COMPARISON OF FREEZING AND THAWING TREATMENTS ON SELECTED CHARACTERISTICS OF LAMB RIB CHOPS

by

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INTRODUCTION

Modern meat merchandising procedures employ freezing and frozen storage to preserve meat products in a condition that closely approaches the condition of the fresh product. Much of the available information concerning the effects of freezing meat resulted from studies with beef and pork. Effects of freezing on the palatability of lamb have not been studied extensively. Therefore, it is important from the standpoint of the consumer, industry, and research to study the effects of current methods of freezing on the characteristics of lamb. Lester and Branson (1966) concluded from recent consumer surveys that the homemaker is aware of the advantages and disadvantages of frozen retail meats. Of their interview group, 82-88% said that they would purchase frozen lamb roasts if they were available only in that form.

The use of frozen meat samples in research emphasizes the need for greater knowledge of the effects of freezing on palatability and related characteristics. The effects of varying freezing and thawing treatments upon lamb are, as a whole, unknown. Moreover, implications drawn from investigations on meat from other species justify studies of current freezing and handling procedures for lamb. The objectives of the present study were:

1. To investigate the effects of three freezing and two thawing methods on selected characteristics of lamb.

2. To provide a guide for selecting methods of handling frozen samples when designing research experiments with lamb.

REVIEW OF LITERATURE

Factors Related to the Freezing of Muscle Tissue

Crystallization.. Knowledge of the principles of crystallization is necessary if food substances are to be frozen, stored, and thawed under optimum circumstances. The crystallization process can be divided conveniently into two parts, nucleation and crystal growth.

Crystallization begins when conditions are appropriate to bring about the aggregation of a group of molecules into a tiny ordered particle known as a crystal nucleus. Heterogeneous nucleation occurs when water molecules aggregate in a crystalline arrangement on a tiny, nonaqueous, solid particle (Fennema and Powrie, 1964, p. 244). Since ice-nucleating particles are present in all aqueous materials, except highly purified water, heterogeneous nucleation occurs in food materials during freezing (Lusena, 1955). Heterogeneous nucleation is unlikely near 0°C (32°F). However, a temperature of -39°C (-38.2°F) generally is regarded as the limit to which water can be supercooled (Meryman, 1956). Thus, heterogeneous nucleation occurs between the temperatures of 0°C (32°F) and -39°C (-38.2°F).

Crystal growth, in contrast to nucleation, will occur readily at temperatures close to the freezing point. This indicates that it is more difficult to initiate crystallization than it is to continue it (Fennema and Powrie, 1964, p. 247). The net crystal growth rate of pure ice is governed by two factors, temperature and rate of heat removal. The rate of ice crystal growth decreases with decreasing temperature, provided all other factors are held constant.

Luyet (1968, p. 21) reviewed the findings on relationships among freezing temperature, freezing rate, and size of the ice particles in frozen muscle. With slow freezing, when the temperature remains at the freezing plateau from 15 min to 2 hrs, ice forms between muscle fibers, and the width of the spaces occupied by ice varies from 2 to 150 μ. When freezing is rapid, such as when a small bundle of fibers is immersed in a bath at -58 to -148°F (-50 to -100°C), a large number of nuclei form within the fibers, and the spears grown from those nuclei have diameters of a few microns. When freezing is ultrarapid, such as when single fibers are immersed in a bath at -238°F (-150°C), the ice spears have diameters of 200 to 2300 Å.

Hiner and Hankins (1946) froze 1.5-in. cubes of beef in still air at 18, 0, -10, -40, and -114°F (-7.8, -17.8, -23.3, -40, and -81.1°C) and at -40°F (-40°C) in an air blast. When freezing was done at 18°F (-7.8°C), the water was drawn from the fibers and crystals formed between the fibers creating large ice areas, and left the fibers in large irregular groups. With lower temperatures crystals became smaller and more numerous, were evenly distributed, and formed within the fiber itself. With a temperature of -10°F (-23.3°C) the crystals became so numerous within the fiber that some splitting of the fiber wall occurred. With -114°F (-81.1°C), the fiber splitting was more evident. Similar descriptions of ice crystal formation were given by Birkner and Auerbach (1960, pp. 33-37), Hiner et al. (1945), Levie (1963, p. 53), Love (1958), Meryman (1956), Moran (1932), Moulton and Lewis (1948, p. 67), Ramsbottom and Koonz (1939).

It is not known why extracellular crystallization occurs in preference to intracellular crystallization during slow freezing. Luyet (1968, p. 21) reported that the effect of slow freezing on muscle tissue apparently resulted from the ability of the fibers to exert the osmotic function. However, Meryman (1956) suggested that the freezing point of the extracellular material may be higher than that of the intracellular material, and/or the intracellular material may be deficient in heterogeneous nucleation sites.

Control of crystal size would be simple if all crystals, once formed, remained unchanged in size during subsequent frozen storage and thawing. However, ice crystals generally have a tendency to enlarge during frozen storage and the early stages of thawing. At near-freezing temperatures there is a decrease in the number of small crystals and a growth of the large ones (Luyet, 1968, p. 23).

Moran and Hale (1932) observed that ice crystals in frozen meat stored at -3.1°C (26.4°F) increased in size during 180 days of storage. Ramsbottom and Koonz (1941) indicated that no crystal growth was noted in beef tissue stored one year at -12.2 and -34.4°C (10 and -30°F).

Recrystallization occurs at a decreasing rate as the temperature is lowered below the freezing point (Meryman, 1956). Low and uniform temperatures are the obvious way of minimizing recrystallization during storage of frozen meat. Recrystallization also will occur during thawing, but it can be minimized by rapid thawing (Fennema and Powrie, 1964, p. 257).

After ice crystals are formed, the remaining material is left in a concentrated state, somewhat similar to products partially dehydrated by conventional methods. The extent of the concentration is influenced by characteristics of the product, the rate of freezing, and the ultimate temperature. Concentration of solutes during freezing is accompanied by changes of such properties as pH, titratable acidity, ionic strength, viscosity, osmotic pressure, vapor pressure, freezing point, surface and interfacial tension, and oxidation-reduction potential (Fennema and Powrie, 1964, p. 270).

Bound water. Definitions for bound water arise from the techniques used for its measurement. In general, two common definitions have been presented in the literature. Robinson (1931) stated that bound water can be defined as the water that remains unfrozen at some prescribed temperature below 0°C (32°F). The temperature usually chosen is -20°C (-4°F). However, Luyet (1961, p. 74) defined bound water as water that does not crystallize at any temperature. The second common definition of bound water is the water in a system that is unavailable as a solvent (Gortner and Gortner, 1949, pp. 247-248).

