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Effect of Aging on the Quality of Beef Semitendinosus Muscle Treated with Ultra High Temperature Pasteurization

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EFFECT OF AGING ON THE QUALITY OF BEEF SEMITENDINOSUS MUSCLE TREATED WITH ULTRA HIGH TEMPERATURE PASTEURIZATION

by

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ABSTRACT

Effect of Aging on the Quality of Beef
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by

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The objective of this study was to determine the effect of aging on the tenderness and palatability of beef from the semitendinosus muscle of the round. Tenderness may be affected by the length of the aging period and the aging temperature. Steaks from the semitendinosus muscle were stored for 0, 3, 6, 9, 12, and 24 hr at two temperatures, 43.3°C and 2.2° C. Ultra high temperature (UHT) pasteurization was accomplished by subjecting the meat to 1100°C for 20 seconds. UHT pasteurization denatures surface proteins, destroys vegetative pathogens, and eliminates some spoilage organisms from the surface of the meat. UHT-treated steaks were cooked in a microwave oven to an internal temperature of 71.1°C. Two cores were taken from the center of each cooked steak.

Shear values (lb) were determined on the cores using a Warner Bratzler shear. The results of the study showed that the UHT-treated steaks that were stored at 43.3^{0}C were significantly more tender than those that were refrigerated at 2.2^{0}C regardless of the length of the aging period up to 24 hr. Additional tenderness at 2.2^{0}C when the aging period exceeds 24 hr may be possible.

Total plate count (TPC) of raw and UHT-treated steaks was determined using the standard plate count method. The average TPC for the raw steaks was significantly higher than the UHT-treated steaks. The TPC was not significantly different between the UHT- treated steaks that were aged and those that were not aged. A trained panel was used for sensory evaluation to evaluate the moistness, tenderness, and flavor of the steaks using a 9-point hedonic scale.

Sensory scores of the UHT-treated steaks revealed that steaks stored at 43.3^{0}C had significantly more moisture and were more tender than those stored at 2.2^{0}C. The panel noted more spoiled flavor among the steaks stored at 43.3°C than 2.2^{0}C. Steaks stored at 2.2°C received significantly higher flavor scores than those stored at 43.3^{0}C.

(46 pages)

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Habiba Ali Nur

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Meat is defined as animal tissue that is suitable for use as food. Meat is a highly perishable product because of its unique biological and chemical nature. Meat undergoes progressive deterioration from the time of slaughter until consumption. A number of interrelated factors influence the shelf life and keeping quality of meat, specifically holding temperature, atmospheric oxygen (O_2), indigenous enzymes, water activity, air moisture (dehydration), light, and, most importantly, the growth and reproduction of microorganisms on the meat surfaces (National Livestock and Meat Board, 1991).

Scientists have developed several methods that extend storage life of meat and meat products. Among these methods are cooking, smoking, refrigeration, salting (NaCl), acidification, adding sugar, vacuum packaging, and curing (sodium nitrite). All the methods have certain limitations. All of these methods render meat less susceptible to spoilage, but the flavor of the meat is altered, sometimes drastically, and the meat is still subject to eventual spoilage (Lambert et al., 1991).

A more effective method of preservation would be using additional chemical additives, but consumer acceptance of fresh meat with chemical additives would not be easily accomplished. Frozen meat may be stored for extended periods of time without seriously affecting the palatability, but maintaining meat in a frozen state is expensive.

A combination of antibiotics and high temperature (40°C) was shown to extend the shelf life of meat and produce a given degree of tenderization in a considerably shorter time than did a low storage (4.4°C) temperature without antibiotics (Dransfield et al., 1981). Even though high temperature aging with antibiotics improved the tenderness

and the shelf life of the meat, antibiotic residues posed an even greater problem for the consumer.

A more recent development in meat preservation is the use of ultra high temperatures. Subjecting meat to 1100°C for 20 to 50 seconds denatures surface protein without burning and destroys vegetative pathogens on the surface. The UHT treatment denatures surface proteins, and destroys vegetative pathogens and some spoilage organisms on the surface of the meat, thereby enabling an extended storage time at refrigerated temperatures. The appearance is stabilized so that color changes on the surface do not occur during refrigerated storage. UHT treatment provides an opportunity to age meat for a longer period without spoilage.

In this study, UHT-treated beef steaks from the semitendinosus muscle of the round were aged at different temperatures for different periods of time. The quality of the resulting meat products was measured using shear values, microbial count, and sensory panel scores.

The main goal of this study was to determine the effect of high temperature aging (HTA) on the tenderness and palatability of beef from the semitendinosus muscle of the round. The specific objectives outlined to achieve this goal were:

1. To determine the effect of the length of aging period and the temperature of aging on the tenderness of UHT-treated steaks;
2. To determine the effect of UHT on the growth and reproduction of microorganisms on the surface of the steaks; and

3. To determine the palatability and quality of UHT-treated steaks using sensory panel scores and Warner Bratzler shear values.

LITERATURE REVIEW

Meat is defined as the eatable part of the skeletal muscle of healthy animals at the time of slaughter (Canada, 1990). Chemically, meat is composed of four major components: water, protein, lipid, and carbohydrates. Many other minor components are present such as vitamins, enzymes, pigments, and flavor compounds. The relative proportion of all these constituents gives meat its particular structure, texture, flavor, color, and nutritive value. However, because of its unique biological and chemical nature, meat undergoes progressive deterioration from the time of slaughter until consumption. A number of interrelated factors influence the shelf life and keeping quality of meat, specifically holding temperature, atmospheric oxygen (O_2), indigenous enzymes, moisture (dehydration), light, and, most importantly, the growth and reproduction of microorganisms on the meat surfaces. All of these factors, either alone or in combination, can result in detrimental changes in the color, odor, texture, and flavor of meat (Lambert et al., 1991).

Several types of microorganisms have been isolated from meat, including bacteria, viruses, and fungi. Bacteria are the most predominant and important to meat quality (National Livestock and Meat Board, 1991). Some microorganisms (aerobic) must have free oxygen to grow; others (anaerobic) grow only in its absence, and some (facultative) will grow with or without oxygen. Aerobic conditions are present primarily on the surface of meat. Organisms that need free oxygen are found on the exterior, whereas the internal growth of microorganisms is largely anaerobic in nature. However,

the internal portion of intact muscles remains sterile if taken from healthy animals and not contaminated during processing.

