chilled at 3C until fabrication at 48 hr post-mortem. Temperature and pH decline data was obtained hourly until 12 hr (temperature) and 8 hr (pH) and at 24 hr post-mortem. Taste panel responses were obtained on the longissimus (LD) muscle only, whereas shear force and sarcomere length values included the LD, semitendinosus (ST), semimembranosus (SM) and biceps femoris (BF). Percent total cooking, drip and volatile loss data involved all muscles except the BF. Data was analyzed using analysis of variance and resultant F-test. To determine differences between means, the least significant difference was utilized.

Taste panel results indicated longissimus steaks from grass-fed cattle had improved tenderness, juiciness and over-all acceptability due to conditioning at 13C vs conventional chilling at 3C. However, no differences ($P>.05$) for short, long and silage regimes in 3C vs 13C comparisons were noted for tenderness, juiciness, desirability of flavor and over-all acceptability.

Taste panel tenderness responses for 3C vs 13C comparisons indicated that cold shortening occurred to a limited extent in 3C halves from grass-fed animals. Even though the cold shortening effect was minimal in grass-feds and not observed in the other regimes, these results may indicate that chill rates observed in this study were just below or at the point at which cold shortening might occur.

Even though not always statistically different from the other nutritional regimes the grass-feds were consistently least desirable and acceptable considering each taste panel trait. Silage-finished cattle were the most desirable with short- and long-fed regimes being intermediate. The majority of taste panel responses did not indicate that the samples from grass-fed cattle were unacceptable or undesirable.

Mean shear force values and sarcomere length responses from halves chilled at 3C vs counterparts conditioned at 13C generally exhibited no differences ($P>.05$) regardless of nutritional regime when individual muscles or muscle averages were compared. These results were upheld by over-all means by muscles and averaged over muscles. The results indicate that conventional chilling of halves at 3C for 8 hr did not increase shear force values when compared to conditioning at 13C nor did the 3C treatment decrease sarcomere lengths when compared to 13C conditioning as might have been expected.

When muscle responses were averaged, there were no differences ($P>.05$) in mean shear force and sarcomere length values between nutritional regimes for halves chilled at 3C or conditioned for 8 hr at 13C. This was true even though differences in marbling and quality grades existed.

Responses for 3C vs 13C averaged over muscles showed no differences ($P>.05$) for total cooking and volatile losses regardless of feeding regime. Drip loss mean responses for elevated temperature conditioning (13C) were smaller ($P<.05$) in the grass- and short-fed regimes when compared to conventionally chilled counterparts.

Grass-feds generally had less mean total cooking, drip and volatile loss even though not always statistically different from other regimes. Short- and long-feds were comparable in their total cooking, drip and volatile loss data.

Even though taste panel results indicated minimal cold shortening for grass-fed cattle, the other data (e.g. other taste panel responses, shear values, sarcomere length and cooking loss analyses) indicate that carcasses described herein may be chilled at 3C without experiencing significant cold shortening.