Bound water is of great importance in many food systems. Proteins, because of their many charged groups, are the principal water-binding substance of animal tissue (Fennema and Powrie, 1964, p. 235). Consideration of this fact is essential to understanding protein reactions. Borgstrom (1961) pointed out that cells containing large quantities of bound water undergo less damage during thawing than cells with smaller quantities. Furthermore, bound water influences reactions during freezing and is an important factor in hindering crystal formation. Meryman (1960) estimated that 8 to 10% of the total water in animal tissue is unavailable for ice formation.

Rate of freezing. In general, the rate of freezing meat may be expressed as a function of two variables; namely, the driving force and the resistance to heat transfer. The driving force is the difference in temperature between the product and the cooling medium. The three most common types of freezing systems are air blast (gaseous coolant), indirect contact (solid coolant), and direct immersion (liquid coolant).

Freezing in air is economical, but generally it is slower than the other methods, and will dehydrate unpackaged meat. Commonly used air temperatures range from 0 to -40°F (-17.8 to -40°C), and air velocities in the freezing chamber range from 100 to 3500 linear feet per minute (Fennema and Powrie, 1964, p. 318).

Indirect contact involves placing the food product against a cold metal surface. The metal surface generally is cooled by circulating a liquid coolant through the hollow cores of freezing plates. Packaged meat rests on or slides against a cold plate, or is pressed between two plates.

Immersion freezing involves immersing the meat in a cold liquid medium, such as liquid nitrogen, liquid nitrous oxide, liquid air, or aqueous solutions of sugar, salt, or glycerol. Since the coolant comes into direct contact with the meat, the rate of freezing is more rapid than for the other methods.

Packaging of meat helps to retard both dehydration of the tissue and frosting of the equipment. Many packaging materials such as films, laminates, foils, and papers have been used to package meat. Those materials have some effect on the rate of freezing. Borgstrom (1968, p. 141) compared the thermal conductivity of aluminum, glass, plastics, and paper (in Btu/hr/sq ft/°F/inch thickness). He stated that aluminum was about 850 to 1575 times more conductive than paper or plastics (aluminum, 1416; glass, 3.6 to 7.2; plastics, 0.96 to 1.68; paper, 0.9). He also reported that the equal volumes of water were frozen at 30°F in various packaging materials. The water packaged in aluminum foil required 45 min to freeze; in plastic 4.5 hr; in glass, 5.5 hr; and in paper the water still was not frozen solid in 7.25 hr.

Resistance depends on factors such as thickness and composition of the product. When the thickness of common food packages is doubled from about 2 to 4 in., freezing time increases about 2.5 fold (Potter, 1968). The inner portion of the product freezes at a slower rate than the outer portions, and somewhat offsets any advantages of rapid freezing.

The effect of the composition of the product on the rate of freezing involves both the chemical composition and thermal conductiveness of the various constituents. The thermal conductivities of food materials generally increase markedly upon freezing. Thermal conductivities of frozen meat, fish, and fat, as determined by Lentz (1961), are approximately 3 to 4 times as large as those of the corresponding unfrozen products. The rate that thermal energy travels through a substance is dependent on the molecular structure, mean free path between molecules, and, if it is a solid, the type of lattice structure and the nature and quantity of lattice defects (Dickerson, 1968).

Bratzler and Tucker (1963) reported that the rate of freezing beef increased with an increase in fat content and a decrease in moisture content. This is in agreement with Ramsbottom _et al_. (1950) who studied freezing time of beef, pork, lamb, and veal. Those investigators pointed out that the specific heat of water is greater than that of fat. The latent heat of fat tissue is dissipated by fat crystallization at temperatures around 32°F (0°C), whereas most of the latent heat of lean tissue is extracted from 30 to 20°F (-1.1 to -6.7°C). Thus, the greater amount of moisture and the consequent higher heat capacity of lean meat accounts for the slower rate of freezing.

In contrast, other studies have shown that the thermal conductivity of muscle tissue decreased as the moisture content decreased and the fat content increased (Hill _et al_., 1963; Miller and Sunderland, 1963). Hill _et al_. (1963) also found that when comparing samples from the same muscle, the conductivity was 8 to 16% higher when heat was removed parallel with the fiber than when it was removed perpendicular to the muscle fiber.

Effects of Freezing, Storage, and Thawing on Selected Characteristics of Muscle

Thawing and cooking losses. Several investigators found that drip loss during thawing was related to temperature of freezing. A review of the literature revealed that, in general, for beef, slow freezing resulted in more and rapid freezing in less drip loss.

When frozen under similar conditions mutton showed much less ice formation and distortion of structure than beef cuts ranging from 3.0 to 26.0 cm in thickness (Cook _et al_., 1926). However, Empey

(1933) found that when frozen and thawed in small pieces (10x6x1 cm) mutton was only slightly less susceptible to drip than beef. Sair and Cook (1938) concluded that the formation of drip is not related to crystal size alone.

Empey (1933) showed that thaw drip was primarily a function of hydrogen-ion concentration rather than of rate of freezing or thawing. The least drip was associated with muscle tissue having a pH of 6.3 or higher. Data of Sair and Cook (1938) indicated that drip in thawing beef, pork, and mutton was maximum when the pH was between 5.0 and 5.2. As pH values increased, the amount of drip decreased progressively until no drip was obtained with thawed tissue at pH 6.4. At that pH drip was negligible, regardless of whether the meat had been frozen rapidly or slowly.

Lowe et al. (1952) found that weight losses during cooking were practically the same for frozen and thawed lamb leg roasts. When comparing fresh and frozen (-18°C, -0.4°F) lamb leg roasts, Smith et al. (1968) found that cooking losses were less for the fresh roasts, although the difference was nonsignificant. However, those authors reported that cooking losses were greater for fresh lamb loin chops than for chops frozen at -23°C (-9.4°F), although not significantly different. Causey et al. (1950) reported that lamb patties thawed during cooking had less cooking drip loss than prethawed patties.

Weir (1960a, pp. 287-288) reviewed the literature relative to thawing meat in cool air, in warm air, in circulating water, and during cooking. She reported that the higher the drip loss during thawing, the less moisture lost during cooking. Therefore, the overall loss from the frozen to the cooked state was almost the same for all methods of thawing.

Palatability. Many references found in the literature related to the effect of freezing on meat reported the effect on only one palatability factor, i.e. tenderness. A review of published studies on beef, pork, and poultry revealed disagreement regarding the effect of freezing on tenderness. Weir (1960b, p. 217) pointed out that investigators have reported no effect, increased tenderness, and decreased tenderness on freezer stored beef.