Temperature is a critical factor during meat handling and storage. Meat cannot be held at temperatures higher than 40°F without compromising quality appearance and safety. Low refrigerator temperatures (26°F to 32°F) prevent nearly all bacterial growth. As the temperature approaches 32°F, few microorganisms grow and reproduction is greatly retarded. It is for this reason that refrigeration and freezing prolong shelf life (National Livestock and Meat Board, 1991). It has been shown that holding meat at refrigerated temperatures (4.4°C) for 2 weeks improves tenderness (Dransfield et al., 1981).

Quality deterioration and subsequent spoilage of refrigerated beef are due largely to the metabolic activity of psychotrophic, aerobic bacteria, which is manifested by changes in the odor, flavor, and color of meat (Ingram, 1962; Jay, 1993). Refrigeration and freezing only slow or stop growth of microorganisms but does not destroy them.

Many studies have evaluated changes that occur in muscle during postmortem storage and their relationship with meat tenderization. Higher constant temperatures early in the postmortem period speed the aging process and result ultimately in increased tenderness (Lochner et al., 1980; Marsh, 1981). Several mechanisms may explain this effect. A more rapid decrease in pH at higher temperatures may rupture the lysosomal membrane (Moeller et al., 1977) in which some cathepsin could hydrolyze specific myofibrillar proteins. Incubation of bovine longissimus muscle slice obtained at 12 hr

postmortem (Koohmaraie et al., 1986) in a buffer solution containing $CaCl_2$ demonstrated that most of the postmortem changes occurred within the first 24 hr of incubation. When muscle slices were incubated in the same buffer for 24 hr, it was concluded that the postmortem tenderization events are Ca^{2+} mediated, and that calcium-dependent proteoses are responsible for postmortem tenderization.

The combination of low pH and high temperatures could promote an earlier release of Ca^{2+} from the sarcoplasmic reticulum, thus activating calcium-dependent proteoses. It retains only 24 to 28% of the maximum activity at postmortem conditions of pH 5.5 to 5.8 and 5°C (Koohmaraie et al., 1986).

Effects of high temperature conditions (HTC) on beef longissimus (LM) and semitendinosus muscles (ST) show that the higher temperature treatment increased the rate of tenderization in LM but not in ST muscles (Whipple and Koohmaraie, 1993).

Dranisfield et al. (1981) observed that a 5°C rise in temperature increased the rate of tenderization in several beef muscles, including LM. Yei and Lee (1988) reported that delayed chilling at 25°C for 8 hr increased LM tenderness. In grass-fed cattle, Lee and Ashmore (1985) found that LM steaks from HTC sides were more tender at day 3 but not day 7. Tenderness often is related to the amount of muscle fiber fragmentation (Olson and Parrish, 1977; Cutler et al., 1978; Koohmaraie et al., 1987). Enzymes that occur naturally in muscle tissue continue to function during the aging of meat. Proteolytic enzymes are those that degrade protein during aging of meat. Proteolytic enzymes break down myofibrillar proteins, thereby contributing to the tenderness of meat (National

Livestock and Meat Board, 1991). It is also clear that muscles contain proteolytic enzymes that operate much more rapidly at 37°C than at 4.4°C (Sharp, 1963). The increase in the tenderness of meat that occurs during storage at temperatures above freezing point, so called meat aging, is usually considered a consequence of changes within the fibrous components of muscle. The two more obvious changes that have been shown to occur during aging are the considerable breakdown in the meat fibers and loss of resolution in the fine structure of myofibrilla (Harrison et al., 1949; Stromer and Gall, 1967). Changes in the fine structure of meat during aging are due to disruption and possible dissolution of Z-line material, leading to weakening of intermyofibrillar linkages probably located at the junctions of adjacent Z-lines and to loss of tensile strength of myofibrilla themselves (Davey and Gilbert, 1996).

The effect of low calcium-requiring, calcium-activated factor (CAF) on the myofibrilla under varying pH at 5°C was examined and results indicate that at conditions similar to those of postmortem storage (pH 5.5-8 and 5°C) CAF retained 24-28% of its maximum activity (pH 7.5 at 25°C) (Koohmaraie et al., 1986). The exact mechanism of postmortem tenderization of beef remains controversial. However, it is generally agreed that proteolysis of myofibrillar protein is the major contributor to tenderization of beef during postmortem storage (Gall et al., 1983; Tarrant, 1987). The protease indigenous to skeletal muscle, calcium-dependent proteases (CDP) and lysosomal enzymes appear to be the best candidates for bringing about the tenderness changes during postmortem storage (Dutson, 1983; Gall et al., 1983; Etherington et al., 1987; Tarrant, 1987).

Association of CDP and lysosomal enzymes under various incubation conditions in vitro was established to enhance or preclude the role of calcium in the postmortem tenderization process (Koohmaraie et al., 1986, 1987, 1988).

Calcium chloride solutions used in infusion, injection, or marination of meat have a positive effect on tenderness (Koohmaraie et al., 1990; Morgan, 1991; Wheeler et al., 1993; Whipple and Koohmaraie, 1993). According to Wheeler et al. (1991a), carcasses that are infused or injected with 10% Ca Cl_2 (0.3M) solution in the pre-rigor stage result in a maximum tenderization that can occur as soon as 1 day postmortem. This tenderizing effect has been attributed to the activation of calpains, the Ca^{++} -dependent proteases, involved in the aging of meat (Koohmaraie, 1994) and also to the increase in the intracellular ionic strength inducing protein solubilization (Taylor and Etherington, 1991; Takahashi, 1992). Other salts such as NaCl, $MgCl_2$, and KCl have also been shown to have positive effects on preservation and decreasing toughness, but they were less efficient than $CaCl_2$ (Alarcon-Rijo and Dransfield, 1995; Koohmaraie, 1995; Koohmaraie et al., 1995). When $CaCl_2$ (0.3M, 10% w/w) was injected post-rigor, Wheeler et al. (1993) obtained a tenderization similar to that induced by pre-rigor injection. The addition of $CaCl_2$ did not affect lean color through 3 days of retail display (Wheeler et al., 1993) but resulted in a tendency for greater discoloration after 7 days of retail display (Kerth et al., 1995; Landsdell et al., 1995; Whipple et al., 1990). St. Angelo et al. (1991) combined calcium chloride and vitamin C to reduce oxidation induced by the calcium chloride. Wheeler et al. (1991b) found that a combination of vitamin C and calcium

chloride has simultaneously enhanced tenderness and color stability during retail display.

