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EFFECTS OF PROCESSING VARIABLES AND STORAGE ON THE PHYSICAL, CHEMICAL, AND MICROBIAL CHARACTERISTICS OF RESTRUCTURED BEEF STEAKS

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ABSTRACT

Production of restructured beef steaks allows utilization of lower cost raw materials to produce higher quality, lower cost products for consumers and more profitable products for processors. The effects of flaking temperature, flake size, mixing time, and storage on this type of product were studied. Semimembranosis, Semitendinosis, and Biceps femoris muscles were obtained from U.S. Commercial and Utility cow carcasses. Muscles were trimmed of external fat and ground through a 2.54 cm plate, mixed 2 minutes, divided in half and tempered to -2.2C or 4.4C. Meat was flaked to produce 1.27 and 1.93 cm flakes. Three batches of meat from each temperature were formulated to contain 100% 1.27 cm flakes, 50% 1.27 cm and 50% 1.93 cm flakes, and 100% 1.93 cm flakes. Mixing times of 10 and 20 minutes were applied to each batch. Three steaks from each batch were allotted to each of 3 storage times of 0, 10, or 20 days at 3.3C. This study was completed in duplicate.

The color of steaks was affected by storage and flaking temperature. Hunter color values a and b decreased with storage time. Also, steaks flaked at -2.2C had higher Hunter L values.

Cooking losses were affected by flaking temperature, mixing time, and storage time. Steaks formed from meat flaked at 4.4C had lower non-volatile cooking loss. Batches mixed for 10 minutes had lower volatile cooking loss. Steaks stored for 20 days had the highest volatile cooking loss while those stored for 0 days had the highest non-volatile cooking loss.

Oxidation, measured by TBA numbers, was affected by flaking temperature. The steaks formed from meat tempered to 4.4C had lower TBA values. Also,steaks stored 0 days had lower TBA values than steaks stored 20.

Mixing time affected proximate composition as steaks formed after 20 minutes of mixing had higher raw moisture. Flaking temperature of 4.4C also resulted in higher raw moisture. Steaks stored for 0 days had the highest water holding capacity. and were the hardest.

Microbial counts were influenced by flake size. Aerobic plate count (APC), lactic acid bacteria count (LAB), and psychrotrophic plate count (PPC) all increased with increased flake size. The highest counts for each type were recorded after 0 days of storage. LAB and PPC increased with increased mixing time. All counts decreased over storage.

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Chapter 1

Introduction

The goal in manufacturing restructured steaks is to produce steaks that are similar to their whole muscle counterparts in physical, chemical, and sensory properties while utilizing lower cost, less desirable parts of carcasses rather than making ground beef from those parts (Booren et al., 1981; Mandigo, 1974; Seideman et al., 1982b). Much of the early research with restructured products was done with pork in order to increase pork consumption by offering a wider variety of products for the hotel, restaurant and institutional trade (Mandigo, 1975). Industry changes toward central slaughter and fabrication as well as consumer demands for a wider variety of convenient products have increased the practicality of restructured beef products (Schmidt et al., 1986).

Restructured products offer several advantages to the processor and the consumer. First, and most obvious for the processors, is the lowered cost of manufacturing through use of by-products such as trimmings and lower quality carcasses such as US Standard, Commercial, and Utility. Since the average low quality carcass yields approximately 70% meat that is tough and requires further processing (Cross and Stanfield, 1976), restructured products provide an opportunity for higher profit margins than ground meat Seideman et al., 1982b). Furthermore, several researchers have reported advantages of flaked restructured products which including

shape and weight control (Mandigo, 1975), better composition control (Pearson and Tauber, 1984), reduced and predictable cooking losses (Huffman et al., 1981; Pearson and Tauber, 1984), and improved textural and sensory properties (Huffman et al., 1981). Additionally, restructured products are totally edible (Booren et al., 1981) which is very desirable in the retail case as Savell et al. (1991) showed that 42% of retail cuts sampled across the United States had been completely trimmed of external fat and 72% of the retail cuts were boneless which shows the trend toward products that are totally edible.

Despite all the advantages of restructured products, there are also some disadvantages. An important problem when evaluating beef restructured steaks is discoloration and rapid loss of the desired bright red color (Huffman and Cordray, 1979). Another disadvantage of uncooked restructured products is that they must be kept frozen to maintain their shape. This is a serious barrier to marketing restructured steaks since most whole muscle cuts are marketed as fresh from the refrigerated case (Schmidt et al., 1986).

Consumer evaluations of restructured products indicated that they would eat this product if it was available, but would not go out of their way to purchase it (Cross and Stanfield, 1976). If restructured products are to find a niche in the meat retail counter, consumer demand must be created for this type of convenient, cooked from frozen state, totally edible product (Schmidt et al., 1986).

Lack of agreement exists among researchers about the processing procedures that yield the most desirable products. Conflicting data about the most desirable flake size has been reported by several researchers (Berry et al., 1987; Caradello et al., 1983; Chesney and Mandigo, 1973; Durland et al., 1982; Popenhagen and Mandigo, 1978). Differing optimum mixing times have been reported by Belohlavy and Mandigo (1974), Booren et al. (1981) and Thomas and Carpenter (1992). Additionally, no one flaking temperature has been determined as optimum (Chesney et al., 1978; Popenhagen and Mandigo, 1978; Costello et al., 1981). Therefore, the objectives of this study were to determine the effects of flaking temperature, flake size, mixing time and storage time on the physical, chemical, and microbiological characteristics of restructured beef steaks.

Chapter 2

Review of Literature

Color

Color instability and variability are major obstacles to the acceptance of restructured products, especially beef products. The color pigment primarily responsible for the color of fresh meat is myoglobin (Ockerman, 1983). The state of the myoglobin determines the color. In the reduced form, myoglobin appears purplish-red which is the color associated with vacuum packaged fresh meat products. After exposure to oxygen, myoglobin becomes oxygenated to oxymyoglobin and appears a bright cherry red, a color associated with fresh meat products. However, after prolonged exposure to oxygen, the pigment becomes oxidized to metmyoglobin which has an unacceptable brown color (Ockerman, 1983). Jeremiah et al. (1972) demonstrated that appearance of retail cuts in the display case was the most important factor influencing consumer selection of retail cuts. Restructured products tend to discolor quickly and/or have a mottled appearance with brownish or greenish spots (Secrist, 1982). Beef restructured products appear to have more discoloration problems than products from other species because beef is more highly pigmented (Hunt and Kropf, 1987). Ockerman and Organisciak (1979) reported that color scores given by a sensory panel increased (indicating darker colors) significantly during refrigerated storage, especially in the early stages of storage. Schwartz and Mandigo

(1976) reported that color desirability decreased severely in restructured pork products over an eight week period of storage, especially during the first four weeks. They also reported that salt was most detrimental to raw meat color of restructured pork products particularly at higher concentrations of 1.25 and 2.25%. Mandigo (1975) also stated that added salt decreases color and shelf life. This is in contrast to Seideman et al. (1982b) who stated that salt enhances color stability.

Other factors have also been associated with discoloration. Booren et al. (1981) reported that mixing time and color score from a sensory panel were negatively related. Restructured beef steaks formed after mixing for 18 minutes were scored significantly less desirable than steaks formed by mixing for 12 minutes. Mixing and grinding have been shown to increase myoglobin oxidation (Chu et al., 1987). Akamittath et al. (1990) concluded that discoloration and lipid oxidation were related. In beef, pigment oxidation preceded lipid oxidation. However, in pork and turkey these events were simultaneous (Akamittath et al., 1990). The authors attributed the difference to proportions of saturated and unsaturated fatty acids. These results are in contrast to Govindarajan et al. (1977) who theorized that myoglobin oxidation that occurs after grinding was caused by lipid oxidation. Further, Mariott et al. (1987), in a study comparing restructured beef steaks to restructured beef and turkey steaks, showed that storage affected overall appearance and discoloration more than the raw materials (turkey) which would be more subject to oxidation. Additionally, Ockerman and Organisciak

(1979) reported that for uncooked restructured beef steaks, color score increased indicating darker color during refrigerated and frozen storage of beef steaks made from 3 mm slices. Costello et al. (1981) determined that restructured beef steaks made from flakes at 2.2 C were redder than steaks made from ground or sliced meat. Additionally, Costello et al. (1981) found that meat restructured at 2.2C was redder than meat restructured at 15C or -2.2C.

Cooking loss

Conflicting data have been reported on cooking losses of restructured pork products. Chesney and Mandigo (1973) reported that cooking loss decreased as particle size decreased. Also, Chesney et al. (1978) showed that percentage cooking loss decreased as comminution size decreased. Conversely, Pepper and Schmidt (1975) found that smaller sized particles did not affect cooking yield of beef rolls. Also, Berry et al. (1987) noted that the highest cooking loss was found for beef steaks made from the smallest size flakes but found no trend in cooking loss due to flake size. This is in agreement with Seidemann et al. (1982a) who reported no differences in cooking loss due to particle thickness. Durland et al. (1982) also found no effect of particle size on cooking loss. Flaking temperature has also been shown to affect cooking losses. Mandigo (1974) reported that restructured pork products fabricated from pork flaked at -5.6C had greater cooking losses than those flaked at 2.2 or 32.2C.

Mixing time is another factor which may influence cooking loss. Booren et al. (1981) showed that cooking yield increased with increased mixing time. Likewise, Belohlavy and Mandigo (1974) as well as Pepper and Schmidt (1975) reported increased water retention as mixing time increased which would lead to lower cooking loss. Optimum mixing time for all factors considered has been reported to be 12 minutes by Booren et al. (1981) and 8-10 minutes by Belohlavy and Mandigo (1974). Furthermore, cooking yield has also been reported to be influenced by surface area of particles. Acton (1971) reported increased cooking yield for chicken loaves as surface area increased while Pepper and Schmidt (1975) reported increases in cooking loss due to increasing surface area. Cooking losses for restructured pork roasts stored for four weeks were reported to be greater than those stored for one week (Hand et al., 1982).

Lipid oxidation

Lipid oxidation is another major concern in the production of restructured meat products and is a hindrance to the acceptance of fresh restructured meat products (Secrist, 1982). Warmed over flavor is an undesirable off-flavor produced by lipid oxidation which was first characterized by Tims and Watts (1958). Lipid oxidation initiates at carbon atoms adjacent to double bonds (Lillard, 1985). Moerck and Ball (1974) found that increased numbers of double bonds in a fatty acid make it more susceptible to oxidation. Once the

reaction has started it proceeds in a chain reaction through the stages of initiation, propagation, and termination (Lillard, 1985).

Watts (1954) proposed that lipid oxidation and myoglobin oxidation could accelerate each other or occur independently. Hutchins et al. (1967) and Govindarajan (1973) proposed that the products of lipid oxidation increased the discoloration rate. Love and Pearson (1984) found that metmyoglobin had little or no activity in catalyzing the oxidation reaction. In constrast, several researchers (Harrel and Kanner, 1985; Kanner and Harrel, 1985; Rhee et al., 1987) have suggested because of the oxidation of myoglobin and oxymyoglobin to metmyoglobin (MMb) that the H_2O_2 produced could form an activated molecule with metmyoglobin MMb-H_2O_2 which in turn catalyzed lipid oxidation. Chu et al. (1987) found that lipid oxidation was poorly correlated with myoglobin oxidation ($r=0.52$, $P<0.0001$) and that in effect one did not cause the other.

Processing conditions have been shown to affect lipid oxidation in restructured products. The addition of salt, a common processing step to extract salt soluble proteins, has been shown to enhance lipid oxidation in restructured steaks made from beef, pork and turkey (Akamittath et al., 1990; Huffman et al., 1981; Lamkey et al., 1986). Lipid oxidation reported as TBA numbers has been shown to remain constant over mixing time (Booren et al., 1981) while grinding and mixing did not increase the rate of lipid oxidation (Chu et al., 1987). Work by Govindarajan et al., (1977) suggested that lipid oxidation occurred after mixing and then caused rapid myoglobin oxidation. Also, Sato and Hegarty (1971) determined that reduction in particle

size by grinding, chopping, flaking or emulsification had similar effects of increasing warmed over flavor which is caused by increased lipid oxidation. Increased TBA numbers have been negatively correlated with odor scores where 1=bad odor and 8=good odor (Ockerman and Organisciak,1979). Furthermore, the process of restructuring has been shown to increase the rate of lipid oxidation during both frozen (Chu et al., 1987) and refrigerated storage time (Ockerman and Organisciak, 1979). Additionally, tempering has been shown to produce rapid increase in lipid oxidation (Chu et al., 1987).

Water holding capacity

Water holding capacity (WHC) has been defined by Hamm (1960) as the ability of meat to hold fast to its own or added water during application of any force. WHC has been related to color, tenderness, and textural attributes of restructured meat products (Hamm, 1960). Minced meat samples have been shown to have lower WHC than whole muscle samples in lamb (Bouton et al., 1971) which would be expected. This is a problem for restructured products as the restructuring process itself is detrimental to WHC. Bouton et al. (1971) found a significant correlation of pH of raw meat with WHC. Hamm (1960) reported high correlation between water holding capacity and swelling capacity of meat.

Flaked products have been shown to have greater WHC than ground products (Ockerman and Organisciak, 1979). WHC has been shown to be greatly affected by mixing time. Belohlavy and Mandigo (1974) and Pepper and Schmidt (1975) both reported increased

water holding capacity with increased mixing time. However, Belohlavy and Mandigo (1974) reported the water holding capacity was the lowest at 14 minutes of mixing. They recommended 8-10 minutes as the best mixing time when considering multiple factors. Flaking temperature has also been shown to affect the WHC of restructured products (Mandigo, 1974). Pork products made from meat flaked at -5.6C had lower WHC than those made from meat flaked at 2.2 or 32.2C.