According to Marsh et al. (1968) the tenderness of frozen lamb loin was affected greatly by the time-temperature pattern imposed on the dressed carcass during the onset of rigor mortis. Carcasses were held at 18 to 24°C (64.4 to 75.2°F) for 0.5, 3, 6, 9, 12, 16, and 24 hr before being frozen at -18 to -15°C (-0.4 to 5.0°F). Highly significant tendering occurred between the carcasses held 16 hr and any groups held shorter periods of time. No significant difference was detected between the groups held for 16 and 24 hr. All longissimus dorsi (LD) samples were acceptable to the panel, although several were considered only moderately tender.

Smith et al. (1968) compared fresh and frozen lamb chops and leg roasts from 190 carcasses. Treatments for loin chops were: (1) unfrozen and (2) frozen and stored 3 to 6 wks at -23°C (-9.4°F). Treatments for rib chops were: (1) unfrozen, (2) unwrapped chops frozen at -23°C (-9.4°F), (3) wrapped chops frozen at -23°C (-9.4°F), and (4) wrapped chops frozen at -34°C (-29.2°F). The frozen rib chops were stored 11 to 14 days at the same temperature as used for freezing.

Freezing significantly ($P < 0.01$) increased shear force values for cooked loin chops, whereas for cooked rib chops shear force decreased significantly ($P < 0.01$) with freezing. The mean shear value for frozen leg roasts was slightly greater than that for unfrozen leg roasts, but values for the two treatments were not significantly different. It was suggested that differences in anatomical location, time in frozen storage, temperatures employed in freezing, and cooking temperature may have contributed to the contrasting results for tenderness of rib chops and the cuts from the loin and leg areas. Subjective values for tenderness of lamb leg roasts supported shear force data for semimembranosus muscle and for loin chops (LD muscle).

Some studies reviewed on the effect of freezing on cooked lamb included data on the flavor, juiciness, and over-all acceptability of the meat. Similar to tenderness data, these data varied among the studies.

Flavor and over-all satisfaction scores for frozen leg roasts were significantly ($P < 0.01$) lower than those for unfrozen lamb roasts, whereas juiciness scores were not significantly different for the two treatments (Smith et al., 1968). Laboratory panel ratings for over-all acceptability revealed no differences between fresh and frozen lamb roasts (Lester and Branson, 1966). Ary and McLean (1946) reported no appreciable differences in "eating quality" of lamb legs frozen at 20, 10, 0, and -10°F (-6.7, -12.2, -17.8, and -23.3°C).

Over-all acceptability scores showed no difference between quick-frozen (-26.1°C, -15°F) and slow-frozen (-17.8°C, 0°F) lamb steaks, or between steaks cooked while frozen or thawed before cooking (Brady et al., 1942). Lowe et al. (1952) found no differences in aroma, texture, flavor, and juiciness of sirloin, loin, and rib lamb chops thawed before cooking and those thawed during cooking. However, both sirloin and rib chops thawed during cooking tended to be less tender than those thawed prior to cooking. However, lamb patties thawed during cooking were favored by a palatability panel over pre-thawed patties (Causey et al., 1950).

EXPERIMENTAL PROCEDURE

Samples, Experimental Design, and Analysis of Variance

Fifteen lamb racks, similar in quality, were obtained from a commercial packing plant in St. Joseph, Missouri. Four pair of chops (1.5 in. thick) were cut from the region posterior to the 5th rib to posterior to the 12th rib of each rack. A pair consisted of one chop from the left and one from the same region in the right side of the rack. The longissimus dorsi (LD) muscle in chops from the right side of the rack were used for subjective measurements of selected palatability characteristics of the muscle, whereas the LD in chops from the left side of the rack were used for selected objective measurements. Additional objective measurements such as thawing and cooking losses and cooking time were made for each 1.5-in. chop.

Individual chops were placed in oxygen permeable bags (L-300) supplied by the Cryovac Division of W. R. Grace and Co.; the air was evacuated and the bags were sealed. Chops were frozen and evaluated according to an incomplete block design that provided three rates of freezing (slow, rapid, extremely rapid) and two methods of thawing (before and during cooking), Cochran and Cox, 1957, p. 443-446. The specific design is given in Table 1. The analysis of variance was:

Source of Variation	D/F
Groups of replications	4
Treatments (unadjusted)	5
Blocks in groups	10
Intra block error	38
Total	57

Fundamentally groups of replications and blocks in groups are blocks, and take out of error and treatments the animal (rack) and cooking period variations.

Storage, Cooking, and Thawing Procedures

All chops were stored in a household freezer (-20°F; -28.9°C) until evaluated (1 to 7 wk). Chops thawed before cooking were left in the Cryovac bags and placed in a refrigerator at 45°F (7°C) for 20 hr. The internal temperature of the thawed chops ranged from 4 to 12°C (39.2 to 53.6°F) and averaged 6°C (42.8°F).

Chops were cooked by the modified broiling method described by Hay _et al_. (1953) except that an oven temperature of 375°F

[a] The design was completed with chops from the right side of the lamb rack, and the subjective measurements for palatability characteristics of the muscle were made on the LD from those chops. The design was repeated with chops from the left side of the lamb rack, and objective measurements were made on the LD from those chops (Fig. 1).

[b] A block consists of one side from one lamb rack and represents one cooking period.

[c] Chops, 1, 2, 3, 4; chop 1 from 5th rib; chop 4 from 12th rib.

[d] Treatments (6): F_1T_1, F_1T_2, F_2T_1, F_2T_2, F_3T_1, F_3T_2, where F = freezing and T = thawing method:

F_1 – rapid freezing, moving air, -20°F (-29.9°C).

F_2 – slow freezing, still air, 0°F (-18°C).

F_3 – extremely rapid freezing, liquid nitrogen, -160°F (-71°C) at the surface of the chops.

T_2 – thaw during cooking

T_1 – thaw before cooking

Table 1. Experimental design for evaluating lamb rib chops subjected to three rates of freezing and two methods of thawing.[a]

Block[b]	Replication	Position (1, 2, 3, 4)[c] within rack and treatments[d] within blocks			
		1	2	3	4
1	I	F_1T_2	F_1T_1	F_2T_2	F_2T_1
2	and	F_3T_2	F_3T_1	F_1T_1	F_2T_2
3	II	F_1T_2	F_3T_2	F_3T_1	F_2T_1
4	III	F_1T_2	F_3T_2	F_1T_1	F_2T_2
5	and	F_3T_2	F_2T_2	F_3T_1	F_2T_1
6	IV	F_2T_1	F_1T_1	F_1T_2	F_3T_1
7	V	F_3T_1	F_3T_2	F_2T_2	F_1T_2
8	and	F_2T_2	F_1T_1	F_3T_1	F_2T_1
9	VI	F_2T_1	F_1T_1	F_3T_2	F_1T_2
10	VII	F_2T_2	F_1T_2	F_1T_1	F_3T_1
11	and	F_1T_2	F_3T_2	F_2T_1	F_2T_2
12	VIII	F_2T_1	F_1T_1	F_3T_2	F_3T_1
13	IX	F_1T_1	F_3T_2	F_2T_2	F_2T_1
14	and	F_3T_2	F_3T_1	F_1T_1	F_1T_2
15	X	F_1T_2	F_3T_1	F_2T_2	F_2T_1