When food spoils, the color, odor, and texture of meat deteriorate, thus reducing its acceptability and providing a warning for the consumer (National Livestock and Meat Board, 1991). Proper storage is essential to maintain food safety and quality.

Consumers discriminate against fresh beef steaks that contain more than 25% surface discoloration (Hood and Riordan, 1973). Surface discoloration of 50% to 75% is evident in fresh beef steaks after 4 days of retail display using primal cut aerobic packaging/precutting treatments (Miller et al., 1985). Similarly, vacuum-packed primal beef cuts lose quality after 40 to 60 days of storage depending on storage temperature, degree of evacuation, permeability of packaging material, initial microbial load, and composition of the primal (Seideman et al., 1976). Consumers discriminate against meat in vacuum packages because of the loss of bloom, the bright red color.

Use of antibiotics for meat preservation became a common practice in the 1950s. Antibiotics were found to be 100 to 1000 times more effective in controlling microorganisms than permitted chemical preservatives. The low toxicity of antibiotics to humans and their effectiveness against microorganisms encouraged more use of antibiotics as food preservatives (Tarr et al., 1952). Although many antibiotics are selective in their action, it is important to emphasize that at practical concentrations, these antibiotics slow bacterial growth and hence delay spoilage. They do not sterilize. One concern with the use of antibiotics as preservatives is the question of toxicity caused by residues of active material in the treated products. In general, high temperature

conditioning in the presence of antibiotics produces a given degree of tenderization in a considerably shorter period of time than does a low temperature. This effect has been studied by Lawrie (1966) and Wilson et al. (1959). The former worker found that conditioning for 2 days at 20°C gave the same degree of tenderization as 14 days at 0°C and that the benefits of conditioning were more marked with beef of poor quality. Even though high temperature aging improves the tenderness and the shelf life of the meat, antibiotic residues remain a problem. Other methods of controlling microorganisms should be investigated.

A common method of meat preservation is the application of heat to the surface of the meat. This method reduces the overall microbial load of meat, thereby extending the shelf life of meat and meat products, but should be combined with refrigeration to control microorganisms that survive the cooking process. Heat processing will destroy microorganisms that cause spoilage or that are potentially toxic. Two types of heat treatment preserve meat: pasteurization and sterilization. Pasteurized meat is heated to 155°C to 167°C (internal temperature) to kill some of the microorganisms and to inactivate others. Meat must be stored in the refrigerator following pasteurization. In sterilization, meat can be made shelf-stable by heating to above 100°C, which kills all vegetative pathogens and spores. Sterilization compromises the flavor and texture of meat because protein denaturation takes place and connective tissues are broken down.

It is generally accepted that the higher the process temperature, the shorter the time necessary to kill microorganisms and the greater the killing effect of heat (Jay,

1993). Heat changes the physical properties of meat, so cooked meat is more tender, flavorful, and safe to eat. Different cooking methods are used to maximize the flavor and eating enjoyment of different cuts of meat. Meat develops its desirable flavor and aroma during cooking. The flavor of cooked meat depends in part on the amount and kind of heat applied. The greater the degree of doneness, the less juicy the meat cut will be. Cooking brings about changes in the myoglobin, which affects the color of meat because of the change in the color pigments. The color of cooked meat is typically used as an index for doneness (National Livestock and Meat Board, 1991).

A more recent development in meat preservation is the use of UHT pasteurization. Treating meat with UHT at 1100°C for 20 to 50 seconds is sufficient to denature surface proteins without burning (Fig. 1). This is a new method of pasteurizing the surface of raw meat and meat products for storage and marketing. Mattinson (1993) demonstrated that UHT pasteurization at 1100°C could reduce the numbers of both pathogenic and nonpathogenic vegetative microorganisms from $1x10^4$ to $1x10^0$ CFU/sq. in. UHT pasteurization is not effective in destroying spores, and hence refrigeration after pasteurization is essential to ensure safety and extend shelf life. UHT pasteurization also stabilizes the appearance of meat (Fig. 1). UHT essentially eliminates color changes on the surface normally associated with fresh meat spoilage, thus reducing waste. Denaturation resulting from UHT does not extend beyond 0.5 mm below the surface. The inside of the treated meat is raw (Fig. 2). UHT treatment stabilizes the appearance, destroys vegetative pathogens, and eliminates some spoilage microorganisms on the

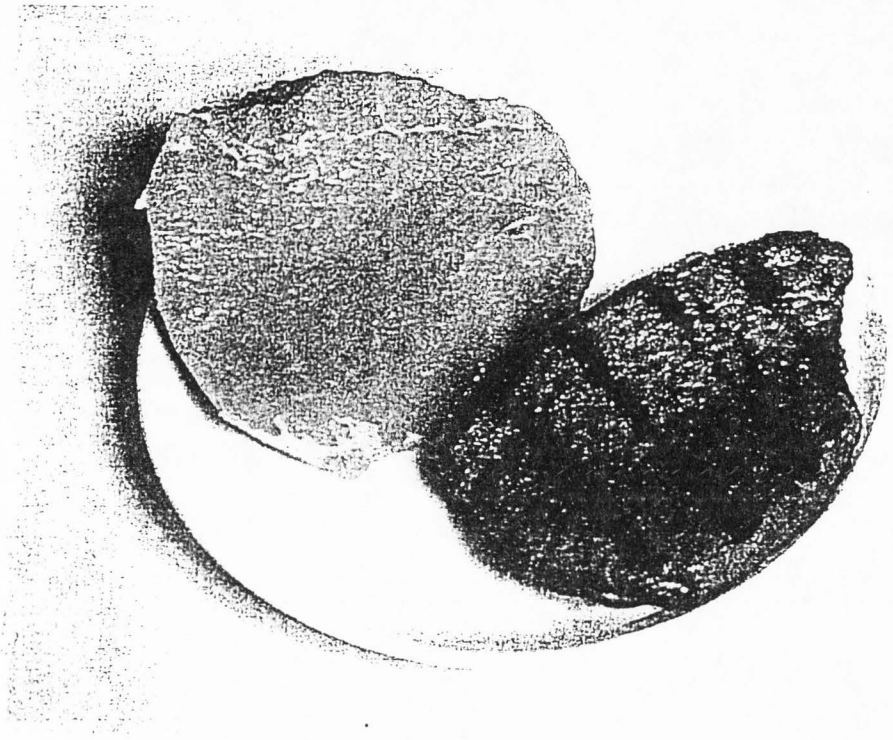

Fig. 1. Effect of UHT pasteurization on the appearance of the meat surface.