Texture

Attempts to achieve textural properties in restructured steaks similar to whole muscle cuts using different flake sizes and flaking temperatures have been studied extensively. For producing restructured products, flaked meat has produced a texture more similar to whole muscle than ground meat (Chesney et al., 1978). Flaked pork meat has been shown to have greater cohesivenesss than ground pork (Chesney and Mandigo, 1973). However, the size of meat flakes or combinations of flake sizes and flaking temperatures which produce the most desirable product are not as easily discerned. Sheard et al., (1990) demonstrated that the variability in size and surface area of particles produced through a common flaking head is directly related to the temperature of the meat being flaked and the form (pre-broken or chunked) in which the meat was introduced into the commitrol. Caradello et al., (1983) showed that small flakes produced resturctured beef steaks with texture more like ground beef while intermediate and larger flakes

produced a texture more like a whole muscle steak. Popenhagen and Mandigo (1973) found that restructured pork products made from medium and larger size flakes (6.9mm and 12.7mm) were more acceptable in bind, juciness and overall acceptability than smaller flakes (3mm) when flaked at 2.2C but reported no differences among flake sizes when flakes were prepared at 5.6C. Popenhagen and Mandigo (1978) concluded that a high quality product may be formulated using a blend of small flakes with larger flakes cut at a different temperature in a 50:50 blend. Conversely, Mandigo (1974) reported chops made from smaller flakes were more tender and juicy than those made from larger flakes. Durland et al., (1982) also reported that when comparing small and intermediate size flakes, products produced from small flakes had more desirable tenderness and overall desirability. One study using a consumer preference panel found no difference in preference when comparing restructured pork products flaked at 32.2C and -5.6C (Mandigo et al., 1972). Booren et al. (1981) showed that tenderness increased with increasing mixing time up to 16 minutes. Thomas and Carpenter (1992) determined 18 minutes of mixing produced steaks with optimum texture profile analysis compared to similar treatments mixed for 12 or 24 minutes. Noble et al., (1985) recommended mixing times of 10 minutes or less. Berry et al. (1987) found that beef and pork steaks produced from smaller flakes were less hard than those produced from intermediate and larger size flakes and the steaks produced with smaller flakes had less cohesiveness. Penfield et al., (1992) reported that in restructured reindeer steaks chewiness

increased with increased flake size. Furthermore, Neer and Mandigo (1974) showed that acceptability decreased over time of frozen storage.

Proximate analysis

Studies have reported that the process of restructuring has no effect on proximate analysis (Mandigo, 1974; Whiting and Strange, 1991). Chesney et al., (1978) found no differences in proximate analysis due to particle size in restructured pork products. However, Durland et al., (1982) reported that although flake size had no effect on moisture losses during cooking, it did affect the fat loss. As the flake size increased from fine to coarse, the fat loss also increased. Popenhagen and Mandigo (1978) reported that when using a flaking temperature of -5.6C, raw pork samples made from 100% 3.0mm flakes had significantly less moisture and higher ether extract than products formed from 6.9mm flakes or 12.7mm flakes. Furthermore, when comparing products made from meat flaked at 2.2C, 100% 6.9mm flakes had less moisture than 100% 12.7mm flakes. Akamittaath et al., (1990) reported that ash increased with addition of salt as would be expected. Ockerman and Organisciak (1979) found that raw restructured beef steaks made from US Good grade beef chuck roasts had 65.9 $\pm$ 3.8% moisture and 14.7 $\pm$ 4.1% fat. Durland et al., (1982) reported values from 65.3-66.35% moisture and 15.02- 16.16% fat for restructured steaks made from US Utility cow rounds. Neither study used any phosphates or other additives except salt.

Microbiological quality

The microbiological condition of restructured meat is dependent on several factors including the initial number and species of microorganisms present, temperature, and availability of nutrients (Kotula et al., 1987). Processing temperature and storage temperature of raw materials and finished products are critical in maintaining quality of restructured products (Kotula et al., 1987). Fabrication of restructured products (grinding, flaking, mixing, forming) increases the surface area and distribution of bacteria within the meat block. Presence of aerobic microorganisms has also been shown to increase the rate of discoloration due to products of their metabolism such as H_2O_2 (Robach and Costilow, 1961). Therefore, it is essential to produce restructured products from high quality raw materials (Pearson and Tauber, 1984).

The microbiological quality of restructured meat products may also be affected by the packaging material and type of packaging system used. Studies have been conducted using vacuum packaging of the restructured products (Berry et al., 1986; Booren et al., 1981; Costello et al., 1985; and Ockerman and Organisciak, 1979) as well as oxygen permeable wraps (Mariott et al., 1987; Newsome et al., 1987; Van Laack and Smulders, 1991). Microbiological quality of restructured beef steaks made from postrigor meat has been compared to comminuted meat products for spoilage reference values (Kotula et al., 1986). Van Laack and Smulders (1991) found that restructured beef steaks made from cold processed flank and neck muscles had lower initial counts than reference values.

Ockerman and Organisciak (1979) found that the refrigerated and frozen shelf-life deteriorated rapidly with increased aerobic and anaerobic counts during storage. They reported increased aerobic counts over refrigerated storage of 10 days but counts did not change significantly during frozen storage over 90 days. Also, decreases in flavor scores for cooked products was negatively correlated with aerobic plate count. Kotula et al., (1987) reported that bacterial spoilage from a high initial number of spoliage microorganisms evidenced by slime and off-odors develops before rancidity can be identified by the consumer. Chestnut et al., (1977) reported total aerobes for frozen, flaked meat as an ingredient for ground beef at 3.92 and 3.88 $\log_{10}$ colony forming units/g and psychrotrophic counts of 2.95 and 3.10 $\log_{10}$ colony forming units/g.

Chapter 3

Materials and Methods

Steak preparation

Semimembranosis, Semitendinosis, and Biceps femoris muscles from U.S. Commercial and Utility cow carcasses were obtained from cattle slaughtered at the University of Tennessee Meat Laboratory. The muscles were trimmed of all external fat and heavy connective tissue and ground (Biro grinder, Marblehead, Ohio) through a 2.54 cm plate, mixed 2 minutes, divided in half, and then tempered to either -2.2C or 4.4C. One half of the meat assigned to each temperature treatment was flaked using an Urschel Commitrol (Model 2100, Valparaiso, IN) with a 1.27 cm cutting head and the other half was flaked using a 1.93 cm cutting head. Three 9.1 kg batches of meat from each temperature treatment were weighed so that one batch consisted of 100% 1.27 cm flakes, the second batch consisted of 50% 1.27 cm flakes and 50% 1.93 cm flakes, and a third batch which consisted of 100% 1.93 cm flakes. Each batch of meat was placed in a Leland Mixer (Model 1-100DA, Detroit, MI) with .5% salt. The entire batch (9.1 kg) was mixed for 10 minutes and then one half (4.5 kg) of the meat was removed while the remaining half (4.5 kg) was allowed to mix 10 more minutes. After the appropriate mixing time, each 4.5 kg batch was fed into a Koppens Food Forming Machine (Model VM 100, Bakel, Holland) equipped with a strip steak plate and restructured strip steaks (227g, 2.54 cm thick) were formed.

Immediately after forming, steaks were crust frozen in a carbon dioxide batch freezer (Kryospray Liquid Freezing System, Cryo-Chem, Inc., Gardena, CA.) and vacuum packaged in individual bags using a Koch Multivac (Model AG4) packaging machine. Steaks were then randomly assigned to a fresh (3.3C) storage time of 0, 10, or 20 days and replication one or two. Three steaks were assigned to each storage and replication combination and the two replicates of this study required a total of 216 steaks.

Steak one was used for measurement of color, oxidation, water holding capacity, and determination of water and fat percentages in the uncooked steak. Steak two was cooked to an internal temperature of 70C by the modified oven broiling method (AMSA, 1978) and used to measure cooking losses, textural traits of bind, cohesiveness, and chewiness, and percentages of water and fat in the cooked steak. Steak three was used for microbial analysis of aerobic plate count (APC),lactic acid bacteria count(LAB) , and psychrotrophic plate count (PPC).

Color measurement

Surface color measurements were taken after 0, 2, 4, 6, 8, and 10 days of storage using a Hunter Color Difference Meter (Model D25-2). These days were selected rather than just days 0 and 10 as visible color deterioration was noted after one day of storage. Steaks assigned to 0 days of storage were used for the 0 day measurements. The measurements for days 2, 4, 6, 8, and 10 were made on the steak assigned to 10 days of storage. The Hunter Colorimeter was

standardized with a pink colored standard tile (L=69.4, a=16.0, b=9.4).

Oxidation (TBA)

Lipid oxidation was determined using the modified distillate method (Rhee, 1978). Samples to be analyzed were frozen in liquid nitrogen and then powdered in a commercial Waring blender. Ten grams of powdered sample along with 5 mL of 0.5% propylgallate (PG), 5 mL of 0.5% ethylenediamine tetra-acetic acid (EDTA) and 40 mL of deionized water were blended in a Virtis homogenizer at speed of 30 for 2 minutes. Next, 2.5 mL of 4N hydrochloric acid (HCl) was added to the homogenate. The homogenate was quantitatively transferred to an 800 mL Kjeldahl flask using 47.5 mL of deionized water. One mL of antifoaming agent (Silicone defoamer, Arthur H Thomas Company, Philadelphia, PA.)and some boiling chips were added to the flask. The homogenate was distilled until 50 mL of distillate was collected (approximately 5-15 minutes). The distillate was stored under nitrogen until analyzed for malonaldehyde (MA) content.

To prepare the standard curve for MA determination, 5 mL of $1*10^{-4}$ M tetraethoxypropane (TEP) (Sigma Chemical Co., St. Louis MO) were mixed with 2.5 mL of 4N HCl and 92.5 mL of deionized water in a Kjeldahl flask. The mixture was distilled and 50 mL of distillate was collected. The distillate was used to prepare the solutions of differing concentrations of the colored malonaldehyde-2-thiobarbituric acid (TBA) complex used to determine the standard

curve. Solutions containing $1*10^{-5}$, $2*10^{-5}$, $3*10^{-5}$, $4*10^{-5}$, and $5*10^{-5}$ moles MA/10 mL solution were prepared by pipetting, respectively, 1, 2, 3, 4, and 5 mL of the distillate from TEP into separate test tubes. Five mL of 0.02 M TBA solution was added to each test tube. Deionized water was added to each tube to bring the total volume to 10 mL. The tubes were heated 30-35 minutes in a boiling water bath to propagate the formation of the colored MA-TBA complex. The absorbance of each concentration of MA was determined at 532 nm on a spectrophotometer (Hitachi Model 100-60, Tokyo, Japan). The standard curve equation of absorbance (ABS) versus MA concentration was determined by linear regression.

For each sample, 5 mL of the distillate was mixed with 5 mL of 0.02M TBA solution in a test tube. The ABS of each sample was measured a 532 nm and converted to moles of MA by using the linear regression equation. Moles of MA was converted to mg MA/ kg meat which is the TBA number. TBA analyses were run in duplicate on the raw samples after 0, 10, and 20 days of storage.

Proximate composition

A portion of each steak frozen for TBA analysis was also powdered and used to determine moisture and fat in the raw samples. For moisture determination, samples (2 g) were placed into sample envelopes and dried in a vacuum oven (AOAC, 1984). The samples were then placed into a Soxhlet apparatus for fat extraction (AOAC, 1984).

Water holding capacity

Water holding capacity was determined using a modification of the method reported by Wierbicki and Deatherage (1958). Raw meat samples (300 mg) were placed in the center of Whatman No. 1 filter paper (11.0 cm diameter). The filter papers were stacked between two pieces of 15.2 cm by 15.2 cm plexiglass and subjected to 351.53 kg/cm^2 for 5 minutes using the Carver Laboratory Press (Model C, Fred S. Carver, Inc., Menomonee Falls, Wis.). Samples were analyzed in duplicate and ten samples were pressed at a time. After pressing, the plates were separated and the filter paper with the pressed meat film was carefully removed as the pressed meat tends of adhere to the plate. The perimeter of the meat film was immediately traced with a pencil, and the filter paper was then allowed to air dry.

The area of expressed water was measured using a compensating polar planimeter. The results are given as expressible water area per gram of muscle tissue. A smaller value means greater water holding capacity.

Cooking loss

Cooking loss was determined by weighing each steak then cooking to an internal temperature of 70C. After cooking, the steaks were weighed, the volatile cooking loss was calculated and nonvolatile cook loss was measured by weighing the drip weight and calculating the percentage of drip loss. Total cooking loss was determined by combining volatile and nonvolatile cooking losses.

Texture

Hardness, cohesiveness, and chewiness and bind were determined by using the Instron Universal Testing Machine (Instron Corp., Atlanta, GA.). Using a 50 kg load cell, crosshead speed of 10 cm/min and a chart speed of 10 cm/sec, a 0.5 cm blunt probe was forced 80% of the way into the steak twice at the same location. The curves produced were used to quantify hardness, cohesiveness, and chewiness as defined by Bouton et al. (1971). Breaking strength (bind) was measured by placing the steak on a bridge (7.5 cm span) and applying downward force to a flat plate (12cmx7cmx.2cm) perpendicular to and in the middle of the steak. Bind was the force required to break the steak.

Microbiological measurements

Microbiological condition of the steaks was determined by aerobic plate count (APC),lactic acid bacteria count (LAB), and psychrotrophic plate count (PPC). All plate counts were determined using the pour plate method on samples after 0, 10, and 20 days of storage at 3.3C.. The initial dilution was made by combining 22 g of meat with 198 mL of 0.1% sterile peptone water and blending in a stomacher blender for 5 minutes. Additional dilutions of 1:1000 and 1:100000 were also made by appropriate procedure. Standard methods agar (Becton Dickinson Microbiology Systems, Cockeysville, MD) was used for both the APC and PPC. APC plates were incubated at 32C for 48 hours while the PPC plates were incubated for 7 days at 7C. For the measurement of LAB, MRS agar (Becton Dickinson

Microbioloby Systems, Cockeysville, MD) was used and the plates were incubated for 3 days at 32C. All plates were counted with the use of a Quebec Colony Counter.

Statistical analysis

The General Linear Models procedure of SAS (1985) was used to analyze main effects of flake size, flaking temperature, mixing time, storage time, and interactions. Interactions that were not significant (P>0.25) were dropped from the model and became part of the error term. Mean separation for balanced data was accomplished using the Student-Newman-Keuls test. Least squares means for unbalanced data were separated using the probability of difference test available through SAS.