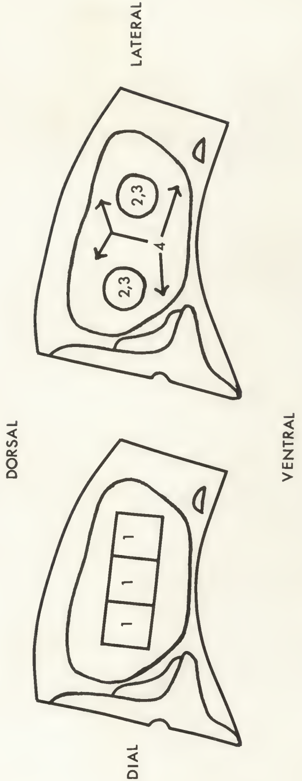
Fig. 1. Plan for sampling the longissimus dorsi muscle from a pair of chops.

1—Cubes ($\frac{1}{2}$-in.) for palatability scores. Six cubes were cut from the area (two layers of 3, $\frac{1}{2}$-in. cubes).

2—Cores ($\frac{1}{2}$-in.) for shear value.

3—Water-holding capacity (the center portion of each core).

4—Meat remaining after samples for 2 and 3 are removed was ground and used for determination of total moisture.


LATERAL
DORSAL
VENTRAL
MEDIAL
2,3
2,3
4
1
1
1

(190.5°C) and an end point temperature of 80°C (176°F) were used. Four chops were cooked at one time according to the experimental design (Table 1).

Measurements for Evaluating Effects of Treatments

Sensory evaluation. Flavor, tenderness, juiciness, and over-all acceptability of the LD were evaluated by a laboratory panel of five members using a 7- to 1-point scale (Form I, Appendix). Flavor and over-all acceptability were scored on the basis of desirability, whereas tenderness and juiciness were scored on an intensity scale.

Panel members selected at random and evaluated a 0.5-in. cube of LD muscle. Cubes of muscle were placed in the top of 1-pint enamel double boilers and set over hot water (approximately 150°F, 60°C) in the bottom part of the double boiler. The entire system was held at low heat (95 ± 2°F, 35 ± 1°C) on a General Electric hot tray until the muscle was evaluated by all panel members (not more than 30 min).

Instructions for sensory evaluation (Appendix, p. 37) were given to panel members before the first evaluation period. Each panel member standardized his tenderness scores by counting the number of chews necessary to masticate the cube completely.

The following objective measurements were made:

Cooking time. Total cooking time (min) was recorded for each chop.

Cooking losses. Percentage total, volatile, and dripping cooking losses, based on the weight of the thawed (T_1) or frozen

(T_2) chop, were calculated.

Warner-Bratzler shear value. Two 0.5-in. cores of LD (Fig. 1) were sheared on a Warner-Bratzler shearing apparatus with a 25-lb. dynamometer. Duplicate readings were made on each core.

Waterholding capacity. Waterholding capacity (WHC) was measured by the method described by Miller and Harrison (1965) except that two instead of three samples per chop were used (Fig. 1) and the samples (4) from two chops were pressed at one time.

Total moisture. Percentage total moisture (TM) was determined by drying duplicate 10-g samples of ground muscle (Fig. 1) in a C. W. Brabender Semi-Automatic Rapid Moisture Tester for 60 min. at 121°C.

RESULTS AND DISCUSSION

For ease in discussion of most of the topics, abbreviations are used for the six treatment combinations:

S-B, slow freezing - thawed before cooking

S-D, slow freezing - thawed during cooking

R-B, rapid freezing - thawed before cooking

R-D, rapid freezing - thawed during cooking

ER-B, extremely rapid freezing - thawed before cooking

ER-D, extremely rapid freezing - thawed during cooking

Appearance of the Chops

There were no apparent differences in color among lamb chops frozen at the three freezing rates. However, there was a tendency for chops frozen by liquid nitrogen to crack and separate between the LD muscle and fat areas, but the separation was not observed after thawing.

It has been reported that freezing rate affected the color of beef, veal, and pork. Plate freezing at -50°F (-45.5°C) resulted in almost complete loss of surface meat color, whereas freezing at 0°F (-17.8°C) resulted in an extremely dark meat surface (Robertson, 1950). Costello (1964) froze beef steaks in liquid nitrogen at 0, -70, -150, -200 and -320°F (-17.8, -56.7, -101.1, -128.9, and -195.6°C). Color of frozen steaks was lighter after freezing at -320°F and darker after freezing at 0°F than color of fresh beef steaks.

Cooking Time

Cooking time was affected ($P < 0.05$) by thawing method. For all three freezing rates, total cooking time was approximately one-third less (12 to 15 min) for chops cooked from the thawed than from the frozen state. However, there was no significant difference in cooking time between any two freezing rates for chops thawed either before or during cooking (Table 2).

Similar results have been reported by other researchers for the effect of method of thawing on cooking time. Kalen _et_ _al_. (1948) thawed beef pot roasts at room temperature and as part of the cooking process. Cooking time for pre-thawed roasts was 11 to 15 min/lb less than for roasts cooked from the frozen state to an end point temperature of $185^{\circ}F$ ($85^{\circ}C$). Causey _et_ _al_. (1950) reported an average of 5 min less time to oven-broil lamb patties thawed at room temperature to an end point of $85^{\circ}C$ ($185^{\circ}F$) than to oven-broil unthawed patties to the same internal temperature.

When data for all treatment combinations were pooled, a _t_-test indicated that cooking time for chops from the right side of the carcass was less (2.5 min; $P < 0.01$) than for chops from the left side. No studies were found that reported data for differences in cooking time between right and left sides of lamb carcasses, and no explanation can be given for the difference in cooking time reported here.

Table 2. Adjusted mean values for cooking time and losses (N = 20)[a] and for waterholding capacity, total moisture, and palatability scores (N = 10) as affected by freezing rate and thawing method.