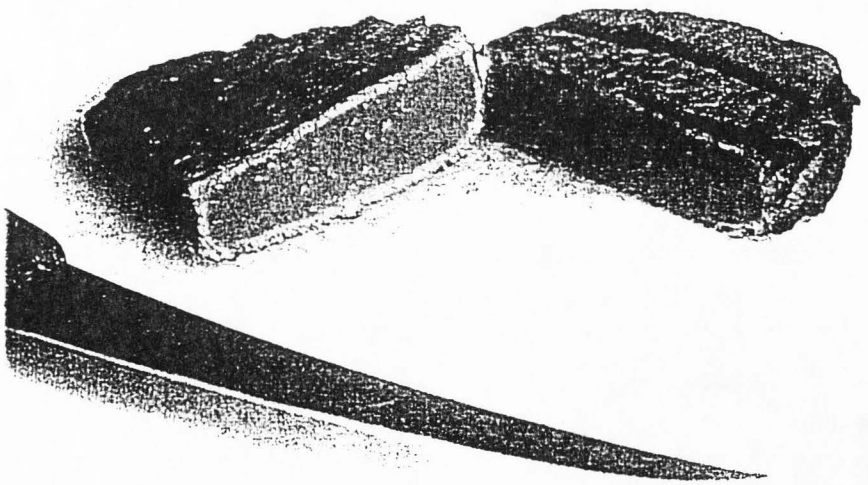

Fig. 2. The depth of denaturation resulting from the UHT treatment .

surface of the meat. UHT treatment extends storage time at 2.2^0 C without using chemical preservatives.

Rawlings (unpublished) conducted a study to determine the effect of UHT combined with modified atmospheric packaging (MAP) on the shelf life (2.2^0 C) of raw meat. The preliminary results of this study indicated that UHT pasteurization will extend the shelf life (2.2^0 C) of raw meat from 2-3 days to 60-90 days.

METHODS AND MATERIALS

UHT Treatment and Packaging

Semitendinosus muscles were removed from the left and right round of animals (Choice Grade). Each untrimmed muscle weighed approximately 2,200 g. Steaks that weigh 100 g and are 2.54 cm thick were cut from each muscle and treated with UHT. All contact equipment such as knives, forceps, and cutting boards were cleaned with detergent and sanitized with 200 ppm chlorine. Steaks were placed in sterile Whirl-Pak (Nasco West, Modesto, CA) plastic bags, closed aseptically, and stored at 2.2^0 C. A muffle furnace oven (Thermolyne Barnstead 1, Thermolyne Corporation, Dubuque, Iowa) was preheated to 1100°C. A stainless grill was placed into the oven about 20 seconds to warm and then was removed. Four steaks were aseptically removed from the sterile bags, and placed on the grill in the oven for 15 seconds (Fig. 3). The grill and the steaks were removed from the oven. Steaks were turned using sterile tongs, returned to the oven for another 15 seconds, and then removed to a sterile surface (Fig. 4). Grill marks were applied to each side using a grill heated to 900°C. The steaks were placed in sterile Whirl-Pak bags and cooled to 2.2°C. A 2-cm deep pocket was formed in Cryovac (W.R. Grace & Co., Duncan, SC) R169B film 14 mil (0.3556 mm) thick with an oxygen transmission rate of 1.0 cm^3/24 hr at 100% relative humidity. The top film was Cryovac R669B film 3 mil (.762 mm) thick with an oxygen transmission rate of 1.0 cm^3/645.16

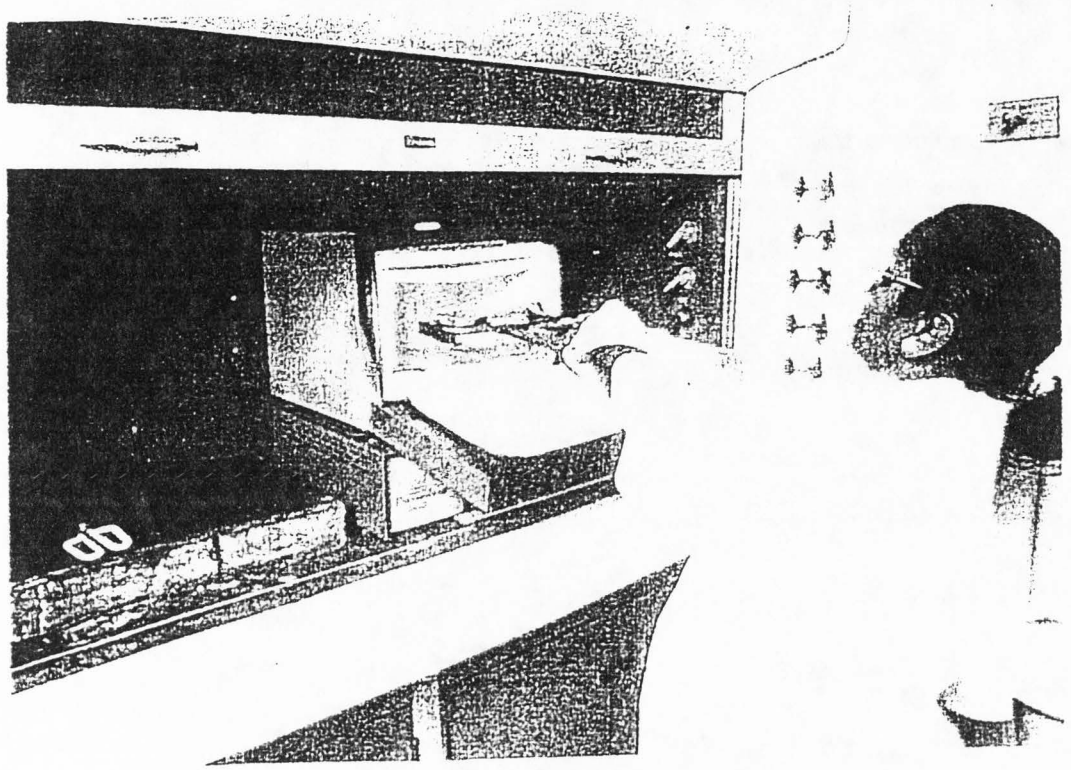

Fig. 3. Placing steaks in Muffle Furnace oven, preheated to 1100^0 C.