Chapter 4

Results and Discussion

Results have been separated into sections based on the dependent variables. Within each section the effects of flake size, flaking temperature, mixing time, storage and significant interactions among the independent variables are explained. A probability level of 0.05 or less was used as the level for determining significant differences. Values for Hunter color values, water holding capacity, lipid oxidation (2-thiobarbituric acid numbers) and cooking losses are reported as means. Values for proximate analysis variables and texture attributes are reported as least squares means due to unbalanced data. Microbial results are reported as mean $\log_{10}$ colony forming units/gram.

Steak color

Analysis of variance tables showing significance of main effects and interactions can be seen in the Appendix. Means for Hunter L, a, and b values for all processing variables are shown in Table 1. Overall means for Hunter color measurements across time are shown graphically in Figure 1. Hunter a and b values decreased ($P<0.05$) as storage days increased. Flaking temperature exerted a significant effect (Appendix) on Hunter L values, which denote lightness. Steaks made from meat flaked at -2.2C had higher ($P<0.05$) Hunter L values than steaks made from 4.4C flakes. Interactions between

Table 1: Mean Hunter L, a, and b values for all processing variables.

	L	a	b
Flake temperature (°C)			
-2.2	34.23	7.19	7.08
4.4	32.89	7.36	7.06
Flake size (cm)			
1.27	33.91	6.74	7.09
1.27:1.93	33.51	7.54	7.07
1.93	33.26	7.53	7.06
Mixing time (min.)			
10	33.67	7.31	7.07
20	33.45	7.24	7.07
Storage (days)			
0	32.64	21.34	9.96
2	33.07	12.91	7.63
4	33.80	6.93	7.07
6	33.93	5.48	7.17
8	33.63	5.43	6.80
10	33.35	5.61	6.68

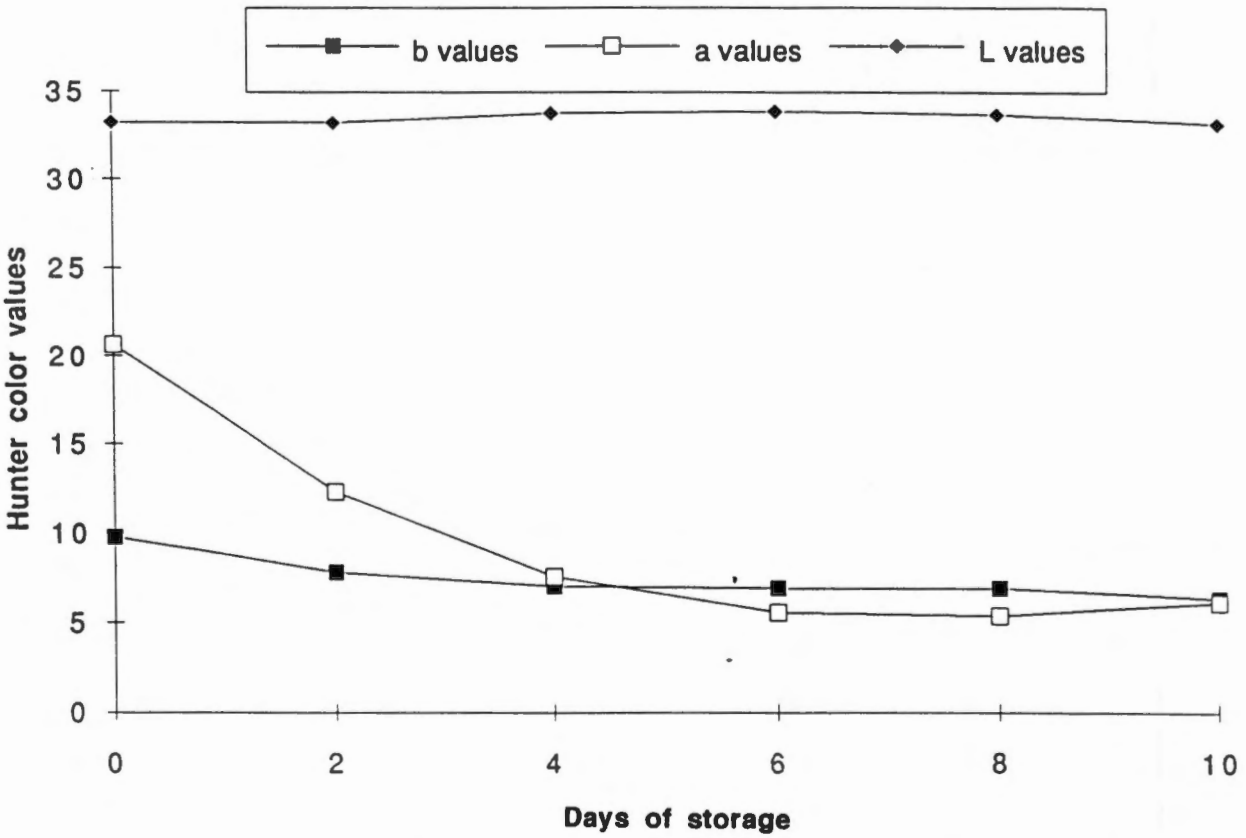

Figure 1: Effect of days of storage on Hunter L, a, and b values.

combinations of flake size and storage days, and between combinations of flaking temperature and storage days were all significant for Hunter a values which represent redness. These interactions are shown in Figures 2 and 3. Generally, as storage increased from 0 to 6 days, the Hunter a value decreased in steaks produced from all three flake sizes and also at two different flaking temperatures. The interactions occurred as the a values from one storage period to another had different orders with increasing flake size and flaking temperature. Storage days also affected Hunter b values (Appendix) which decreased as storage days increased. (Figure 4).

A second analysis of variance (shown in a separate table in the Appendix) was used to test for differences among days 2, 4, 6, 8, and 10 of storage using repeated measures analysis available through SAS which increased the sensitivity of the test. According to repeated measures analysis, flaking temperature and storage days significantly affected Hunter L values just as in the model including all days. The lower flaking temperature resulted in higher mean Hunter L values. The second analysis of variance also showed a decrease in Hunter a values across storage days and the combinations of flake size and storage days affected redness. Hunter b values were affected by storage days.

Lipid oxidation

Flaking temperature and storage had significant effects on TBA numbers (Table 2). Steaks formed using a flaking temperature of

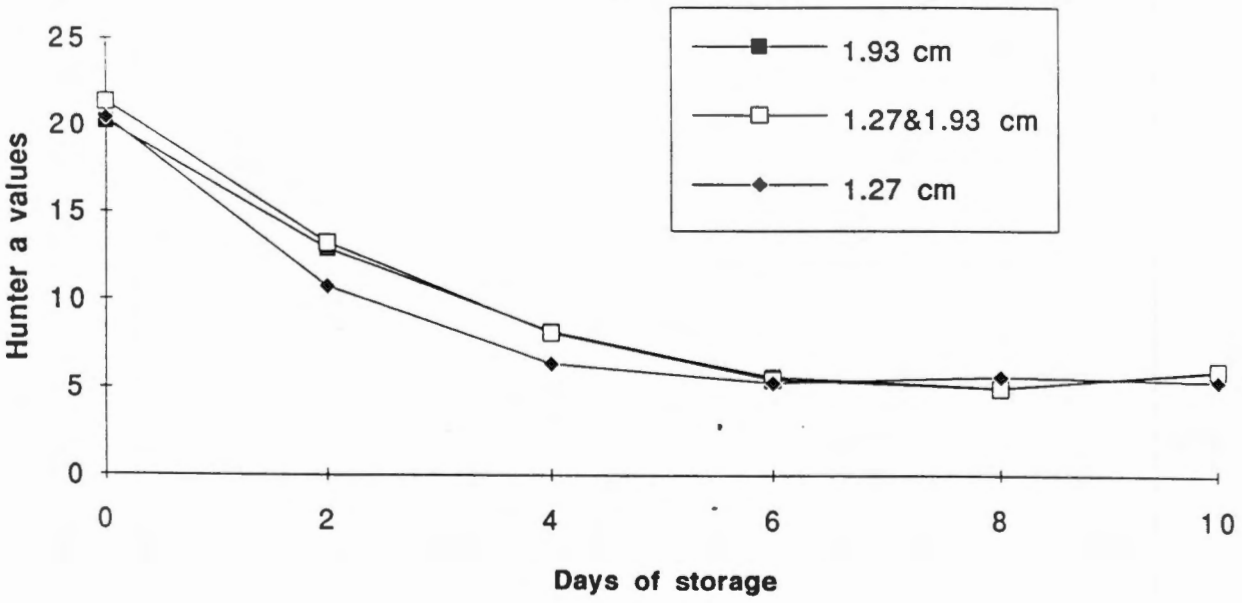

Figure 2: Hunter a values of steaks of different flake sizes versus days of storage.

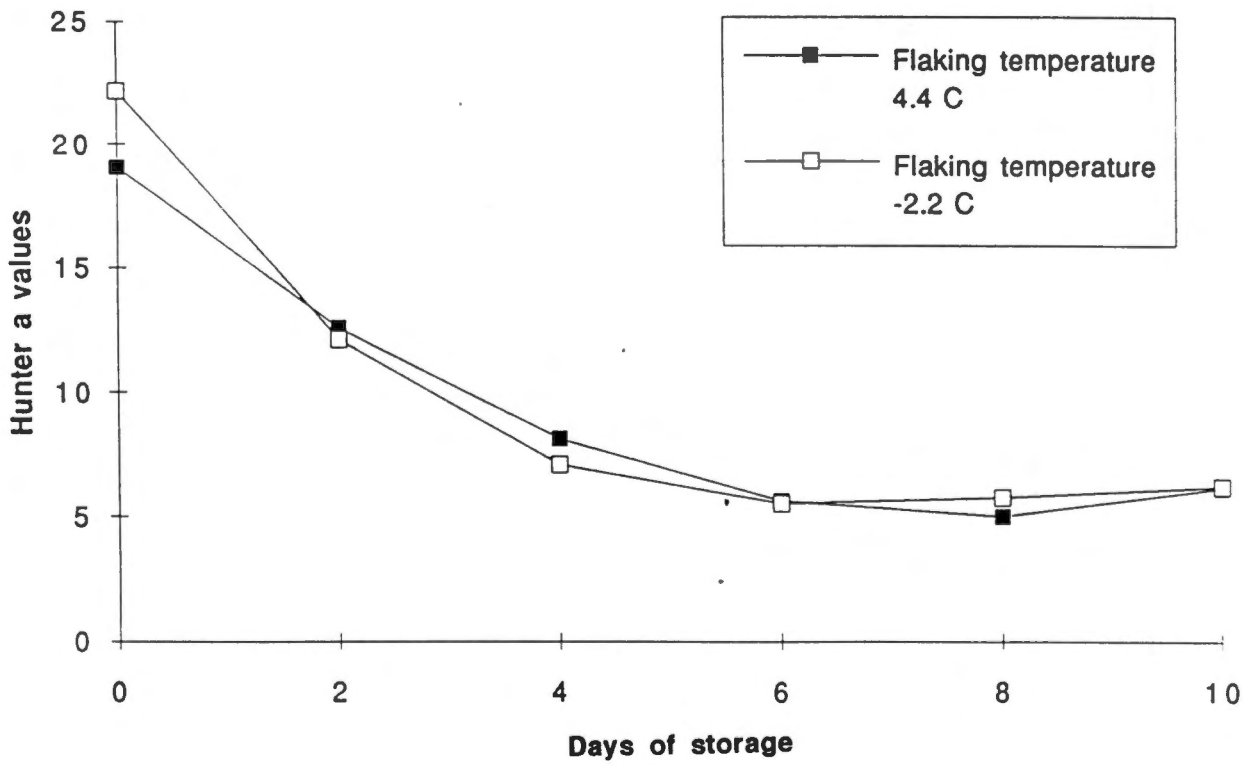

Figure 3: Hunter a values of steaks of different flaking temperatures versus days of storage.

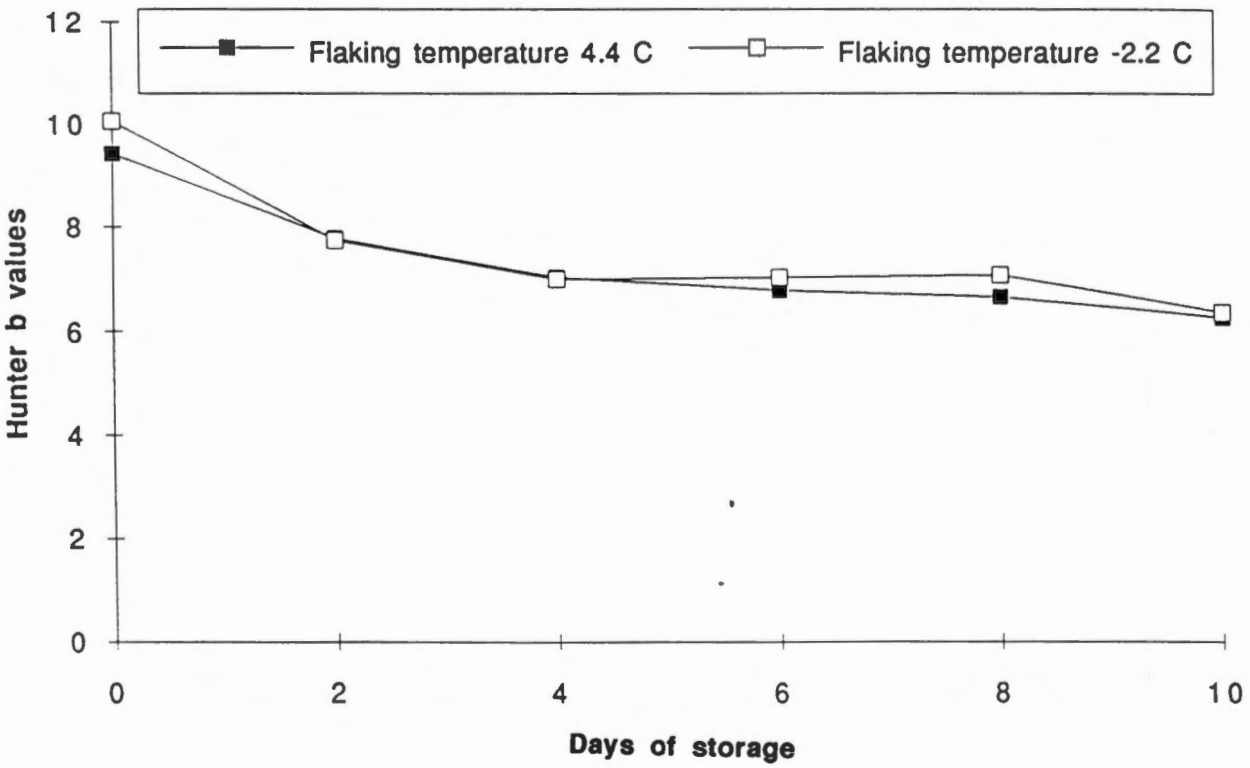

Figure 4: Hunter b values of steaks of different flaking temperatures versus days of storage.