	Slow (0°F, still air)		Rapid (-20°F, moving air)		Extremely Rapid (-160°F, liquid N)		
Measurement	Before cooking[b]	During cooking	Before cooking	During cooking	Before cooking	During cooking	LSD[c]
Cooking time, total min	30.4	45.2	33.9	46.4	31.6	47.1	6.73
Cooking losses, % Total	19.8	21.8	19.6	21.3	22.5	23.9	2.24
Dripping	6.7	6.6	5.6	6.3	7.7	7.6	1.09
Volatile	13.4	15.3	14.1	14.9	14.9	16.1	1.98
Waterholding[d] Capacity	0.719	0.723	0.714	0.693	0.733	0.689	——
Total moisture, %	64.62	65.71	65.62	63.58	65.05	63.65	——
Juiciness score,[e] 7–1	5.4	5.5	5.4	5.4	5.2	5.1	——
Flavor score,[e] 7–1	5.9	6.0	6.1	5.8	5.8	5.8	——
Over-all acceptability score, 7–1[e]	5.5	5.8	5.8	5.6	5.5	5.5	——

Table 2. (cont'd)

Measurement	Slow (0°F, still air)		Rapid (-20°F, moving air)		Extremely Rapid (-160°F, liquid N)		
	Before cooking[b]	During cooking	Before cooking	During cooking	Before cooking	During cooking	LSD[c]
Tenderness score, 7-1[e]	5.8	6.0	6.3	6.1	6.3	6.2	0.36
W-B shear, lb/$\frac{1}{2}$-in. core	6.2	6.6	5.8	5.9	5.3	5.8	----

[a] N = 20; data for left and right sides.

[b] In oxygen permeable bags (L-300, Cryovac Division of W. R. Grace & Co.), in refrigerator (45°F) for 20 hr.

[c] LSD, approximate least significant difference at the 5% level.

[d] The higher the value the greater the amount of liquid expressed; 1.0 represents the maximum expressible liquid index; WHC = 1.0 - expressible liquid index.

[e] Range, 7 (extremely desirable flavor and over-all acceptability, extremely juicy, or extremely tender) to 1 (extremely undesirable flavor and over-all acceptability, extremely dry, or extremely tough).

Cooking Losses

Cooking losses were not affected significantly by thawing method. Irrespective of freezing rate, chops thawed during cooking averaged only slightly greater losses (total, 1.7%; dripping, 0.2%; volatile, 1.3%) than those thawed before cooking. Dripping losses composed about one-third and volatile losses about two-thirds of the total losses (Table 2).

Lowe et al. (1952) reported the same average total cooking loss for lamb leg roasts cooked from the frozen and thawed states. Causey et al. (1950) found slightly more dripping loss from pre-thawed lamb patties than from patties cooked from the frozen state.

Total and dripping cooking losses tended to be greater for chops frozen with liquid nitrogen than for chops frozen by the two slower methods, but differences were not always significant. ER-B chops had greater ($P < 0.05$) total losses than S-B or R-B chops, and greater ($P < 0.05$) dripping loss than S-D, R-B, and R-D chops. Also, total losses were greater for ER-D chops than for S-B, R-B, and R-D chops. The only differences ($P < 0.05$) in volatile losses were that ER-D chops had greater loss than either S-B or R-B chops (Table 2).

Differences attributable to the right and left side of the carcass were not significant for total and dripping cooking losses as indicated by t-values calculated from data for all treatment combinations. However, the t-value indicated that chops from the right side had greater ($P < 0.05$) volatile loss than those from the left side.

Waterholding Capacity and Total Moisture

Neither WHC nor percentage total moisture of the cooked LD muscle were affected significantly by the six treatment combinations. Adjusted mean values for those measurements are presented in Table 2.

The ratio of the area of a pressed meat sample to the area of expressed liquid formed on filter paper on which the meat was pressed was designated as expressible-liquid index by Miller and Harrison (1965). They obtained values for WHC by subtracting the expressible liquid index from 1.0, which arbitrarily was assumed to be the maximum expressible-liquid index. Since the magnitude of the expressible-liquid index is inversely related to the amount of liquid expressed from the sample, the larger the value for WHC, the greater the amount of liquid expressed.

Palatability Factors

Adjusted mean values of panel scores for all palatability factors were in the scoring range of 5.1 to 6.3 on a scale of 7.0 to 1.0 points. Seven points indicated the most tender and juicy meat, and the most desirable flavor, and degree of over-all acceptability. Scores for juiciness, flavor, and over-all acceptability did not vary significantly among the six treatment combinations. Tenderness scores varied among the freezing-thawing treatments. R-B, ER-B, and ER-D chops were more tender ($P < 0.05$) than S-B chops, but there was no difference among R-B, ER-B, and ER-D chops. Analysis of Warner-Bratzler shear values, the objective measurement of tenderness, indicated no significant differences among the treatment combinations (Table 2).

In general, the results of this study agree with those of Ary and McLean (1946) and Brady _et al_. (1942), who froze lamb cuts at various freezing rates, and Brady _et al_. (1942), who also thawed lamb steaks before and during cooking. However, as mentioned earlier, Causey _et al_. (1950) reported lamb patties thawed during cooking were more desirable than pre-thawed patties.

Relationships Between Paired Measurements

Correlation coefficients were computed with data from all six treatment combinations to establish relationships between paired measurements used to evaluate the chops. Coefficients for selected paired variates are reported in Table 3, and those for other variates are in Table 16, Appendix.

Table 3. Correlation coefficients for selected paired variates.

Paired variates	Combined treatments D/F = 56
Dripping losses vs total cooking time	0.834**
Total moisture vs volatile cooking losses	-0.434**
Juiciness vs volatile cooking losses	0.666**
Over-all acceptability vs juiciness	0.285*
Over-all acceptability vs tenderness scores	0.247
Over-all acceptability vs flavor	-0.260*

*, $P < 0.05$
**, $P < 0.01$

In this manuscript, a coefficient between 0.00 and 0.39 is considered low (a poor relationship between the variates). A coefficient between 0.40 and 0.79 is considered moderate, and one of 0.80 or above is considered high (moderate and good relationships, respectively).

The coefficient for dripping losses vs total cooking time was high and highly significant, but those for total cooking losses and volatile losses vs total cooking time were low. Total moisture was moderately correlated with percentage volatile losses. As volatile losses increased, total moisture decreased. Goll et al. (1965) obtained a low correlation coefficient (N = -0.255) for percentage moisture of broiled beef LD muscle and percentage volatile cooking losses.

Also, in the present study, the relationship between juiciness and percentage volatile loss was moderate, positive, and highly significant, whereas Goll et al. (1965) reported a low negative, but significant correlation (r = -0.34*) between juiciness and volatile loss for broiled beef LD muscle.