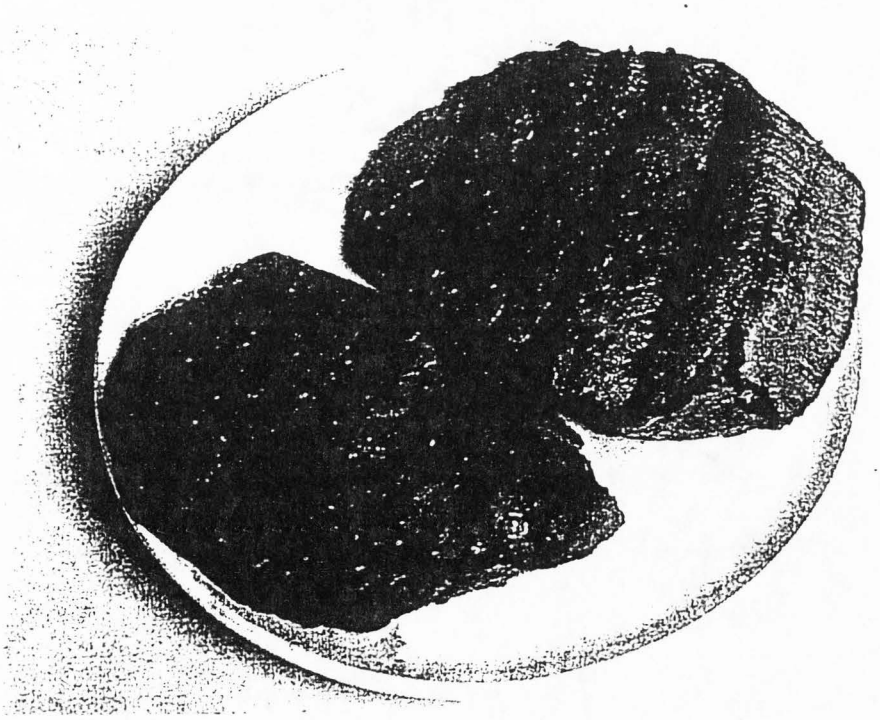

Fig. 4. Pasteurized surface of UHT-treated steaks with grill marks.

cm^2/24 hr and 0% relative humidity and a water vapor transmission rate of 0.50 grams / 645.16 cm^2 / 24 hr at 100% relative humidity at 23° C. The steaks were aseptically transferred from the sterile bags to film pockets on a Multivac M855F (Multivac Inc., Kansas City, MO) packaging machine. A vacuum was pulled to a final residual atmosphere of 10 mbar after which the package was back flushed with a gas mixture of 80% CO_2 20% N_2 and 0% O_2 using a Thermco apparatus (Thermco Instrument Corp., Laparte, IN) and heat sealed (Fig. 5).

Measuring the Shear Value

Eighteen semitendinosus muscles were removed from the left and right round of nine animals (Choice Grade). Twelve 2.54-cm thick, 100-g steaks were cut from each muscle and treated with UHT. UHT-treated steaks (108) were randomly divided between two storage temperatures (43.3°C and at 2.2°C) and one of the six aging periods (0, 3, 6, 9, 12, 24 hours). After aging, all steaks were cooled to 2.2°C before cooking. Nine steaks from each aging/storage treatment were cooked in a microwave oven (700 watts) about 2-3 minutes, to an internal temperature of 71.1°C (160°F). When the internal temperature of the steaks reached 71.1°C, two 13-mm cores were taken from the center of each steak. Shear values (lb) were determined at 21°C using a Warner Bratzler (The G.R-Electric MFG. Co., Manhattan, KS) shear.

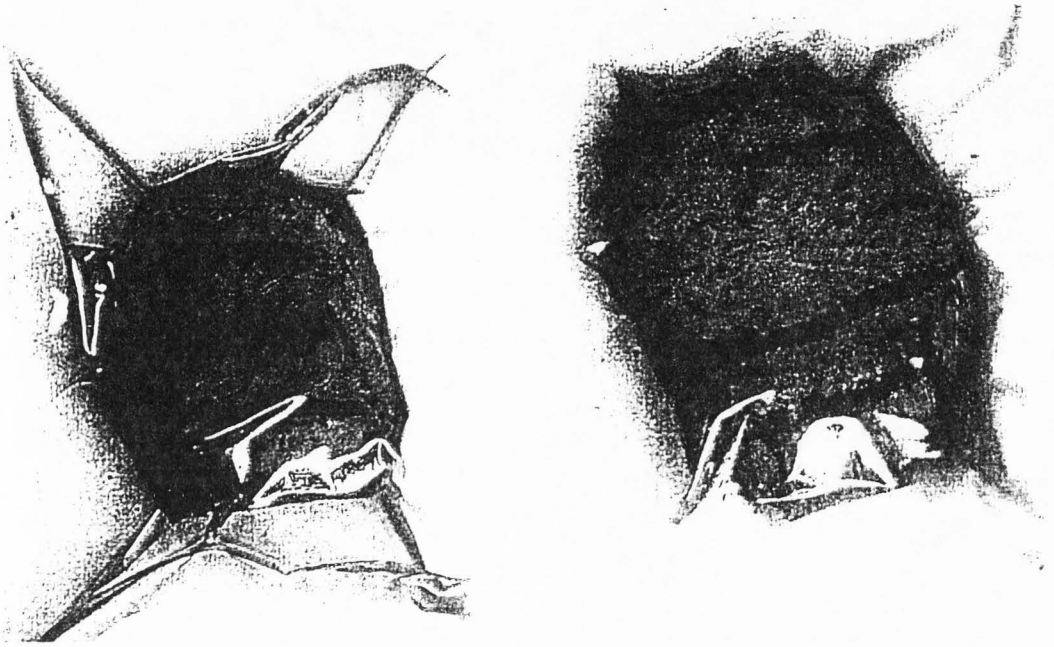

Fig. 5. Vacuum packaged UHT-treated steaks.