Table 2: Mean values for water holding capacity, TBA values, and cooking losses of restructured strip steaks.

	Processing variables									
	Flake size (cm)			Flaking temperature (oC)		Mixing time (min.)		Storage (days)		
Characteristic	1.27	1.27:1.93	1.93	-2.2	4.4	10	20	0	10	20
TBA values mg malonaldehyde/kg	.52[a]	.55[a]	.51[a]	.79[b]	.26[a]	.52[a]	.53[a]	.46[a]	.53[ab]	.58[n]
Water holding capacity juice area/g	12.32[a]	11.89[a]	11.76[a]	11.56[a]	12.42[b]	12.24[a]	11.74[a]	12.97[c]	12.13[b]	10.88[a]
Cooking loss (%)										
Volatile	14.30[a]	13.55[a]	13.85[a]	14.08[a]	13.72[a]	13.13[a]	14.66[b]	13.15[a]	12.99[a]	15.56[b]
Non-volatile	9.22[a]	8.60[a]	8.26[a]	9.38[b]	8.00[a]	9.09[a]	8.30[a]	10.35[c]	7.09[a]	8.64[b]
Total	23.55[a]	22.15[a]	21.71[a]	23.18[a]	21.76[a]	21.94[a]	22.99[a]	23.15[b]	20.08[a]	24.18[b]

[a,b,c] Row means within each processing variable followed by unlike superscripts are different ($P<0.05$).

4.4C had lower (P<0.05) TBA values than steaks made using -2.2C flakes. Steaks at 0 days of storage time had lower (P<0.05) TBA values than steaks at 20 days of storage, but TBA values for steaks stored 10 days were not different (P<0.05) from the 0 or 20 day steaks. Combinations of flaking temperatures and storage had significant effects on TBA numbers as shown in Table 3. TBA values for steaks flaked at different temperatures across storage of 0 to 20 days had different trends. In steaks flaked at -2.2C, TBA values increased with increased storage but tended to decrease in steaks flaked at 4.4C and stored 0 to 10 days before increasing from 10 to 20 days. Some of this effect could be due to the freezing of some of the water which would reduce the water activity in the steak thus making it more like an intermediate moisture food and more susceptible to oxidation.

TBA numbers were not affected (P>0.05) by mixing time. This agrees with previous reports of Booren et al. (1981) who reported TBA values were constant over mixing time after 0 days of storage and Chu et al. (1987) who reported lipid oxidation did not increase with mixing and grinding. Also, flake size had no effect (P>0.05) on TBA numbers.

Water holding capacity

Flaking temperature had a significant effect on WHC (Table 2). Restructured steaks prepared from meat flaked at 4.4C had less (P<0.05) WHC than steaks made from meat flaked at -2.2C. This conflicts with data presented by Mandigo (1974) who reported that

Table 3: Probability of difference values for means of flaking temperature and storage combinations on TBA values.[a]

	Combinations [b]				
Combinations[b] 1	2	3	4	5	6
1	0.0001	0.0001	0.0001	0.0001	0.0001
2		0.8101	0.0001	0.0001	0.0001
3			0.0001	0.0001	0.0001
4				0.0433	0.4882
5					0.1765

[a] Combinations are different if $P < 0.05$.

[b] Flake temperature:storage combinations with mean TBA values.

Combination	Mean TBA value
1 = -2.2 C: 0 days	.61
2.= -2.2 C: 10 days	.87
3.= -2.2 C: 20 days	.89
4 = 4.4 C:0 days	.31
5.= 4.4 C: 10 days	.19
6.= 4.4 C: 20 days	.27

restructured pork products made from meat flaked at -5.6C had lower WHC than those made from meat flaked at 2.2C or 32.2C using 1% salt.

Storage time also had a significant effect on WHC (Table 2). Steaks stored 20 days had greater ($P<0.05$) WHC than those stored for 0 or 10 days. Also, 10 days stored steaks had greater ($P<0.05$) WHC than 0 day stored steaks. Steaks stored for 0 days had the lowest WHC. It was observed during storage that some purge (meat juice) developed inside the vacuum packages which represented a loss of free water. Because of this loss, it is reasonable to expect the WHC values for 10 and 20 day steaks to be lower since the juice area/g measurement in the WHC test represents free water.

The combinations of flaking temperature and storage had a significant effect on WHC (Table 4). Products made from meat flaked at -2.2C and stored 20 days had significantly greater WHC means than all other flaking temperature and storage combinations. Steaks formed from -2.2C flaked meat and stored 0 days had higher WHC means than steaks processed from meat flaked at the same temperature and stored for 10 or 20 days. WHC of steaks containing -2.2C flaked meat and stored 0 days was also different from the WHC for steaks processed from 4.4C meat and stored for 0, 10, or 20 days.

Mixing time had no effect on WHC in this study. This is in contrast to Belohlavy and Mandigo (1974) and Pepper and Schmidt (1975) who reported that WHC increased with increased mixing time. Additionally, flake size showed no effect on WHC.

Table 4: Probability of difference values for means of flaking temperature and storage combinations on water holding capacity.[a]

	Combinations [b]				
Combinations [b] 1	2	3	4	5	6
1	0.0051	0.0001	0.9293	0.4255	0.0075
2		0.0014	0.0065	0.0395	0.8870
3			0.0001	0.0001	0.0009
4				0.4784	0.0096
5					0.0544

[a] Combinations are different if probability <0.05.

[b] Flake temperature:storage combinations with mean WHC values. (juice area/g) .

Combination	Mean WHC value
1 = -2.2 C: 0 days	12.99
2.= -2.2 C: 10 days	11.63
3.= -2.2 C: 20 days	10.07
4 = 4.4 C:0 days	12.95
5.= 4.4 C: 10 days	12.61
6.= 4.4 C: 20 days	11.70

Cooking loss

Volatile cooking loss. Mixing time had a significant effect on volatile cooking loss (Table 2). Mean volatile cooking loss for steaks formed from meat mixed for 10 minutes was lower ($P< 0.05$) than for meat mixed 20 minutes. This does not agree with reports by Booren et al.(1981) who reported increased cook yield (lower cooking loss) with increased mixing time

Storage also affected volatile cooking loss. Steaks stored for 20 days had significantly higher mean volatile cooking loss than steaks stored for 0 or 10 days. The results agree with Hand et al. (1982) who reported that restructured pork roasts stored for four weeks had higher cooking losses than those stored for one week.

Flake size showed no effect ($P>0.05$) on volatile cooking loss. This is in agreement with Seidemann (1982) and Durland et al. (1982) who reported no effect of particle thickness or particle size on cooking loss. Also, flaking temperature did not affect ($P>0.05$) volatile cooking loss.

Non-volatile cooking loss. Flaking temperature had a significant effect on non-volatile cooking loss as seen in Table 2. Steaks formed from meat flaked at 4.4C had lower non-volatile cooking loss than those formed from meat flaked at -2.2C. Mandigo (1974) reported that products made from meat flaked at -5.6C had greater cooking loss than those flaked at 2.2 or 32.2C

Storage also affected non-volatile cooking loss. Steaks stored for 0 days had higher ($P<0.05$) nonvolatile cooking loss (drip) than

those stored for 10 or 20 days. This could possibly be due to the lower WHC exhibited at 0 days. The 0 day steaks had a greater amount of water released upon cooking whereas the 10 and 20 day steaks lost this unbound water during storage. Purge was observed in the packages of the steaks stored for 10 and 20 days. The steaks stored for 20 days had greater ($P<0.05$) non-volatile cooking loss than steaks stored for 10 days.

Mixing time and flake size had no effect ($P>0.05$) on non-volatile cooking loss.

Total cooking loss. Storage was the only main effect to influence total cooking loss independently. Means are reported in Table 2. Steaks stored for 10 days had lower ($P<0.05$) total cooking loss than those stored for 0 or 20 days. Flake temperature, flake size, and mixing time showed no effects ($P>0.05$) on total cooking loss.

Proximate analysis

Raw steak moisture. Flaking temperature, mixing time, and storage all had significant effects on moisture content of raw steaks. Least squares means are presented in Table 5. Raw steak moisture content was higher in products formed from 4.4C flakes than in products formed from -2.2C flakes. Additionally, raw products mixed for 20 minutes had a higher ($P<0.05$) percentage of moisture than those mixed for 10 minutes. Also, products stored for 10 days had a higher ($P>0.05$) percentage of moisture than those stored for 0 or 20 days.

Table 5: Least squares means for proximate analysis of restructured strip steaks

	Processing variables									
	Flake size (cm)			Flaking temperature (oC)		Mixing time (min.)		Storage (days)		
Characteristic	1.27	1.27:1.93	1.93	-2.2	4.4	10	20	0	10	20
Moisture, raw (%)	72.25[a]	72.09[a]	72.13[a]	72.06[a]	72.26[b]	72.07[a]	72.24[a]	72.08[a]	72.38[b]	72.03[a]
Fat, raw(%)	5.75[a]	5.74[a]	5.84[a]	5.94[a]	5.61[a]	5.83[a]	5.72[a]	5.54[a]	5.82[a]	5.97[a]
Moisture, cooked(%)	62.80[a]	62.82[a]	62.69[a]	62.36[a]	63.18[a]	63.13[a]	62.41[a]	63.21[a]	62.94[a]	62.17[a]
Fat, cooked (%)	9.08[b]	8.16[a]	8.36[a]	9.03[b]	8.03[a]	8.53[a]	8.53[a]	7.69[a]	8.19[b]	9.71[c]

[a,b,c] Row means within each processing variable followed by unlike superscrips are different ($P<0.05$).

The interaction between flaking temperature and storage was significant for raw steak moisture as shown in Table 6. The moisture percentage for steaks made from -2.2C flakes and stored for 20 days was lower than for any other combination of flaking temperature and storage. The interaction for flaking temperature and storage on raw moisture content occurs during 0 to 10 days of storage. Steaks from 4.4C flakes had similar moisture levels at 0 and 10 days of storage while steaks from -2.2°C flakes contained less moisture at 0 day than 10 days of storage. These results are in contrast to Mandigo (1974) and Whiting and Strange (1991) who found that restructuring did not affect proximate analysis.

Raw steak fat. No significant main effects were found for flake size, flaking temperature, mixing time, or storage on percentage of fat in raw steaks. However, the interaction of flaking temperature and storage revealed significant (Table 7) but inconsistent differences in raw steak fat.

Cooked steak moisture. None of the processing variables showed any effect on cooked steak moisture. Results are shown in Table 5. These results agree with Durland et al. (1982) who found flake size had no effect on moisture losses from cooking.

Cooked steak fat. Percentages of cooked steak fat are listed in Table 5. The percentage of fat in cooked steaks was higher ($P<0.05$) for steaks prepared from meat flaked at -2.2C than 4.4C. Additionally, flake size had a significant effect with products made from 1.27 cm flakes having more fat than the blend of flake sizes or the 1.93 cm flakes. Storage also affected cooked fat. Steaks cooked

Table 6: Probability of difference values for means of flaking temperature and storage combinations on raw steak moisture.[a]

	Combinations [b]				
Combinations [b]	1	2	3	4	5	6
1		0.1999	0.0200	0.6513	0.0149	0.2233
2			0.0005	0.0854	0.2165	0.9478
3				0.0572	0.0001	0.0006
4					0.0046	0.0975
5						0.1942

[a] Combinations are different if probability <0.05.

[b] Flake temperature:storage combinations with mean raw steak moisture percentages.

Combination	Mean raw steak moisture percentages
1 = -2.2 C: 0 days	72.11
2.= -2.2 C: 10 days	72.29
3.= -2.2 C: 20 days	71.77
4 = 4.4 C:0 days	72.04
5.= 4.4 C: 10 days	72.46
6.= 4.4 C: 20 days	72.28

Table 7: Probability of difference values for means of flaking temperature and storage combinations on raw steak fat.[a]

	Combinations [b]				
Combinations [b]	2	3	4	5	6
1	0.0665	0.0104	0.0441	0.1145	0.0593
2		0.0001	0.8524	0.0010	0.9576
3			0.0001	0.3021	0.0001
4				0.0005	0.8943
5					0.0008

[a] Combinations are different if probability <0.05.

[b] Flake temperature:storage combinations with mean raw steak fat percentages.

Combination	Mean raw steak fat percentages
1 = -2.2 C: 0 days	5.86
2.= -2.2 C: 10 days	5.28
3.= -2.2 C: 20 days	6.68
4 = 4.4 C:0 days	5.22
5.= 4.4 C: 10 days	6.36
6.= 4.4 C: 20 days	5.26

after 20 days of storage had more ($P<0.05$) fat than did those stored for 10 or 0 days. Likewise, steaks cooked after 10 days of storage had a higher ($P<0.05$) percentage of fat than those stored for 0 days. These results may be a reflection of the water holding capacity of the meat which increased with storage due to loss of unbound water as purge in the package resulting in a possible fat increase. The interaction of flake size and storage time was significant for cooked steak fat and can be seen in Table 8. Products formed from 1.27 cm flakes and stored for 20 days were higher in cooked fat than all other flake size and storage combinations except flake size of 1.93 cm stored for 20 days which only had a probability of difference value of 0.0554.