Correlation coefficients for over-all acceptability scores with scores for juiciness, flavor, and tenderness were low. However, they may indicate that juiciness, flavor, and tenderness influenced the over-all acceptability score to about the same degree. When interviewed, two panel members, indicated that all three factors equally influenced their over-all acceptability score. One panelist stated that tenderness and juiciness were considered over flavor. Another member gave flavor and tenderness priority, whereas the last panelist considered flavor and juiciness most important. It appears that the information from the panelists also may indicate that all three factors influenced the over-all acceptability score to about the same degree.

Conclusion

In general, the results of the present study confirmed those in the literature concerning various freezing and thawing temperatures used for lamb, beef, and pork. The only apparent differences from previous studies were in cooking losses and shear values. Results previously reported are not in agreement, but tend to conclude that fast freezing produces slightly less cooking losses and more tender meat products. The present study showed more cooking losses with liquid nitrogen freezing than with the two slower methods, and no difference in shear values.

From the consumer standpoint, the results of the present study agreed with previous studies in that there was no practical difference in palatability scores among lamb chops that have been frozen at different rates and thawed before or during cooking. In view of the present cost of the process of liquid nitrogen freezing, it is not feasible for the producer to freeze lamb by that method.

SUMMARY

Lamb rib chops (120), 1.5-in. thick, were cut from 15 fore-saddles, similar in maturity, marbling, and date of slaughter. Paired chops (left and right) were assigned to three rates of

freezing: slow (0°F, still air), rapid (-20°F, moving air), and extremely rapid (-160°F, liquid nitrogen). Half of each frozen group was thawed at 45°F before cooking, and half was thawed during cooking by a modified broiling method at 375°F to an end point temperature of 80°C.

Rates of freezing and thawing did not affect the following significantly: waterholding capacity, total moisture, shear values, juiciness, flavor, and over-all acceptability. Significant differences in tenderness scores were attributable to rates of freezing rather than thawing methods.

There was a tendency for the extremely rapid rate of freezing to cause greater cooking loss than the two slower methods, although the difference was not always significant. Chops from the right side of the carcass had significantly ($P < 0.05$) greater volatile losses than those from the left side. There was no difference between chops from the right and left sides in total cooking and dripping losses.

The greatest difference between treatments existed in cooking time. Adjusted mean values showed that pre-thawed chops required approximately one-third less time to cook than chops cooked from the frozen state. Left side chops required significantly longer ($P < 0.01$) time to cook than right side chops. In general, the rate of freezing had no effect on cooking time.

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APPENDIX

Form I

SCORE CARD FOR EVALUATING THE PALATABILITY OF LAMB LONGISSIMUS DORSI

Judge ____________ Code ____________ Date ____________

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

Descriptive terms for scoring

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

Instructions to Judges for Sensory Evaluation of Lamb Longissimus Dorsi

You may use one cube of meat to score all palatability characteristics for one sample.

Scoring for flavor and juiciness

Record a score for flavor and another for juiciness within a range of 7 to 1 that describes your impression of the sample. See the score card for descriptive terms for specific scores within the range of 7 to 1. Record the score describing your impression of flavor and juiciness at the beginning of the chewing process.

Scoring for tenderness

Count the number of times you chew the $\frac{1}{2}$-in. cube of meat before swallowing. Chew until the cube is masticated completely then swallow. Record the number of chews required to masticate the cube. Record a score from 7 to 1 that describes your impression of the tenderness of the cube. See the score card for descriptive terms for specific scores within the range of 7 to 1.

Use the number of chews to help you standardize your tenderness scores from day to day. Set up for yourself a range of the number of chews for each score from 7 to 1. For example if you chew from 15 to 25 times, you might record a score of 7; if you chew 25 to 35 times, a score of 6; 35 to 45, a score of 5; continuing to reduce the score by a given number of increased chews. Each judge sets his own range of chews for a given score.

Over-all acceptability

Record a score that describes your impression of the general desirability of the sample. This is not a total score, i.e., it is not a score obtained by adding the scores for the other factors. Score over-all acceptability within the range of 7 to 1, the same as for each of the other factors listed on the score card.

Comments

Comments about a sample and/or explaining your reason for giving a particular score are helpful.

Take your time to score each sample. Water is provided for rinsing your mouth between samples.

Table 4. Cooking time in total minutes.

	Slow (0°F, still air)				Rapid (−20°F, moving air)				Extremely rapid (−160°F, liquid N)			
	Before cooking		During cooking		Before cooking		During cooking		Before cooking		During cooking	
Reps	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
I	26	30	—	—	—	—	46	48	35	32	49	43
II	21	28	33	34	27	25	47	63	27	33	41	55
III	22	24	33	40	26	28	45	55	24	24	46	52
IV	34	40	40	50	33	34	36	42	25	24	44	55
V	33	29	33	39	42	38	30	35	37	37	40	45
VI	44	42	59	57	36	35	34	38	34	31	35	40
VII	32	30	58	60	30	34	52	52	29	32	53	49
VIII	45	43	41	42	33	35	58	57	27	28	38	38
IX	27	31	43	47	43	53	35	37	36	32	52	58
X	23	30	37	47	30	23	56	61	38	42	59	47
Av.	30.7	32.7	41.9	46.2	33.3	33.9	43.9	48.8	31.2	31.5	45.7	48.2
Av.	31.7		44.1		33.6		46.4		31.4		47.0	

Table 5. Total cooking losses, %.

	Slow (0°F, still air)				Rapid (-20°F, moving air)				Extremely rapid (-160°F, liquid N)			
	Before cooking		During cooking		Before cooking		During cooking		Before cooking		During cooking	
Reps	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
I	19.5	21.9	—	—	—	—	25.6	21.5	22.6	18.2	24.9	27.3
II	20.2	19.0	19.6	18.0	16.9	12.6	24.3	26.1	22.4	19.9	24.7	24.0
III	19.8	20.4	21.1	17.6	16.2	15.2	18.9	18.9	20.9	27.1	23.3	29.1
IV	21.7	21.7	24.2	23.9	22.7	20.7	22.1	22.9	26.7	20.7	32.1	23.4
V	22.1	22.3	22.2	20.3	22.9	23.1	16.2	18.9	24.1	28.2	22.2	21.7
VI	21.8	19.5	23.2	23.8	20.0	17.8	18.4	19.1	22.6	20.9	17.7	20.9
VII	18.0	16.8	23.1	21.7	17.0	17.0	21.9	20.6	28.3	18.8	23.4	19.5
VIII	21.9	18.6	18.0	17.6	20.4	18.0	22.0	20.8	20.5	20.2	21.7	17.3
IX	18.8	18.9	20.0	19.7	20.7	21.6	17.4	20.0	20.9	22.7	20.9	20.5
X	20.2	20.2	24.6	23.3	16.9	16.5	26.4	25.4	24.5	23.1	22.7	28.7
Av.	20.4	19.9	21.8	20.7	19.3	18.1	21.3	21.4	23.4	22.0	23.4	23.2
Av.	20.2		21.2		18.7		21.4		22.7		23.3	

Table 6. Dripping cooking losses, %.