Microbial Counts

Three semitendinosus muscles were removed from three animals (Choice Grade). Twelve 2.54-cm thick, 100-g steaks were cut from each muscle. Thirty-six steaks were randomly divided between four treatments: raw steaks, steaks immediately (2 minutes) after UHT treatment, and UHT-treated steaks stored at 43.3^0 C and at 2.2^0 C for 24 hr.

The total plate count (TPC) of the raw and UHT-treated steaks was determined using standard methods (Busta et al., 1984). These methods determine the bacterial count per unit surface area and are based on the pour plate technique. Plates containing 30 to 300 colonies were counted. Ninety-nine ml of sterile diluent was poured into sterile

plastic bags containing the steaks and shaken for 20 seconds. Aliquots from the sterile bag were taken for dilution. Poured plates were incubated (2.2° C) in both aerobic and anaerobic environments for 48 hr.

Sensory Analysis

Six panels were used for this study. In each panel, eight steaks cut from one semitendinosus muscle were used. These steaks were randomly divided equally between two aging temperatures, 2.2^0 C and 43.3^0 C. The steaks were cooked in a microwave oven for 2-3 minutes. Four samples, identical in position, two from each steak, were placed in plastic cups (Solo Cup Company, Urbana, IL) identified by four-digit random numbers. Number codes were randomized to block for positional bias by the panel. Samples were then placed on a tray, four cups on each tray, and placed under infrared light to keep them warm (40^0 C). A tray containing four samples was presented to each panelist. The panel members were instructed to rinse their mouths with water between samples.

Panelists rated the moisture content, texture, and flavor of the samples, using a 9-point hedonic scale. A score of 9 was set equal to extremely juicy (moisture), extremely tender (texture), and extremely strong (flavor), and a score of 1 was set equal to extremely dry (moisture), extremely tough (texture), and the absence of (flavor), respectively (see the Appendix). The written responses of the panelists were statistically analyzed.

The panelists for this study were chosen from among the faculty and students of the Nutrition and Food Sciences Department at Utah State University. The panelists were

trained to detect the moisture content, texture, and flavor of the steaks. Panelists were given samples that exhibited known levels of juiciness, texture, or flavor, as indicated by numerical score. Panelists whose scores indicated an inability to detect quality differences were eliminated from the panel.

The panelists consisted of two women and six men, with an average age of 35.5±12.3 years. The same panelists were used throughout the 6-week period. The panel was conducted the same day of the week throughout the 6-week period using isolated booths and white light.

Experimental Design and Statistical Analysis

The experimental design for the shear values was a randomized block, split plot design in which nine animals served as the blocks and legs were the whole plot "treatment." The two temperatures by six aging combinations (0, 3, 6, 9, 12, and 24 hours) gave the 12 subplot treatments. Each semitendinosus muscle was cut into 12 steaks, each of which randomly received one of the two temperatures and one of the six aging times.

A split plot randomized block design was used for the microbial counts, in which the three muscles were the blocks; the four treatments, raw steaks, steaks immediately (2 minutes) after UHT treatment, UHT-treated steaks stored at 43.3^0 C or 2.2^0 C for 24 hr, were the whole plot factors; and the two conditions, aerobic and anaerobic, represent the subplot factors that were used for the microbial plate counts.

A randomized block design with subsampling was used for the sensory

evaluation, in which six muscles were the blocks, two aging temperatures were the treatments, and eight panelists were the subsamples. This design was used for all six dependent variables: moisture, texture, oxidized flavor, acid flavor , steak flavor, and spoiled flavor.

Sample size

The sample size was defined as the number of steaks that would be utilized in each of the three experiments. An initial sample of 30 UHT-treated steaks was used to determine experimental sample size. These samples were treated as was described above, and shear values were obtained. The following results were obtained using analysis of variance.

Sample mean = 7.06

Sample standard deviation (s) = 1.02

Sample size = 30.

The sample size was then calculated by the following formula (Kvanli et al., 1996) using a 99% confidence level:

$$n = (Z_{\alpha/2} \cdot s / E)^2$$

where $\alpha = .01$ and E = 3%. E represents the amount of error allowed between the estimate and the true value. Hence,

$$n = (0.125 \times 1.02 / .03)^2 = 18.06 \simeq 18.$$

Therefore, 18 samples (steaks) were used in the shear value treatment.

Sample sizes for the other two experiments, microbial count and sensory analysis, were obtained using the above procedure.

RESULTS AND DISCUSSIONS

Mean shear values of the cooked steaks from the two storage temperatures are shown in Table 1. The steaks that were aged at 43.3°C were significantly more tender than those that were aged at 2.2°C, regardless of the length of the aging period. This result agrees with Lochner et al. (1980), who demonstrated that higher constant temperatures early in the postmortem aging period result in increased tenderness by speeding the aging process. Whipple and Koohmaraie (1993) also found that higher temperatures during postmortem aging increased the rate of tenderization in beef longissimus but not in semitendinosus muscles. However, a study by Dransfield et al. (1981) indicated that higher temperatures at 20°C for 12 hr increase the rate of tenderization in several beef muscles including semitendinosus muscle.

Mean shear values of the steaks for the six different aging periods were significantly different ($p \leq .05$) from one another (Fig. 6) and (Table 2). This means that the longer the aging period, the more tender the steaks became, regardless of whether they are aged at 43.3°C or 2.2°C.

Several studies suggest that the calcium-dependent proteoses (CDP) and lysosomal enzymes are responsible for the tenderness changes during postmortem storage (Dutson, 1983; Gall et al., 1983; Etherington et al., 1987; Tarrant, 1987). Association of CDP and lysosomal enzymes enhances the role of calcium in the postmortem tenderization process during storage (Koohmaraie et al., 1986, 1987, 1988).

Table 1. Mean shear value of cores from cooked semitendinosus muscles held at two temperatures for all aging periods (0 to 24 hours). (N=108)

Temperature	Mean Shear Value
43.3°C	6.77_a^* (0.22)
2.2°C	7.85_b (0.21)

* Values with different subscripts are significantly different from one another at $p \leq .05$. Values within the parentheses are the standard errors.