Texture

Least squares means are reported for hardness, cohesiveness and chewiness, and breaking strength in Table 9. Hardness was affected ($P<0.05$) by storage time. Steaks stored for 0 days were harder than steaks stored for 10 or 20 days. Flake size, flaking temperature, and mixing time showed no effects ($P>0.05$) on hardness. These results do not agree with Berry et al. (1987) who found that restructured products produced from smaller flakes were less hard than those produced from intermediate flakes with small and intermediate flakes comparable to 1.27 cm and 1.93 cm, respectively. Cohesiveness was not affected ($P>0.05$) by flake size, flaking temperature, mixing time, or days of storage. Chewiness also was not affected by the processing variables. These results are in

Table 8: Probability of difference values for means of flake size and storage combinations on cooked steak fat.[a]

	Combinations [b]							
Combinations [b]	1	2	3	4	5	6	7	8 9
1	0.1364	0.0001	0.0001	0.4802	0.3940	0.0024	0.1441	0.0372
2		0.0001	0.0125	0.4273	0.0211	0.1026	0.9765	0.0006
3			0.0001	0.0001	0.0020	0.0001	0.0001	0.0554
4				0.0013	0.0001	0.3625	0.0116	0.0001
5					0.1219	0.0169	0.4445	0.0061
6						0.0002	0.0227	0.2080
7							0.0967	0.0001
8								0.0006

[a] Interactions are different if probability <0.05.

b Flake size:storage combinations with mean cooked steak fat percentages.

Combinations	Mean cooked steak fat percentages
1 =1.27 cm: 0 days	8.71
2.= 1.27 cm: 10 days	8.07
3.= 1.27 cm: 20 days	10.44
4 = 1.27 cm and 1.93 cm:0 days	6.99
5.= 1.27 cm and 1.93 cm: 10 days	8.41
6.= 1.27 cm and 1.93 cm: 20 days	9.08
7.= 1.93 cm: 0 days	7.38
8.= 1.93 cm: 10 days	8.09
9.= 1.93 cm: 20 days	9.61

contrast with Penfield et al. (1991) who found chewiness, measured by a sensory panel, increased with increased flake size.

Breaking strength was affected ($P<0.05$) by all processing variables (Table 9). Steaks containing 100% 1.27 cm flakes required more force to break than steaks made of other flake sizes. This is possibly due to increased bind because of increased surface area of the smaller particles (Acton 1972). Additionally, the steaks made of meat flaked at -2.2C required more force to break than steaks made of meat flaked at 4.4C. Steaks formed after 10 minutes of mixing had more ($P<0.05$) binding strength (higher breaking force) than those mixed for 20 minutes. Also, steaks stored for 0 days required more ($P<0.05$) force to break than those stored for 10 or 20 days.

Microbial condition

Aerobic plate count (APC). APC was significantly affected by flake size (Table 10). Products made entirely from 1.27 cm flakes had lower ($P<0.05$) counts ($\log_{10}$ colony forming units (CFU) /g) than the steaks formed from a 50:50 blend of 1.27 and 1.93 cm flakes and steaks of entirely 1.93 cm flakes. Also, the blend of flake sizes had lower ($P<0.05$) counts than the steaks containing only 1.93 cm flakes. Storage affected APCs. Steaks stored for 0 days had higher ($P<0.05$) counts than steaks stored for 10 or 20 days. The interaction of flake size with flaking temperature was significant (Figure 5). APC decreased with increasing level of 1.93 cm flakes at 4.4C, but increased at -2.2C.

Table 9: Least squares means for texture characteristics of restructured strip steaks.

	Processing variables									
	Flake size (cm)			Flaking temperature (oC)		Mixing time (min.)		Storage (days)		
Characteristic	1.27	1.27:1.93	1.93	-2.2	4.4	10	20	0	10	20
Hardness (kg)	2.28[a]	2.21[a]	2.25[a]	2.28[a]	2.21[a]	2.22[a]	2.27[a]	2.77[b]	1.93[a]	2.04[a]
Cohesiveness	.46[a]	.47[a]	.50[a]	.47[a]	.49[a]	.47[a]	.49[a]		.49[a]	.46[a]
Chewiness(kg)	.91[a]	.92[a]	1.01[a]	.94[a]	.96[a]	.92[a]	.97[a]		.95[a]	.94[a]
Breaking strength (kg)	2.52[b]	2.16[a]	2.15[a]	2.55[b]	2.01[a]	2.55[b]	2.00[a]	2.60[b]	1.99[a]	2.24[a]

[a,b,c] Row means within each processing variable followed by unlike superscripts are different ($P<0.05$).

Table 10: Mean $\log_{10}$ CFU/g for aerobic plate counts (APC), lactic acid bacteria counts (LAB), and psychrotrophic plate counts (PPC) for restructured strip steaks.

	Processing variables									
	Flake size (cm)			Flaking temperature (oC)		Mixing time (min.)		Storage (days)		
Type of count	1.27	1.27:1.93	1.93	-2.2	4.4	10	20	0	10	20
APC	4.1^{a}	4.4^{b}	4.6^{c}	4.3^{a}	4.4^{a}	4.3^{a}	4.4^{a}	4.5^{b}	4.3^{a}	4.2^{a}
LAB	2.5^{a}	2.6^{a}	2.8^{b}	2.5^{a}	2.8^{b}	2.7^{a}	2.6^{a}	2.8^{c}	2.6^{b}	2.5^{a}
PPC	3.5^{a}	3.8^{b}	4.0^{c}	3.7^{a}	3.9^{b}	3.8^{a}	3.7^{a}	4.0^{b}	3.6^{a}	3.6^{a}

^{a,b,c} Row means within each processing variable followed by unlike superscripts are different ($P<0.05$).

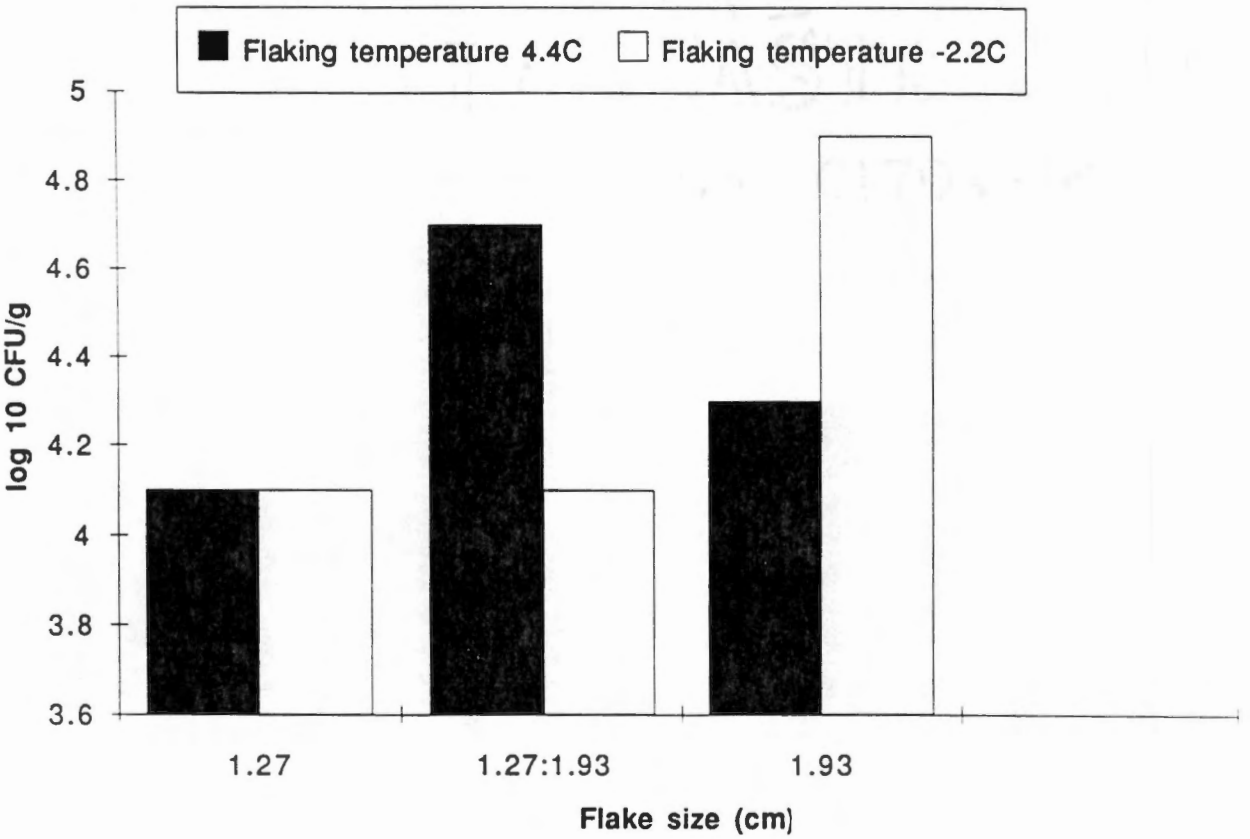

Figure 5: APC of restructured strip steaks produced from different flake sizes and temperatures.

All APCs were lower than reported values that caused off odors and spoilage for comminuted products and other restructured products (Kotula et al., 1987; Van Laack and Smulders, 1991). Results were similar to the findings of Chestnut et al. (1977) for frozen, flaked cow meat. Low APCs could be due to the liquid carbon dioxide freezing just prior to packaging which has been shown to cause a log 2 reduction in ground beef (Kraft et al., 1979). Additionally, vacuum packaging has been shown to slow the growth of aerobic bacteria (Pierson et al., 1970) which would contribute to the lower counts over storage time. Also, the low refrigerated storage temperature could enhance the effectiveness of crust freezing and vacuum packaging.

Lactic acid bacteria counts (LAB). Table 10 shows the LAB counts expressed as $\log_{10}$ CFU/g. Flake size affected LAB counts for these restructured steaks. The steaks consisting of all 1.27 cm flakes and steaks made of the 50:50 blend of 1.27cm and 1.93 cm flakes had lower ($P<0.05$) LAB counts than steaks formed from only 1.93 cm flakes. Flaking temperature also had a significant effect with steaks made from the meat of the higher flaking temperature of 4.4C having higher counts than the -2.2C flaking temperature steaks. Mixing time did not affect the LAB counts. LAB counts decreased over storage time. The steaks sampled at 20 days had lower ($P<0.05$) counts than those stored for 0 or 10 days. Steaks stored for 10 days had lower ($P<0.05$) counts than those stored for 0 days. These results are in contrast to the findings of Johnston et al. (1982) who reported higher initial counts of LAB that increased up to

two weeks of storage and then decreased slightly after three weeks of storage.

Interactions of flake size with flaking temperature, flake temperature with storage, and mixing time with storage are presented in Figures 6, 7, and 8. The higher flaking temperature and larger flake size had higher counts. Also, the higher flaking temperatures and longer storage times resulted in higher counts.

Psychrotrophic plate counts (PPC). Results are shown in Table.10. Flake size exhibited a significant effect on PPCs The steaks containing only 1.93 cm flakes showed higher ($P<0.05$) counts than the 1.27 cm flakes or the blend of the two sizes. Also, the blend had higher ($P<0.05$) counts than the 1.27 cm steaks. Flaking temperature also affected PPC. The higher flaking temperature had higher counts. Zero days of storage resulted in higher ($P<0.05$) counts than 10 or 20 days of storage. Counts for 10 and 20 days of storage were not different ($P>0.05$).

Interactions of flake size with flaking temperature, flake size with mixing time, and flake size with storage are shown in Figures 9,10 and 11. The blend of flake sizes and higher flaking temperature resulted in higher PPCs. The blend of flake sizes and longer mixing time also had a higher PPC. Steaks containing only 1.93 cm flakes and stored for 0 days had the highest PPC.

The factors of crust freezing and vacuum packaging mentioned under the discussion of aerobic plate counts may also have had the same effects on psychrotrophic plate counts.

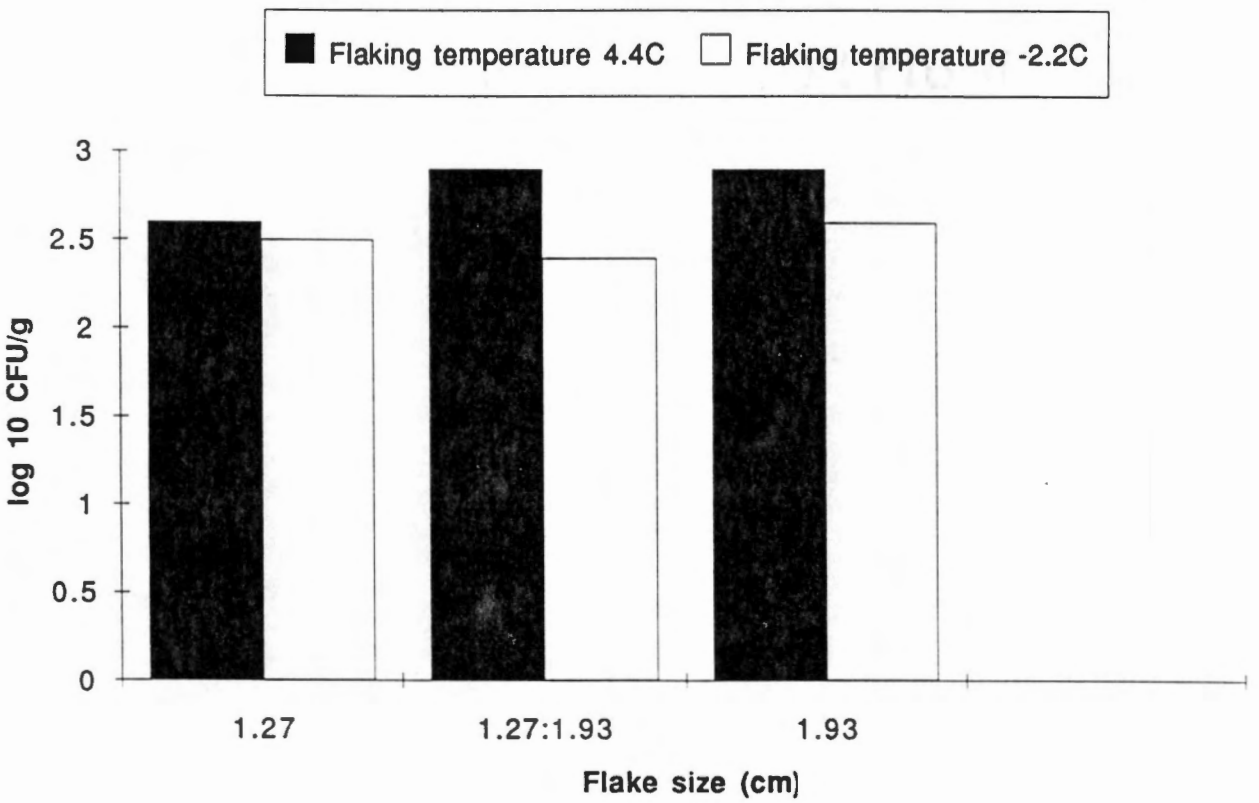

Figure 6: LAB of restructured strip steaks produced from different flake sizes and temperatures.

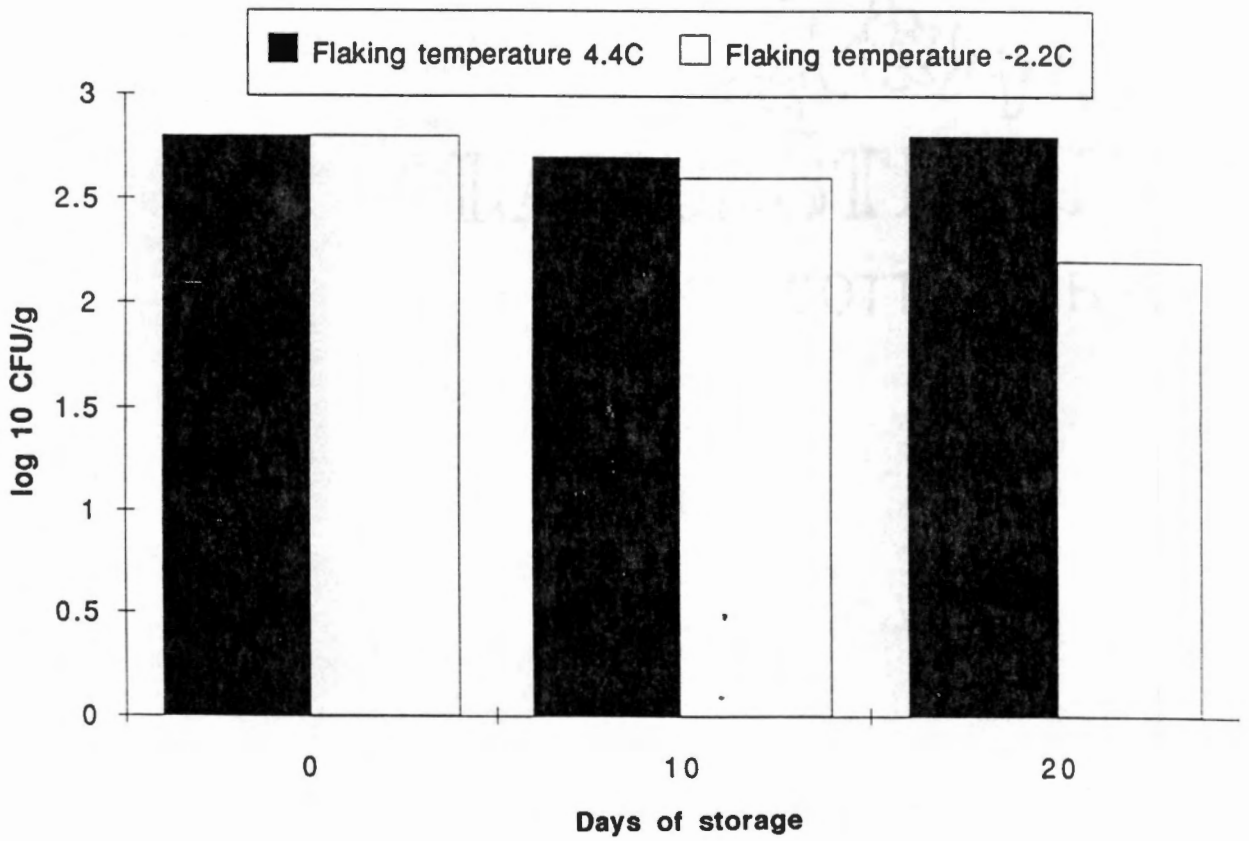

Figure 7: LAB of restructured strip steaks of different flaking temperatures versus days of storage.

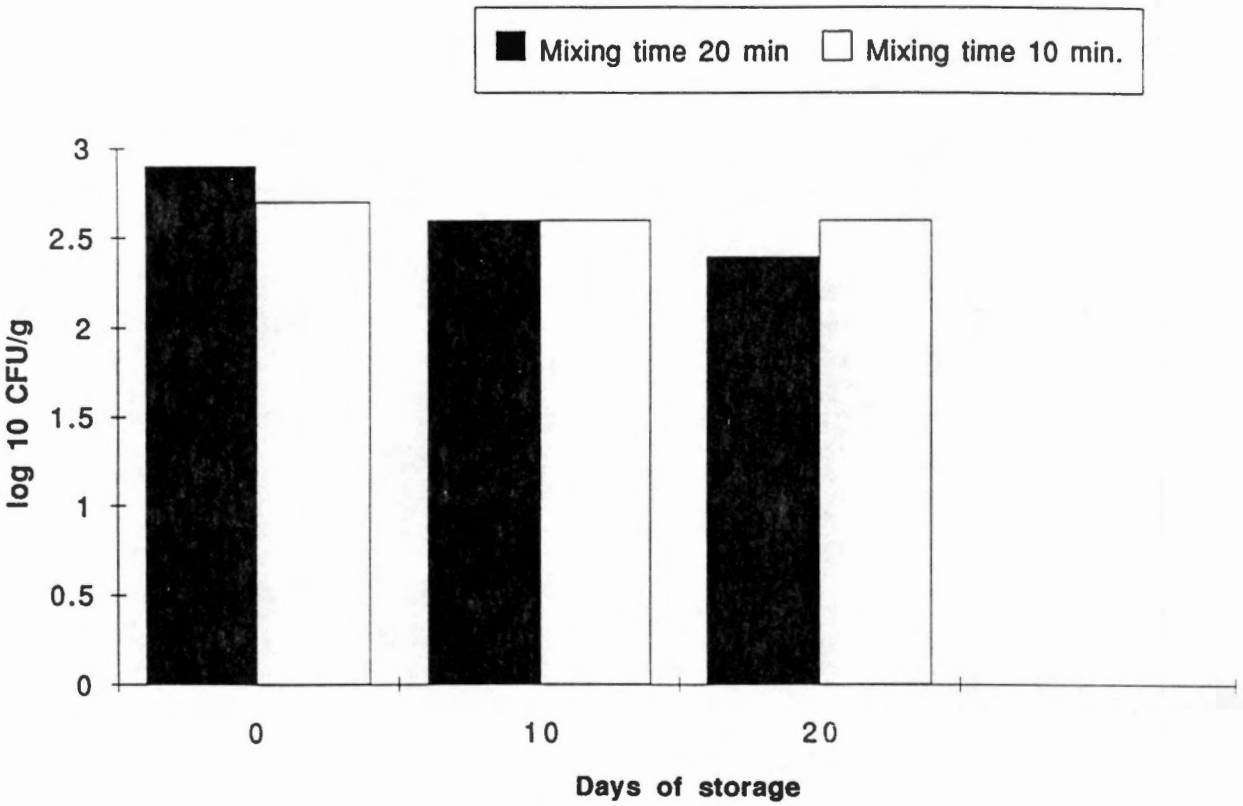

Figure 8: LAB of restructured strip steaks from different mixing times versus days of storage.

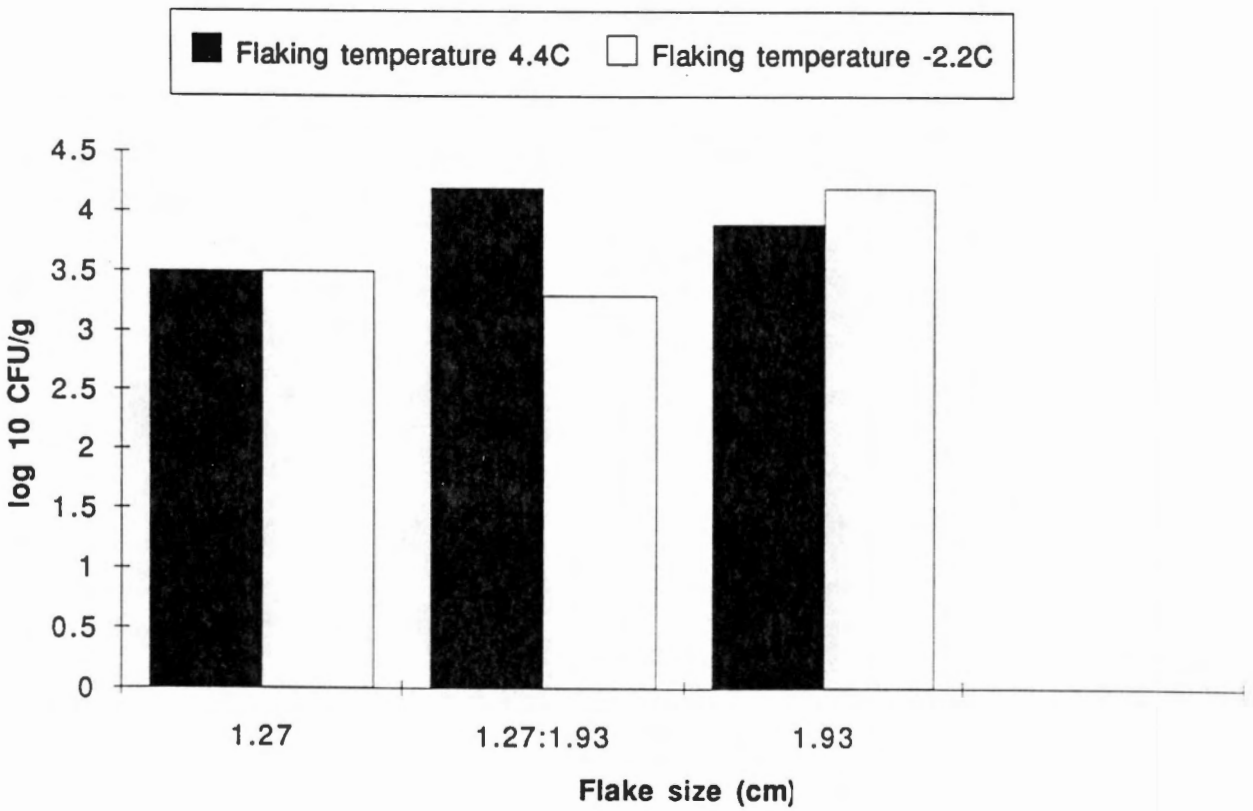

Figure 9: PPC of restructured strip steaks produced from different flake sizes and temperatures.

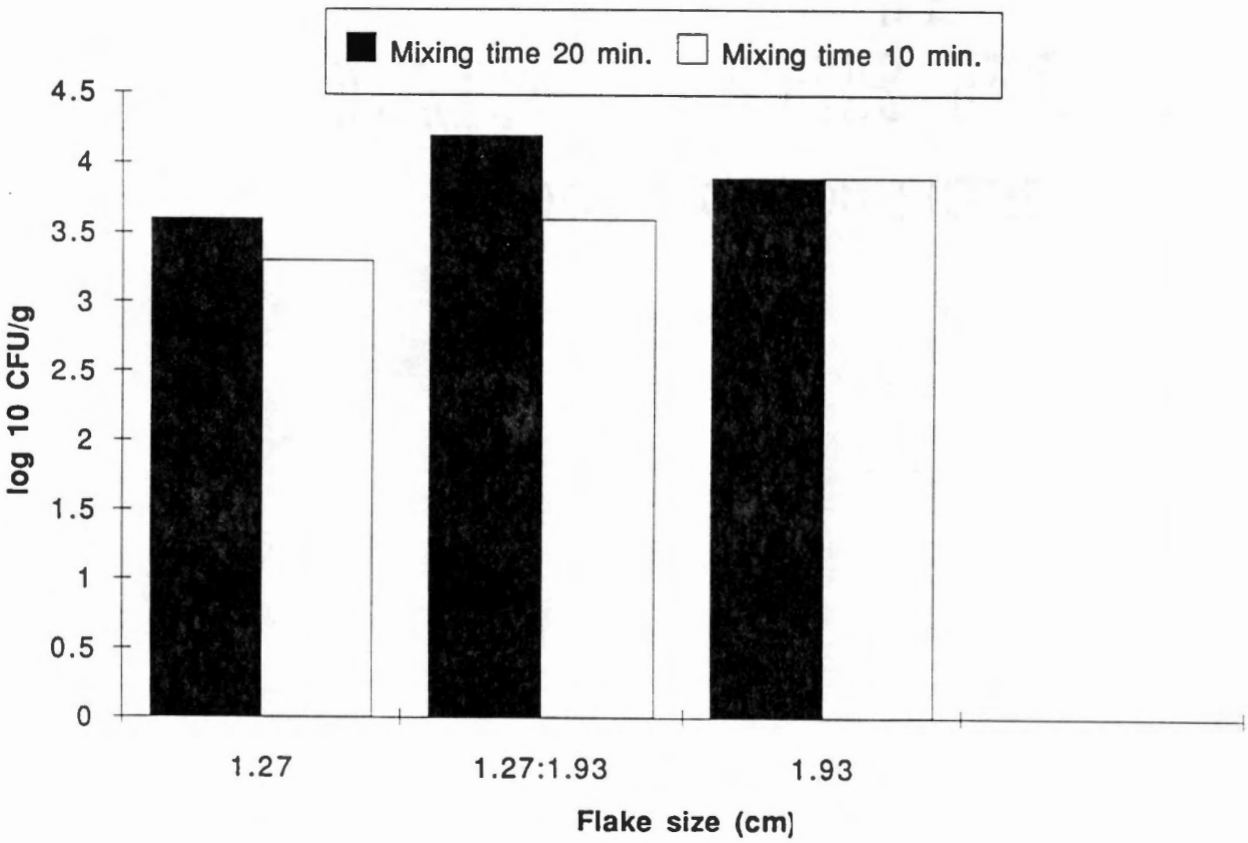

Figure10: PPC of restructured strip steaks produced with different flake sizes and mixing times.

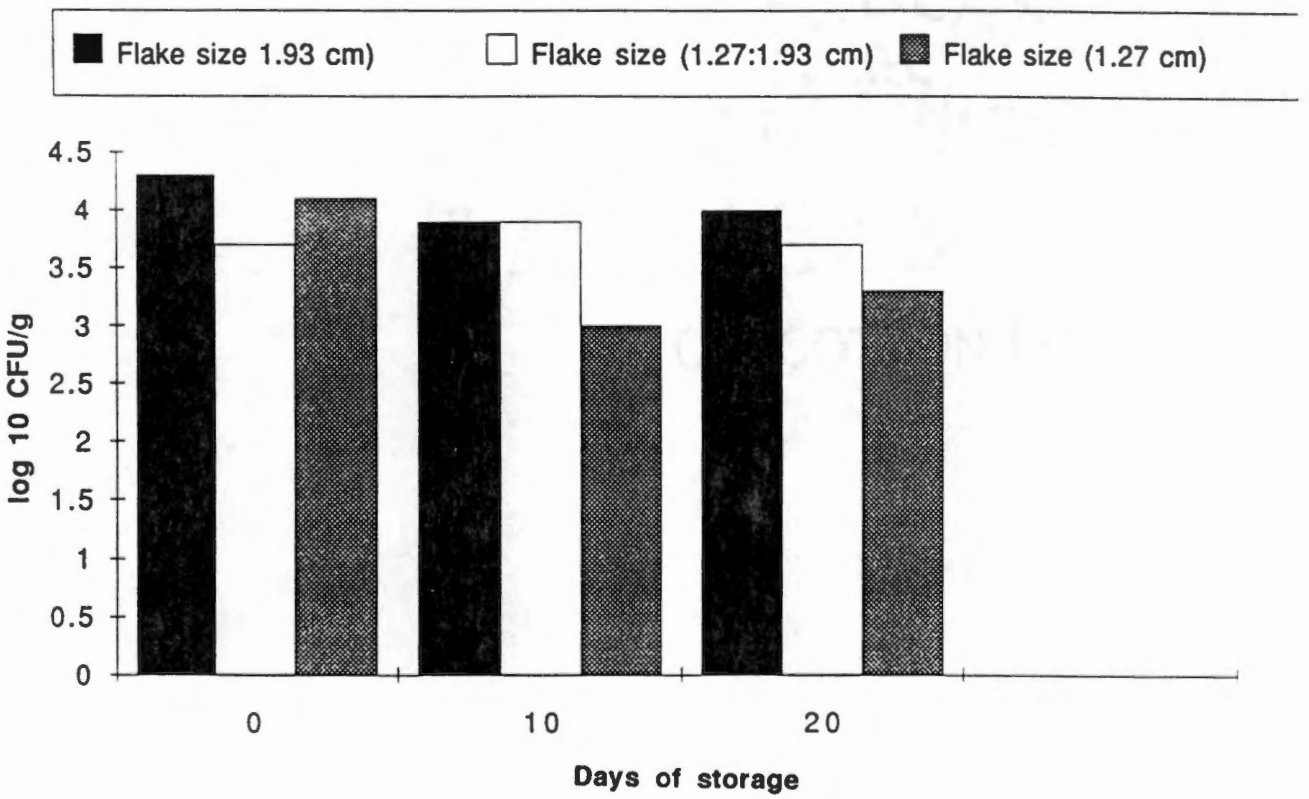

Figure 11: PPC of restructured strip steaks produced with different flake sizes versus days of storage.

Chapter 5

Summary

The objectives of this study were to evaluate the effects of flaking temperature, flake size, mixing time, and storage on several properties of restructured steaks. Comparisons were made based on a number of physical, chemical, and microbial characteristics.

The largest differences in color were due to days of storage. Hunter a values decreased sharply between 0 and 2 days of storage and further decreases in redness occurred between 2 and 4 days of storage as well as between 4 and 6 days of storage after which there was little change in redness values. Additionally, the steaks made from 1.27 cm flakes showed the most rapid decrease in Hunter a values with storage.. Steaks made from -2.2C flakes had a greater decrease in Hunter a values between days 0 and 2 than the same steaks made with flakes from the higher temperature (4.4C). For Hunter b values, the greatest decrease was also measured between 0 and 2 days and declined further between 2 and 4 days of storage. At 0 days of storage, steaks still showed oxygenated color (oxymyoglobin) but after being in a vacuum environment, the color pigment changed state to the myoglobin form which is purple. The purple color persisted through approximately 4 days of storage and then the steaks began to show a brownish appearance (metmyoglobin). Possible explanations for the development of the brown color include oxidation due to enzymatic activity or that air

was incorporated into the meat mix during mixing which encouraged oxidation of the meat color pigment.

Lipid oxidation was also affected by processing conditions. Steaks formed using the higher flaking temperature (4.4C) had lower TBA values. Also, 0 days of storage resulted in lower TBA values for steaks formed from meat flaked at -2.2C, however, the combination of -2.2C flaking temperature and 20 days of storage had the highest TBA values. This was the opposite of what was expected because one would expect meat at a higher temperature to have a higher rate of enzymatic activity leading to oxidation.

Water holding capacity was affected by flaking temperature with the higher flaking temperature resulting in less water holding capacity (more free water) probably because there was more disruption of cell structure during flaking (ragged appearing flakes) which resulted in the release of more cellular fluids. Meat flaked at -2.2C produced flakes with a more distinct shape and more uniform size. The conclusion of more free water due to cell disruption in the 4.4C flaked meat is supported by the greater percentage of water in the uncooked steaks. Also, steaks stored for 0 days had the least WHC while the steaks stored for 20 days had the greatest WHC. This is probably due to the amount of free versus bound water in the steaks stored for different times. The steaks stored for 0 days had more free water while the steaks stored for 20 days lost the free water as purge. Unexpectedly, mixing time had no effect on WHC.

Volatile cooking loss was affected by mixing time with the shorter mixing time having lower volatile cooking loss. Steaks stored

for 20 days had the highest volatile cooking loss. Steaks formed from meat flaked at 4.4C had lower non-volatile cooking loss. The lower non-volatile cooking loss from steaks made of meat flaked at 4.4C was most likely due to the lower fat content of the meat rather than meat flaking temperature. Further, steaks stored for 0 days had the highest non-volatile cooking loss. Steaks stored for 10 days had the lowest total cooking loss compared to 0 or 20 days.

Raw steaks formed from 4.4C meat flakes had a higher percentage of raw moisture than steaks formed from -2.2C flakes. Raw steaks formed after 20 minutes of mixing also had more raw moisture compared to mixing for 10 minutes. Effects of restructuring on percentage of fat in raw steaks were inconsistent. However, flake size had an effect on cooked steak fat because steaks made entirely of 1.27 cm flakes had the highest percentage of cooked steak fat compared to steaks formed from the other flake sizes. Steaks cooked after 20 days of storage had the highest percentage of fat. Furthermore, the interaction of 1.27 cm flakes with 20 days of storage resulted in the highest percentage of cooked steak fat.

Hardness was affected by days of storage. Zero days of storage resulted in harder cooked steaks possibly due to the lower percentage of cooked fat. Cohesiveness and chewiness were not affected by the processing variables or storage. Breaking strength as a measure of bind was affected by all processing variables. Steaks containing 100% 1.27 cm flakes required more force to break than steaks made from either of the other sizes. Also, the lower flaking temperature and shorter mixing time resulted in steaks with more

bind. Steaks stored for 0 days required more force to break than steaks stored for the other storage times again possibly due to the lower cooked fat content of the steaks.

All microbiological counts were highest for 0 days of storage. Flake size affected all types of counts. Steaks containing 100% 1.93 cm flakes had the highest APC, LAB, and PPC. The flaking temperature of 4.4C resulted in higher counts for LAB and PPC.than -2.2C.

These results indicate that each processing variable affects different characteristics of restructured products. One variable that affects on characteristic in a positive way may, at the same level, inversely affect another characteristic. Depending on the type of restructured product to be produced (roll, steak, chop, etc.), the most important characteristics of the finished product need to be defined and quantified. After this, an equation or model could be developed to optimize the most important characteristics while minimizing the negative effects on less important characteristics.

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Appendix

Analysis of variance table for Hunter 'L" values (all days)

Source	DF	SS	MS	F value	
FLTEMP	1	68.89	68.89	29.56	*
FLSIZE	2	11.01	5.503	2.17	
FLTEMP*FLSIZE	2	0.57	0.28	0.12	
MXTIME	1	4.55	4.55	1.95	
FLTEMP*MXTIME	1	1.10	1.10	0.47	
FLSIZE*MXTIME	2	1.21	0.67	0.26	
FLTEMP*FLSIZE*MXTIME	2	3.45	1.73	0.74	
ERROR A	12	27.968	2.331		
DAY	5	45.44	9.09	9.54	*
FLTEMP*DAY	5	4.04	0.807	0.85	
FLSIZE*DAY	10	6.63	0.663	0.69	
MXTIME	5	3.95	0.790	0.83	
ERROR B	76	72.435	0.953		

*Significant at $p<0.05$.

Analysis of variance table for Hunter a values (all days)

Source	DF	SS	MS	F value	
FLTEMP	1	5.52	5.52	2.40	
FLSIZE	2	15.93	7.97	3.47	
FLTEMP*FLSIZE	2	3.15	1.58	0.69	
MXTIME	1	0.03	0.03	0.01	
FLTEMP*MXTIME	1	1.40	1.40	0.61	
FLSIZE*MXTIME	2	5.11	2.56	1.11	
FLTEMP*FLSIZE*MXTIME	2	0.17	0.09	0.04	
ERROR A	12	27.601	2.300		
DAY	5	4449.97	889.99	602.53	*
FLTEMP*DAY	5	66.23	13.25	8.97	*
FLSIZE*DAY	10	49.95	4.99	3.38	*
MXTIME	5	2.14	0.43	0.29	
ERROR B	76	112.256	1.4771		

*Significant at $p<0.05$.

Analysis of variance table for Hunter b values (all days)

Source	DF	SS	MS	F value
FLTEMP	1	0.71	0.71	4.88
FLSIZE	2	0.02	0.01	0.03
FLTEMP*FLSIZE	2	0.40	0.20	0.53
MXTIME	1	0.01	0.01	0.03
FLTEMP*MXTIME	1	0.15	0.15	0.40
FLSIZE*MXTIME	2	1.26	0.63	1.67
FLTEMP*FLSIZE*MXTIME	2	0.10	0.05	0.13
ERROR A	12	4.54	0.378	
DAY	5	159.90	31.98	161.41
FLTEMP*DAY	5	4.44	0.88	4.44
FLSIZE*DAY	10	1.77	0.18	0.91
MXTIME	5	0.22	0.04	0.20
ERROR B	76	15.058	0.198	

*Significant at $p<0.05$.

Analysis of variance for Hunter L values (repeated measures for days 2, 4, 6, 8, and 10).

Source	DF	SS	MS	F value	PR>F
Fltemp	1	54.136333	54.136333	23.23	0.0004
Flsize	2	8.480667	4.240333	1.82	0.2041
Fltemp*Flsize	2	2.712667	1.356333	0.58	0.5738
Mxtime	1	1.452000	1.452000	0.62	0.4453
Fltemp*Mxtime	1	0.936333	0.936333	0.40	0.5381
Flsize*Mxtime	2	3.488000	1.744000	0.75	0.4940
Fltemp*Flsize*Mxtime	2	1.600667	0.800333	0.34	0.7161
Error A	12	27.968000	2.330667		
Day	4	11.726333	2.931584	3.08	0.0210
Fltemp*Day	4	3.747111	0.936750	0.98	0.4221
Flsize*Day	8	5.890167	0.736271	0.77	0.6280
Mxtime*Day	4	0.641333	0.641333	0.17	0.9539
Error B	76	72.435170	0.953090		

Analysis of variance for Hunter a values (repeated measures for days 2, 4, 6, 8, and 10).

Source	DF	SS	MS	F value	PR>F
Fltemp	1	0.850083	0.850083	0.37	0.5546
Flsize	2	17.068667	8.534333	3.71	0.0557
Fltemp*Flsize	2	0.852667	0.426333	0.19	0.8331
Mxtime	1	0.154083	0.154083	0.07	0.8002
Fltemp*Mxtime	1	1.752083	1.752083	0.76	0.3999
Flsize*Mxtime	2	5.116667	2.558333	1.11	0.3605
Fltemp*Flsize*Mxtime	2	0.292667	0.146333	0.06	0.9387
Error A	12	27.601000	2.300800		
Day	4	991.520000	247.880000	167.82	0.0001
Fltemp*Day	4	9.783670	2.445920	1.66	0.1690
Flsize*Day	8	44.315500	5.539440	3.75	0.0010
Mxtime*Day	4	0.264670	0.066170	0.04	0.9961
Error B	76	112.256200	1.4771		

Analysis of variance for Hunter b values (repeated measures for days 2, 4, 6, 8, and 10).

Source	DF	SS	MS	F value	PR>F
Fltemp	1	0.012000	0.0120000	0.03	0.8616
Flsize	2	0.019500	0.0097500	0.03	0.9746
Fltemp*Flsize	2	0.526500	0.263250	0.70	0.5177
Mxtime	1	0.000333	0.0003333	0.00	0.9768
Fltemp*Mxtime	1	0.243000	0.2430000	0.64	0.4385
Flsize*Mxtime	2	0.600167	0.3000833	0.79	0.4748
Fltemp*Flsize*Mxtime	2	0.354500	0.1772500	0.47	0.6369
Error A	12	4.540000	0.3783330		
Day	4	13.110333	3.277583	16.54	0.0001
Fltemp*Day	4	1.834667	0.458667	2.32	0.0649
Flsize*Day	8	1.417167	0.177146	0.89	0.5258
Mxtime*Day	4	0.156333	0.039083	0.20	0.9391
Error B	76	15.057500	0.19125		

GLM analysis table for TBA values

Source	DF	SS	MS	F value	PR>F
Model	12	5.9275611	0.4939634	21.33	0.0001
Error	59	1.3664389	0.0231600		
Corrected total	71	7.2940000			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.0234722	0.0234722	1.01	0.3182
Fltemp	1	5.0456056	5.0456056	217.86	0.0001
Flsize	2	0.0241333	0.0120667	0.52	0.5966
Mxtime	1	0.0024500	0.0024500	0.11	0.7461
Sto	2	0.1596000	0.0798000	3.45	0.0384
Fltemp*Sto	2	0.5093778	0.2546889	11.00	0.0001
Fltemp*Mxtime	1	0.0470222	0.0470222	2.03	0.1595
Mxtime*Sto	2	0.1159000	0.0579500	2.50	0.0906

GLM analysis table for WHC values

Source	DF	SS	MS	F value	PR>F
Model	12	5.9275611	0.4939634	21.33	0.0001
Error	59	1.3664389	0.0231600		
Corrected total	71	7.2940000			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.0234722	0.0234722	1.01	0.3182
Fltemp	1	5.0456056	5.0456056	217.86	0.0001
Flsize	2	0.0241333	0.0120667	0.52	0.5966
Mxtime	1	0.0024500	0.0024500	0.11	0.7461
Sto	2	0.1596000	0.0798000	3.45	0.0384
Fltemp*Sto	2	0.5093778	0.2546889	11.00	0.0001
Fltemp*Mxtime	1	0.0470222	0.0470222	2.03	0.1595
Mxtime*Sto	2	0.1159000	0.0579500	2.50	0.0906

GLM analysis table for volatile cooking loss.

Source	DF	SS	MS	F value	PR>F
Model	7	151.70062	21.67152	2.16	0.0492
Error	64	640.82847	10.01294		
Corrected total	71	792.52909			

Source	DF	SS	MS	F value	PR>F
Rep	1	1.073112	1.073112	0.11	0.7445
Fltemp	1	2.243668	2.243668	0.22	0.6376
Flsize	2	6.831225	3.415613	0.34	0.7123
Mxtime	1	41.876501	41.876501	4.18	0.0450
Sto	2	99.676108	49.838054	4.98	0.0098

GLM analysis table for non-volatile cooking loss.

Source	DF	SS	MS	F value	PR>F
Model	20	296.01982	14.80099	3.13	0.0005
Error	51	241.50932	4.73548		
Corrected total	71	537.52913			

Source	DF	SS	MS	F value	PR>F
Rep	1	3.61357	3.61357	0.76	0.3865
Fltemp	1	34.21023	34.21023	7.22	0.0097
Flsize	2	11.33630	5.66815	1.20	0.3105
Mxtime	1	11.11561	11.561	2.35	0.1317
Sto	2	127.44902	63.72451	13.46	0.0001
Flsize*Sto	4	46.89027	11.72257	2.48	0.0558
Mxtime*Sto	2	16.28791	8.14395	1.72	0.1893
Fltemp*Flsize*Mxtime	7	45.11690	6.44527	1.36	0.2420

GLM analysis table total cooking loss.

Source	DF	SS	MS	F value	PR>F
Model	7	319.37029	45.62433	4.06	0.0010
Error	64	719.05680	11.23526		
Corrected total	71	1038.42709			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.14311	0.14311	0.01	0.9105
Fltemp	1	36.16751	36.16751	3.22	0.0775
Flsize	2	44.60718	22.30359	1.99	0.1457
Mxtime	1	20.00281	20.00281	1.78	0.1868
Sto	2	218.44967	109.22484	9.72	0.0002

GLM analysis table raw moisture.

Source	DF	SS	MS	F value	PR>F
Model	16	5.4392212	0.3399513	2.92	0.0017
Error	54	6.2911506	0.1165028		
Corrected total	70	11.7303718			

Source	DF	Type III SS	MS	F value	PR>F
Rep	1	0.0260736	0.0260736	0.22	0.6381
Fltemp	1	0.7586184	0.7586184	6.51	0.0136
Flsize	2	0.3621510	0.1810755	1.55	0.2207
Mxtime	1	0.5138292	0.5138292	4.41	0.0404
Sto	2	1.6780036	0.8390018	7.20	0.0017
Fltemp*Flsize	2	0.3446479	0.1723239	1.48	0.2369
Fltemp*Sto	2	0.9787566	0.4893783	4.20	0.0202
Fltemp*Flsize*Mxtime	5	0.8044994	0.1608999	1.38	0.2460

GLM analysis table raw fat.

Source	DF	SS	MS	F value	PR>F
Model	9	24.673056	2.741451	4.68	0.0001
Error	62	36.281944	0.585193		
Corrected total	71	60.955000			

Source	DF	Type III SS	MS	F value	PR>F
Rep	1	0.320000	0.320000	0.55	0.4624
Fltemp	1	1.933889	1.933889	3.30	0.0739
Flsize	2	0.140833	0.070417	0.12	0.8868
Mxtime	1	0.200556	0.200556	0.34	0.5604
Sto	2	2.315833	1.157917	1.98	0.1469
Fltemp*Sto	2	19.761944	9.880972	16.88	0.0001

GLM analysis table cooked moisture

Source	DF	SS	MS	F value	PR>F
Model	24	140.89547	5.87064	1.55	0.1011
Error	46	174.66799	3.79713		
Corrected total	70	315.56346			

Source	DF	Type III SS	MS	F value	PR>F
Rep	1	3.002356	3.002356	.079	0.3785
Fltemp	1	11.278667	11.278667	2.97	0.0915
Flsize	2	0.342909	0.171455	0.05	0.9559
Mxtime	1	9.623720	9.623720	2.53	0.1182
Sto	2	13.609912	6.804956	1.79	0.1780
Fltemp*Flsize*Mxtime	5	33.724316	6.744863	1.78	0.1366
Flsize*Mxtime*Sto	10	57.952700	5.795270	1.53	0.1608

GLM analysis table cooked fat.

Source	DF	SS	MS	F value	PR>F
Model	11	92.200833	8.381894	11.75	0.0001
Error	60	42.791944	0.713199		
Corrected total	71	134.992778			

Source	DF	Type III SS	MS	F value	PR>F
Rep	1	0.035556	0.035556	0.05	0.8241
Fltemp	1	18.000000	18.000000	25.24	0.0001
Flsize	2	11.151111	5.575556	7.82	0.0010
Mxtime	1	0.000000	0.000000	0.00	1.0000
Sto	2	52.93778	26.468889	37.11	0.0001
Flsize*Sto	2	10.07	2.519097	3.53	0.0111

GLM analysis table for hardness.

Source	DF	SS	MS	F value	PR>F
Model	36	13.149271	0.365258	5.45	0.0001
Error	35	2.343637	0.066961		
Corrected total	71	15.492908			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.007300	0.007300	0.11	0.7432
Fltemp	1	0.092092	0.92092	1.38	0.2488
Flsize	2	0.065642	0.032821	0.49	0.6167
Mxtime	1	0.038967	0.038967	0.58	0.4507
Sto	2	10.163247	5.081623	75.89	0.0001
Fltemp*Flsize*Mxtime	2	0.370122	0.185061	2.76	0.0768
Fltemp*Flsize*Sto	4	0.702118	0.175530	2.62	0.0513
Fltemp*Mxtime*Sto	2	0.313247	0.156623	2.34	0.1113
Flsize*Mxtime*Sto	4	0.437951	0.109488	1.64	0.1873
Fltemp*Flsize*Mxtime*Sto	4	0.430868	0.107717	1.61	0.1939

GLM analysis table for breaking strenght.

Source	DF	SS	MS	F value	PR>F
Model	10	19.2823738	19.282378	6.87	0.0001
Error	61	17.130503	0.280828		
Corrected total	71	36.412882			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.3542014	0.3542014	1.26	0.2658
Fltemp	1	5.3083681	5.3083681	18.90	0.0001
Flsize	2	2.1536632	1.0768316	3.83	0.0270
Mxtime	1	5.3901389	5.3901389	19.19	0.0001
Sto	2	4.5257465	2.2628733	8.06	0.0008
Fltemp*Mxtime	1	0.5168056	0.5168056	1.84	0.1799
Flsize*Mxtime	2	1.0334549	0.5167274	1.84	0.1675

GLM analysis table for cohesiveness.

Source	DF	SS	MS	F value	PR>F
Model	14	0.1240625	0.0088616	2.16	0.0343
Error	33	0.1353688	0.0041021		
Corrected total	47	0.2594313			

Source	DF	Type III SS	MS	F value	PR>F
Rep	1	0.0150521	0.0150521	3.67	0.0641
Fltemp	1	0.0058521	0.0058521	1.43	0.2408
Flsize	2	0.0134000	0.0067000	1.63	0.2107
Mxtime	1	0.0050021	0.0050021	1.22	0.2775
Sto	1	0.0143521	0.0143521	3.50	0.0703
Fltemp*Flsize*Mxtime	7	0.0599021	0.0085574	2.09	0.0731
Mxtime*Sto	1	0.0105021	0.0105021	2.56	0.1191

GLM analysis table for chewiness.

Source	DF	SS	MS	F value	PR>F
Model	13	0.6075705	0.0467362	1.63	0.1236
Error	34	0.9722041	0.0285942		
Corrected total	47	1.597747			

Source	DF	Type III SS	MS	F value	PR>F
Rep	1	0.0393737	0.393737	1.38	0.2488
Fltemp	1	0.0047551	0.0047551	0.17	0.6860
Flsize	2	0.0942526	0.0471263	1.65	0.2074
Mxtime	1	0.0365617	0.0365617	1.28	0.2661
Sto	1	0.0022584	0.0022584	0.08	0.7804
Fltemp*Flsize*Mxtime	7	0.4303689	0.0614813	2.15	0.0645

GLM analysis table for aerobic plate count.

Source	DF	SS	MS	F value	PR>F
Model	11	9.6287764	0.8753433	7.28	0.0001
Error	60	7.2173222	0.1202887		
Corrected total	71	16.8460986			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.0793347	0.793347	0.66	0.4199
Fltemp	1	0.0007347	0.0007347	0.01	0.9380
Flsize	2	3.3816028	1.6908014	14.06	0.0001
Mxtime	1	0.0351125	0.0351125	.29	0.5910
Sto	2	1.5367361	0.7683681	6.39	0.0031
Fltemp*Sto	2	0.5166361	0.2583181	2.15	0.1257
Fltemp*Flsize	2	4.0786194	2.0393097	16.95	0.0001

GLM analysis table for lactic acid bacteria counts.

Source	DF	SS	MS	F value	PR>F
Model	20	6.4417167	0.3220858	5.81	0.0001
Error	51	2.8250819	0.0553938		
Corrected total	71	9.2667986			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.0806681	0.0806681	1.46	0.2331
Fltemp	1	1.2987347	1.2987347	23.45	0.0001
Flsize	2	0.5335444	0.2667722	4.82	0.0121
Mxtime	1	0.0210125	0.0210125	0.38	0.5407
Sto	2	1.1263194	0.5631597	10.17	0.0002
Fltemp*Flsize	2	0.3714111	0.1857056	3.35	0.0429
Flsize*Mxtime	2	0.1670333	0.0835167	1.51	0.2311
Fltemp*Flsize*Mxtime	2	0.1998111	0.0999056	1.80	0.1751
Fltemp*Sto	2	1.5759528	0.7879764	14.23	0.0001
Mxtime*Sto	2	0.4360750	0.2180375	3.94	0.0257
Fltemp*Mxtime*Sto	2	0.6304194	0.3152097	5.69	0.0059

GLM analysis table for psychrotrophic plate counts.

Source	DF	SS	MS	F value	PR>F
Model	20	18.640271	0.887632	6.02	0.0001
Error	51	7.373217	0.147464		
Corrected total	71	26.013488			

Source	DF	SS	MS	F value	PR>F
Rep	1	0.0045125	0.0045125	0.03	0.8618
Fltemp	1	0.8778125	0.8778125	5.95	0.0183
Flsize	2	4.2237000	2.1118500	14.32	0.0001
Mxtime	1	0.1326125	0.1326125	0.90	0.3475
Sto	2	3.0015083	1.5007542	10.18	0.0002
Fltemp*Flsize	2	4.2452333	2.1226167	14.39	0.0001
Flsize*Mxtime	2	0.9465333	0.4732667	3.21	0.0488
Fltemp*Sto	2	0.6423583	0.3211792	2.18	0.1239
Flsize*Sto	4	3.3042667	0.8260667	5.60	0.0008
Fltemp*Flsize*Sto	4	1.2617333	0.3154333	2.14	0.0897

Vita

Sarah Lynn Prince Jones was born in Chattanooga, Tennessee on November 21, 1968 to Mr. and Mrs. Jerry Prince. Her family moved to Riceville where she then attended McMinn County High School and graduated in 1987. While in high school she was very active in 4-H and the Future Farmers of America and received her American Farmer Degree in 1988.

She entered the University of Tennessee in January of 1988 and became involved with several activities. In May 1991 she received her Bachelor of Science degree in Agriculture with a major in Food Technology and Science, graduating with highest honors. In the summer of 1991 she accepted a graduate research assistantship in the Food Technology and Science Department to work toward a Master of Science degree.

The author is a member of Phi Kappa Phi, Alpha Zeta, Golden Key National Honor Society, the Institute of Food Technologists, and the American Meat Science Association. She has accepted an instructor's position at the University of Tennessee upon completion of her degree.