	Slow (0°F, still air)				Rapid (-20°F, moving air)				Extremely rapid (-160°F, liquid N)			
	Before cooking		During cooking		Before cooking		During cooking		Before cooking		During cooking	
Reps	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
I	4.9	8.0	----	----	----	----	6.9	6.0	5.2	5.1	5.8	10.5
II	8.8	9.5	6.3	5.4	4.6	5.0	9.0	7.5	7.5	8.2	10.1	8.8
III	5.7	7.7	6.0	7.8	5.2	6.9	6.0	6.6	6.6	9.6	6.3	5.8
IV	5.3	5.4	5.3	5.9	5.3	5.3	7.0	6.1	8.3	8.1	6.9	9.7
V	7.7	6.3	5.2	4.9	3.7	4.7	6.1	7.0	6.5	6.8	4.7	5.6
VI	5.8	7.3	8.5	6.8	4.8	6.4	7.5	6.7	6.1	5.3	4.9	10.7
VII	6.9	9.2	8.8	6.1	4.1	4.0	4.4	2.7	7.9	10.7	6.3	9.9
VIII	6.0	5.7	7.0	5.5	5.8	5.9	6.9	7.1	12.5	6.6	12.6	5.7
IX	6.0	5.6	7.2	7.1	6.4	5.9	7.3	7.1	13.4	8.6	7.4	5.3
X	5.5	4.1	6.0	5.6	5.4	5.0	4.8	5.4	8.0	7.1	6.7	6.4
Av.	6.3	6.9	6.7	6.1	5.0	5.5	6.6	6.2	8.2	7.6	7.2	7.8
Av.	6.6		6.4		5.2		6.4		7.9		7.5	

Table 7. Volatile cooking losses, %.

	Slow (0°F, still air)				Rapid (-20°F, moving air)				Extremely rapid (-160°F, liquid N)			
	Before cooking		During cooking		Before cooking		During cooking		Before cooking		During cooking	
Reps	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
I	15.4	14.6	----	----	----	----	18.2	15.0	17.4	13.1	19.1	16.8
II	11.4	10.3	13.4	13.5	13.1	9.2	14.9	18.6	15.0	13.0	14.0	15.2
III	12.9	11.3	12.2	11.5	12.2	11.3	13.2	15.3	13.7	17.1	16.4	18.7
IV	16.3	15.6	17.2	18.4	16.9	16.0	15.3	15.7	15.0	14.0	19.5	17.7
V	16.4	14.6	16.2	13.3	17.6	15.6	11.1	13.2	17.5	19.2	18.8	15.9
VI	16.5	14.1	17.9	17.8	14.0	12.5	12.3	13.9	14.3	13.5	11.5	11.9
VII	13.3	10.5	15.8	14.6	10.6	11.9	14.0	13.5	15.0	10.9	16.0	13.6
VIII	16.4	14.5	12.0	11.3	15.0	13.7	16.3	15.3	14.3	13.1	15.0	12.7
IX	10.3	11.8	16.3	15.5	17.1	16.9	11.3	13.0	13.7	15.9	15.7	13.8
X	14.4	12.9	15.5	16.4	11.3	10.1	18.4	18.2	17.8	17.2	17.3	18.0
Av.	14.3	13.0	15.2	14.7	14.2	13.0	14.5	15.2	15.4	14.7	16.3	15.4
Av.	13.6		15.0		13.6		14.8		15.0		15.8	

Table 8. Waterholding capacity (1.0-expressible liquid index).

Reps	Slow (0^{o}F, still air)		Rapid (-20^{o}F, moving air)		Extremely Rapid (-160^{o}F, liquid N)	
	Before cooking	During cooking	Before cooking	During cooking	Before cooking	During cooking
I	0.683	——	——	0.679	0.743	0.723
II	0.729	0.733	0.736	0.630	0.729	0.631
III	0.756	0.745	0.717	0.686	0.785	0.668
IV	0.647	0.755	0.692	0.712	0.785	0.639
V	0.756	0.724	0.675	0.751	0.717	0.716
VI	0.658	0.642	0.699	0.732	0.743	0.725
VII	0.790	0.660	0.705	0.701	0.717	0.755
VIII	0.677	0.776	0.676	0.691	0.702	0.685
IX	0.769	0.738	0.667	0.722	0.680	0.734
X	0.730	0.649	0.691	0.619	0.667	0.630
Av.	0.720	0.714	0.695	0.692	0.727	0.691

Table 9. Total moisture, %.

	Slow (0°F, still air)		Rapid (-20°F, moving air)		Extremely Rapid (-160°F, liquid N)	
Reps	Before cooking	During cooking	Before cooking	During cooking	Before cooking	During cooking
I	64.04	——	——	65.21	65.87	64.96
II	66.46	65.86	66.82	60.30	66.34	61.38
III	66.07	65.50	67.49	63.50	67.42	64.36
IV	61.70	64.46	62.52	64.49	67.17	61.88
V	64.38	64.95	62.30	65.66	61.35	62.62
VI	62.47	60.66	64.98	67.02	64.82	65.64
VII	67.04	60.99	63.66	62.21	63.35	66.20
VIII	62.64	65.86	63.46	64.08	64.96	65.01
IX	67.00	64.85	58.55	66.35	65.10	60.94
X	64.95	63.95	66.34	59.28	59.20	63.74
Av.	64.68	64.12	64.01	63.81	64.56	63.67

Table 10. Juiciness scores; range, 7.0-extremely juicy to 1.0-extremely dry.

	Slow ($0^{o}F$, still air)		Rapid ($-20^{o}F$, moving air)		Extremely Rapid ($-160^{o}F$, liquid N)	
Reps	Before cooking	During cooking	Before cooking	During cooking	Before cooking	During cooking
I	5.0	—	—	4.8	4.0	4.2
II	5.8	5.2	4.6	6.6	5.6	6.2
III	5.8	6.0	5.0	5.8	5.2	5.2
IV	6.2	5.0	5.2	5.0	5.0	4.6
V	5.2	4.4	5.4	4.8	4.2	4.2
VI	5.2	5.4	5.4	5.0	5.8	5.2
VII	6.0	5.8	5.6	5.4	4.8	5.4
VIII	5.4	5.8	5.4	6.4	5.4	4.6
IX	5.2	5.6	6.0	5.8	6.0	5.6
X	5.2	6.0	5.6	5.2	5.4	5.6
Av.	5.5	5.5	5.4	5.5	5.1	5.1

Table 11. Tenderness scores; range, 7.0–extremely tender to 1.0–extremely tough.

	Slow (0^oF, still air)		Rapid (-20^oF, moving air)		Extremely Rapid (-160^oF, liquid N)	
Reps	Before cooking	During cooking	Before cooking	During cooking	Before cooking	During cooking
I	5.5	——	——	6.2	6.0	6.2
II	6.6	5.6	5.8	6.4	6.6	6.8
III	5.8	6.0	6.2	6.5	6.4	6.2
IV	5.6	6.0	6.0	5.0	5.6	5.6
V	5.6	6.0	6.2	6.0	6.4	6.2
VI	6.4	6.0	6.6	5.4	6.0	6.2
VII	5.8	6.4	6.8	7.0	6.6	6.4
VIII	5.6	5.2	5.2	6.4	5.4	5.2
IX	5.4	6.0	6.2	6.8	6.6	6.2
X	5.6	6.0	6.6	6.4	7.0	6.6
Av.	5.8	5.9	6.2	6.2	6.3	6.2

Table 12. Shear values, lb/½-in. core.

Reps	Slow (0°F, still air)		Rapid (-20°F, moving air)		Extremely Rapid (-160°F, liquid N)	
	Before cooking	During cooking	Before cooking	During cooking	Before cooking	During cooking
I	4.8	—	—	4.2	3.8	6.4
II	4.6	8.7	9.2	5.7	4.1	5.0
III	5.8	6.0	5.1	3.5	5.0	4.4
IV	6.8	6.5	8.6	9.7	7.4	6.6
V	8.5	5.9	5.4	8.4	4.9	6.0
VI	3.6	5.4	4.3	5.8	8.1	4.7
VII	9.4	4.7	4.0	3.2	4.8	7.2
VIII	4.9	11.3	6.2	5.4	8.0	8.4
IX	9.2	8.0	5.0	4.1	3.0	5.8
X	7.3	4.9	3.6	5.5	4.5	3.2
Av.	6.5	6.8	5.7	5.6	5.4	5.8

Table 13. Flavor scores; range, 7.0—extremely desirable to 1.0—extremely undesirable.

	Slow (0°F, still air)		Rapid (−20°F, moving air)		Extremely Rapid (−160°F, liquid N)	
Reps	Before cooking	During cooking	Before cooking	During cooking	Before cooking	During cooking
I	5.8	—	—	6.0	6.0	5.6
II	6.0	5.8	5.8	6.2	6.2	6.4
III	6.4	6.0	5.8	6.0	6.0	5.8
IV	5.8	5.8	5.6	5.6	5.4	5.4
V	5.6	6.0	6.4	5.6	6.0	6.0
VI	6.2	6.2	5.8	6.0	5.8	5.8
VII	5.8	6.0	6.2	5.8	5.6	6.0
VIII	6.0	5.6	5.8	6.0	5.6	5.4
IX	5.6	6.0	6.6	5.6	6.0	6.4
X	6.0	5.4	5.8	5.6	5.4	5.6
Av.	5.9	5.9	6.0	5.8	5.8	5.8

Table 14. Over-all acceptability scores; range, 7.0-extremely acceptable to 1.0-extremely unacceptable.

	Slow (0°F, still air)		Rapid (-20°F, moving air)		Extremely Rapid (-160°F, liquid N)	
Reps	Before cooking	During cooking	Before cooking	During cooking	Before cooking	During cooking
I	5.8	---	---	6.0	5.0	5.0
II	6.4	5.4	5.2	6.2	6.0	6.2
III	6.0	6.0	5.2	6.0	5.6	5.5
IV	5.6	5.4	5.4	4.8	5.2	5.0
V	5.2	5.2	6.0	5.2	5.0	5.4
VI	5.4	6.0	5.8	5.4	5.6	5.8
VII	5.8	6.0	5.8	6.0	5.6	5.8
VIII	5.4	5.2	5.2	6.4	5.4	4.6
IX	4.8	5.8	6.6	5.4	5.8	6.0
X	5.6	5.6	5.6	5.6	5.4	5.4
Av.	5.6	5.6	5.6	5.7	5.5	5.5

Table 15. Correlation coefficients for selected paired variates.

Paired variates	Combined treatments D/F = 56
Total cooking losses vs total cooking time	0.145
Volatile losses vs total cooking time	0.011
Waterholding capacity vs total cooking time	-0.331*
Waterholding capacity vs total cooking losses	-0.030
Waterholding capacity vs dripping losses	-0.354**
Waterholding capacity vs volatile losses	-0.132
Total moisture vs total cooking losses	0.001
Total moisture vs dripping losses	-0.178
Total moisture vs waterholding capacity	0.151
Juiciness vs waterholding capacity	-0.250
Juiciness vs total moisture	-0.350**
Juiciness vs total cooking losses	-0.002
Juiciness vs dripping losses	0.006
Shear values vs tenderness scores	-0.004

*, $P < 0.05$.

**, $P < 0.01$.

COMPARISON OF FREEZING AND THAWING TREATMENTS ON SELECTED CHARACTERISTICS OF LAMB RIB CHOPS

by

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Modern meat merchandising procedures employ freezing and frozen storage to preserve meat products in a condition that closely approaches the condition of the fresh product. Much of the available information concerning the effects of freezing meat resulted from studies with beef and pork. Effects of freezing on the palatability of lamb have not been studied extensively. Therefore, it was considered important from the standpoint of the consumer, industry, and research to study the effects of current methods of freezing on the characteristics of lamb.

Lamb rib chops (120), 1.5-in. thick, were cut from 15 foresaddles, similar in maturity, marbling, and date of slaughter. Paired chops (left and right) were assigned to three rates of freezing: slow (0°F, still air), rapid (-20°F, moving air), and extremely rapid (-160°F, liquid nitrogen). Half of each frozen group was thawed at 45°F before cooking, and half was thawed during cooking by a modified broiling method at 375°F to an end point temperature of 80°C.

Rates of freezing and thawing did not affect the following significantly: waterholding capacity, total moisture, shear values, juiciness, flavor, and over-all acceptability. Significant differences in tenderness scores were attributable to rates of freezing rather than thawing methods.

There was a tendency for the extremely rapid rate of freezing to cause greater cooking loss than the two slower methods, although the difference was not always significant. Chops from the right side of the carcass had significantly ($P < 0.05$) greater volatile losses than those from the left side. There was no difference

between chops from the right and left sides in total cooking and dripping losses.

The greatest difference between treatments existed in cooking time. Adjusted mean values showed that pre-thawed chops required approximately one-third less time to cook than chops cooked from the frozen state. Left side chops required significantly longer ($P < 0.01$) time to cook than right side chops. In general, the rate of freezing had no effect on cooking time.