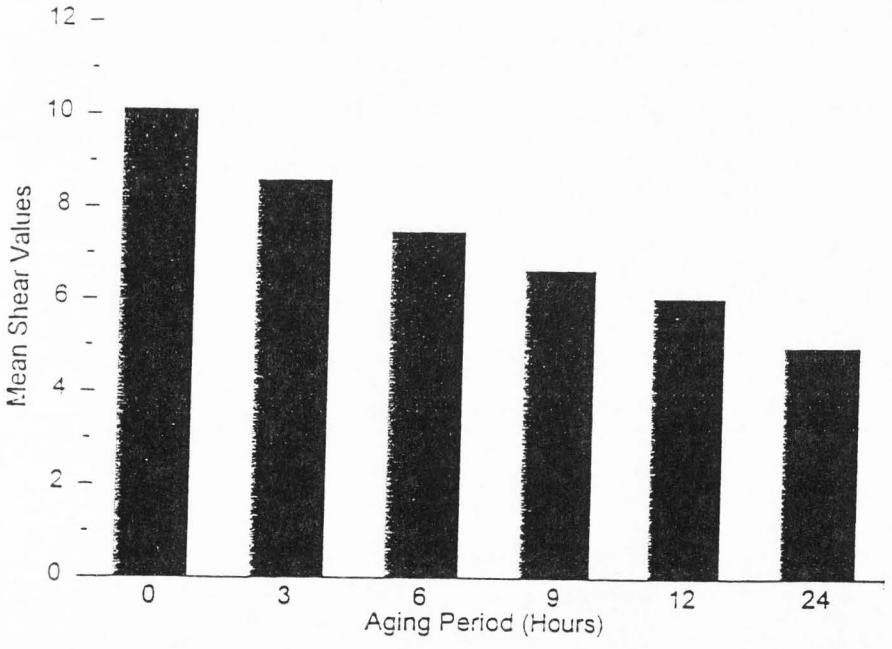

Fig. 6. Mean shear value of cores from cooked semitendinosus muscles from six aging periods at all temperatures.

Table 2. Analysis of variance for the shear value.

Source of variation	Degrees of freedom	Mean squares	F-ratio	P
Animal	8	28.396		
Leg	1	2.949	2.361	0.163
Animal x Leg	8	1.249		
Temperature	1	62.554	54.63	0.000
Aging	5	120.960	105.64	0.000
Temperature x Aging	5	2.631	2.30	0.047
Leg x Temperature	1	0.014	0.01	0.911
Leg x Aging	5	0.602	0.53	0.757
Leg x Temperature x Aging	5	0.028	0.02	1.000
Error	176	1.145		
Total	215			

Mean shear values for steaks that were stored at 43.3°C and 2.2°C significantly decreased (becoming more tender) as the aging period was increased. Mean shear values of both steaks at 0 storage time were not significantly different ($p \leq .05$), verifying the random selection. Steaks that were aged at 43.3°C had a significantly lower shear value (more tender) than those that were aged at 2.2°C (Tables 2 and 3).

An analysis of variance of TPC indicated that the average TPC for raw and UHT-treated steaks stored at 43.3°C and at 2.2°C was significantly different ($p \leq .05$) (Table 6). A comparison of the average microbial counts of the four treatments using the LSD test showed that the average TPC for the raw meat was significantly higher than that of the other three treatments at $p \leq .05$. However, the average microbial plate counts for the other treatments were not significantly different ($p \leq .05$) from one another (Tables 4). This indicates that the UHT reduces the numbers of microorganisms on the surface of the steaks. Similar results were found by Mattinson (1993), who demonstrated that UHT reduces the counts from $1x10^4$ to $1x10^0$ CFU/sq. in. for both pathogenic and nonpathogenic microorganisms.

The average aerobic plate counts of the raw steaks were significantly higher ($p \leq .05$) than anearobic counts of the raw steaks (Tables 5 and 6). Table 5 also shows that there was no significant difference ($p \leq .05$) between aerobic and anaerobic plate counts of meats treated with UHT. Similarly, an LSD for comparing treatments within aerobic showed that the average plate counts for raw meats were significantly higher ($p \leq .05$) than the average plate counts of the other three treatments. In addition, the average plate counts for treatments with the UHT were not significantly ($p \leq .05$) different from one another. In

Table 3. Mean shear value of cores from cooked semitendinosus muscles at six ageing periods and two temperatures. (N=18).

Temperature	Length of aging period					
	0	3	6	9	12	24
43.3°C	9.93_{a}* (0.47)	8.12_{b} (0.38)	7.08_{d} (0.31)	6.11_{f} (0.19)	5.34_{g} (0.20)	4.05_{h} (0.24)
2.2°C	10.27_{a} (0.58)	9.05_{c} (0.44)	7.85_{e} (0.35)	7.18_{d} (0.27)	6.78_{d} (0.28)	5.95_{g} (0.25)

* Values within the same column or row with different subscripts are significantly different from one another ($p \leq .05$). The values within the parentheses are the standard errors.

Table 4. Mean total plate counts of steaks immediately after UHT treatment and UHT-treated steaks stored at 43.3°C or 2.2°C for 24 hours. (N=9)

Treatment	Mean Plate Count
Raw	$1.54 \times 10^{6}{}_{a}$* (3.45×10^{4})
After UHT (2 minutes)	$7.38 \times 10^{3}{}_{b}$ (3.13×10^{3})
UHT Aged at 43.3°C for 24 hours	$1.42 \times 10^{5}{}_{b}$ (3.82×10^{3})
UHT Aged at 2.2°C for 24 hours	$9.96 \times 10^{4}{}_{b}$ (3.16×10^{3})

* Values with the same subscripts are not significantly different from one another ($p \leq .05$). The values within the parentheses are the standard errors.

Table 5. Mean aerobic and anaerobic total plate counts of raw steaks, steaks immediately after UHT treatment, and UHT-treated steaks stored at 43.3°C or 2.2°C for 24 hours. (N=6).

Presence of Oxygen	Treatment			
	Raw	After UHT (2 minutes)	UHT Aged at 43.3°C for 24 hours	UHT Aged at 2.2° C for 24 hours
Aerobic	$2.95 \times 10^{6*}_{a}$ (5.74×10^{5})	$2.86 \times 10^{4}_{b}$ (5.69×10^{3})	$8.26 \times 10^{4}_{b}$ (4.85×10^{4})	$3.33 \times 10^{4}_{b}$ (1.31×10^{3})
Anaerobic	$1.30 \times 10^{5}_{b}$ (1.08×10^{5})	$1.84 \times 10^{4}_{b}$ (6.72×10^{3})	$3.48 \times 10^{4}_{b}$ (9.98×10^{3})	$2.69 \times 10^{4}_{b}$ (6.39×10^{3})

* Within each column or row, values with the same letters are not significantly different from one another at $p \leq .05$. The values within the parentheses are the standard errors.

Table 6. Analysis of variance for the microbial count

Source of variance	DF	Mean squares	F-ratio	P-value
Eye	2	3.873×10^{8}		
Temperature	3	1.569×10^{10}	12.06	0.006
Eye x Temperature	6	1.301×10^{9}		
Dilution	4	7.878×10^{9}	19.58	0.00
Aerobic vs. Anaerobic	1	1.320×10^{8}	32.82	0.00
Dilution / aerobic vs. Anaerobic	3	6.101×10^{9}	15.16	0.00
Temperature x Dilution	12	5.011×10^{8}	12.45	0.00
Temperature x Aerobic vs. Anaerobic	3	9.212×10^{8}	22.89	0.00
Temperature x Dilution / aerobic vs anaerobic	9	3.638×10^{8}	9.04	0.00
Error	32	4.024×10^{8}		
Total	59			

the case of the anaerobic organisms, the average plate counts of the four treatments were not significantly different from one another. These results suggest that UHT destroyed the surface microorganisms, both aerobic and anaerobic. Growth of survivors was not significantly different.

UHT-treated steaks stored at 43.3^{0}C were significantly more juicy, tender, more oxidized, and spoiled than those that were refrigerated (Tables 7 and 8). Steaks stored at 2.2^{0}C had significantly better flavor. The two storage temperatures were not significantly different in the level of oxidation or acidity.

Table 7. Mean sensory evaluation of UHT-treated steaks that are stored at 43.3^{0}C or 2.2^{0}C for 24 hours. (N=4)

Treatment	Moisture	Texture	Oxidized flavor	Acid flavor	Steaks flavor	Spoiled
Aged at 43.3^{0}C for 24 hours	5.50_a (0.21)	6.61_a (0.28)	2.37_a (0.16)	1.58_a (0.13)	4.17_a (0.25)	2.78_a (0.37)
Stores at 2.2^{0}C for 24 hours	4.90_b (0.23)	4.79_b (0.31)	2.17_a (0.21)	1.40_a (0.12)	4.79_b (0.48)	1.79_b (0.85)

* Values within columns with the same subscript are not significantly different ($p<.05$). The values in the parentheses are the standard errors.

Table 8. Analysis of variance for the panel test

		Moisture			Texture			Oxidized			Acid			Steak			Spoiled		
Source	df	MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Eye	5	2.267			0.94			0.275			0.4			1.085			0.99		
Temperatur	1	2.375	7.9	0.05	9.59	8.8	0.041	0.042	0.62	0.47	0.375	1.7	0.25	3.61	6.75	0.05	12.8	20.9	0.01
Eye x Temperatur	5	0.3			1.09			0.067			0.225			0.535			0.61		
Error	84	1.664			4.4			0.455			0.345			1.573			4.87		
Total	95																		

CONCLUSIONS AND RECOMMENDATIONS

The main goal of this study was to determine the effect of high temperature aging (HTA) on the tenderness and palatability of beef from the semitendinosus muscle of the round.

The results of the study showed that the UHT-treated steaks that were stored at 43.3°C were significantly more tender than those that were refrigerated at 2.2°C regardless of the length of the aging period up to 24 hr. Additional tenderness at 2.2°C when the aging period exceeds 24 hr may be possible.

A comparison of the average total plate count of the four treatments (raw, immediately [2 minutes] after UHT, UHT aging at 43.3°C , and UHT aging at 2.2°C) showed that the average total plate count for the raw meat was significantly higher than that of the other three treatments at $p \leq .05$. The average total plate counts for the other three treatments were not significantly different from one another at $p \leq .05$.

The aerobic total plate counts of raw steaks were significantly higher ($p \leq .05$) than the anaerobic total plate count. The raw samples had significantly ($p \leq .05$) higher average aerobic microbial plate counts. These results suggest that UHT destroys some surface microorganisms, both aerobic and anaerobic.

The sensory evaluation of the UHT-treated steaks indicated that steaks that were stored at 43.3°C were significantly more juicy and tender and were more oxidized and spoiled than those that were refrigerated. Refrigerated steaks had significantly higher flavor scores.

Lack of tenderness hindered the acceptability of the semitendinosus muscle. Results of this study show that even though high temperature (43.3^0 C) aging of UHT-treated steaks rendered the steaks more tender and juicy, the flavor of these steaks did not appeal to the consumers. No undesirable flavor scores were obtained by storing the steaks at 2.2^0C. Based on these findings, a combination of UHT pasteurization and refrigeration beyond 24 hr is recommended to obtain a more juicy, tender, and flavorful steak.

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APPENDIX

MEAT PANEL

Name:_____. Date:_____.

Please evaluate the samples in the order provided using the 9-point scale given below. Write the corresponding number from the following scale next to the appropriate sample number in the space provided.

MOISTURE	TEXTURE	FLAVOR
		use any number from 1-9.
9=Extremely Juicy	9=Extremely Tender	(Oxidized/Rancid, Acid/Sour, Characteristic
8=Very Juicy	8=Very tender	Steak Flavor,Spoiled Other Than
7=Moderately Juicy	7=Moderately Tender	Oxized/Rancid)
6=Slightly Juicy	6=Slightly Tender	
5=Neither Juicy nor Dry	5=Neither Tender Nor Tough	9=Extremely Strong
4=Slightly Dry	4=Slightly Tough	7=Strong Flavor
3=Moderately Dry	3=Moderately Tough	5=Moderate
2=Very Dry	2=Very Tough	3=Slight
1Extremely Dry	1=Extremely Tough	1=Absent

Sample #	Moisture	Texture	Flavor			
			Oxidized	Acid	Steak	Spoiled
235	_____	_____	_____	_____	_____	_____
554	_____	_____	_____	_____	_____	_____
138	_____	_____	_____	_____	_____	_____
467	_____	_____	_____	_____	_____	_____

COMMENTS: