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Methods for the Reconstitution of Freeze Dried Meats

Period: 31 March 1961 - 30 November 1962

ARMED FORCES FOOD AND CONTAINER INSTITUTE
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CONTRACT RESEARCH PROJECT REPORT

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Title: Enhancement of Rehydration of Precooked Freeze-Dried Meats.

Summary

Precooked sliced beef (¼"), sliced pork (¼"), and ground beef have been freeze-dried from eight to sixteen hours. Various factors as internal temperature of precooking, grade of meat, prefreezing temperatures and freeze-drying cycles have been considered. Both radiant heat and plate contact methods have been utilized with the best results obtained with the radiant heat principle.

Rehydration studies have indicated the differences in moisture levels regained with the use of different temperature levels of rehydrating fluids. Rehydration in a solution of 0.5% tripolysodium phosphate at 72° F. results in a higher per cent moisture regained than whole slices in water at 72° F. The rehydratability of stored samples regardless of storage temperature were significantly reduced.

Histological studies have indicated no differences in extensibility between cooked and rehydrated samples. Fiber diameter measurements of samples rehydrated in 72° F. and 180° F. water do not show any consistencies in relation to the per cent moisture regained. This would indicate that the moisture regained in a sample is not necessarily reflected by the diameter of the fibers, but rather depends upon the water holding capacity of the proteins making up the tissue complex.

The taste panel evaluation of freeze-dried beef and pork slices and ground beef are as follows: Freeze-drying does not adversely affect flavor. The control and sustained juiciness characteristics are enhanced if beef is precooked to rare (140° F.) rather than well done (180° F.). Pork, when precooked to an internal temperature of 200° F. indicates higher scores in flavor and initial tenderness. The dehydration process does lessen the initial juiciness of ground beef. In all samples, the reheating process (rehydration in 180° F.) significantly reduces the juiciness and tenderness and increases the amount of residue.

Materials and Method

The freeze-drying procedure has been carried out in a F. S. Stokes Model #2003F-2 unit. U. S. Good grade Longissimus dorsi was cooked in an institutional type oven to three internal temperatures (140°, 160°, and 180° F.). Pork Longissimus dorsi was cooked to an internal temperature of 160°, 180° and 200° F. For the ground meat samples a Good grade of chuck was purchased, ground twice through a 3/16 inch plate and pan fried until done. The beef and pork loins were allowed to cool after cooking, and sliced ¼ inch thick on a commercial type slicer. Particular attention was given to the directions of the muscle fibers, so that a cut was made as nearly perpendicular to the fibers as possible. Samples of all types were prefrozen at -20° F. for 15-17 hours. Samples were either placed directly on the heating plates (plate contact method) or 1¼ inch above the plate on a stainless steel mesh (radiant heat principle). Freeze-drying cycles were varied from two to twenty four hours. Plate temperatures were adjusted until an optimal temperature (160° F.) was found that resulted in an acceptable product.

Moisture determinations were made on the raw, cooked and freeze-dried samples. At the end of a predetermined drying cycle, samples were immediately placed into desiccators or canned in vacuum cans on a commercial type canner which produced a vacuum of 17 inches of Hg.

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Upon removal from the containers, samples were immediately weighed and the per cent moisture remaining was calculated by the following formula:

$$\frac{W_f - [W_c - (W_c \times M_c)]}{W_f} \times 100$$

where W_f = weight of freeze-dried sample, W_c = weight of cooked sample, and M_c is the average per cent moisture of the cooked roast. Since fat determinations were not run along with moisture, this formula gives only an approximate calculation of moisture remaining; moisture content will be higher in the original cooked sample when less fat is present. Moisture determinations on the freeze-dried samples, relatively fat free, gave a more accurate determination of the moisture remaining, which in most cases was less than 2%.

Approximately 300 cc of rehydrating solution was used for each slice of freeze-dried meat. This gave more than adequate fluid for complete rehydration. After 15 minutes rehydration, each slice was blotted and reweighed. The per cent total moisture was then calculated from the change in weight and finally the per cent moisture regained to the original was calculated.

Raw, cooked and rehydrated samples were removed from an area of each sample approximately 1½ inches from the edge and placed in 10% or 4% buffered formalin, respectively. Samples were then dehydrated, cleared and embedded in paraffin. Freeze-dried samples were placed directly in amyl acetate, absolute alcohol or a nitrocellulose-amyl acetate mixture, then embedded in paraffin. Sections were cut at 10 microns on a rotary microtome and stained in a combination of Weigerts, haematoxylin and Van Giesons, resulting in differentially stained tissue components.

Muscle fiber diameters were first measured from the cross sections of the histological preparations. Due to difficulty in consistently cutting the fibers at a 90° angle, it was later decided to measure the diameters directly from muscle fibers which were separated by agitation in test tubes and placed on slides. In this way, the error due to oblique cuts is essentially negative. Twenty measurements were recorded for each sample and averaged.

Fiber extensibilities were performed on a dissection microscope on which a millimeter scale was fastened. The individual fibers were extended until they broke and this measurement was recorded as the extensibility. A minimum length of 3 millimeters was used as the base measurement

Samples were stored in vacuum cans at three different temperatures; room, refrigerator (2° F.) and 90° F. Odor, color and rehydratability were the main factors to be considered in the stored samples.

Finally, taste panel studies were performed on each of the various types of meat samples used in this work.

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Introduction

In attempting to enhance the rehydration of freeze-dried raw beef, many factors had to be considered. Previous studies indicated that size of sample, orientation of the muscle fibers, inter - and intramuscular fat content and freeze-drying cycle all influenced the subsequent per cent moisture of water regained (1,2). However, the one factor which is primarily responsible for optimum rehydration is the degree of denaturation of the proteins in the tissue complex. In order to have an acceptable freeze-dried sliced meat product, the rehydrated item must taste, smell and have the chewiness characteristic of freshly cooked meat. A small change in any of these three factors, results in an undesirable product. In respect to freeze-drying of raw meat, protein denaturation may be held to a minimum if proper means of freeze-drying are used. With precooked meat items, we are confronted with an entirely new substrate, one in which some tissue components have become tenderized (fibrous connective tissue), while others may well become toughened. All this may be due to the method of cooking used. It was the object of this investigation to study the rehydration methods for freeze-dried precooked beef and pork slices and ground beef. We did not attempt to study the biophysics of water uptake of precooked fibers, as this has been excellently represented by the studies of Luyet et al. (3) on raw muscle fibers. We would expect differences in the rate and final levels of moisture regained in the precooked as compared to the raw counterpart because of protein denaturation during cooking. In order to interpret the factors influencing the rate and extent of rehydration of precooked meat, it was necessary to determine the final site and rate of water deposition by measurements of appropriate tissue components. Experiments have been conducted on the effect of variation of freeze-drying methods, as well as experiments testing the effect of various solutions and environments on rehydration levels. Other factors such as connective tissue content and fat distribution were carefully considered in this study. Finally, a preliminary experiment was conducted in the use of strain gauges and linear variable transformer as a means of objectively measuring rehydration levels per unit time, however lack of funds prevented completion of this phase of the study.

Report

Of all factors concerned with tenderness of meat, the most significant is probably the amount and distribution of fibrous connective tissue. This component is unappreciably changed in the freeze-drying cycle, but is affected by the cooking process. The apparent reason for selecting the muscle, Longissimus dorsi of a Good grade for our experiments is quite obvious. This muscle has relatively the least amount of fibrous connective tissue and the large muscle size somewaht negates sampling

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differences. It is important to remember that freeze-drying in itself will not upgrade a beef product. In order to produce a highly acceptable precooked beef item, the raw material must be of high quality and particularly suited for this type of processing.

Cooking of meat prior to freeze-drying produces certain effects which may affect the rehydratability of the final product. At an internal temperature of 140° F., we found that the level of rehydration was in the 90-95 percentile range (when rehydrated in water at 72° F.). Comparison of levels of rehydration at three different internal temperatures of cooking are shown in Table I. In analyzing the results it is interesting to note that there is little difference in the three groups of samples when rehydrated in water at 72° F. Generally, rehydration was at a higher level in 72° F. water, and as the roasts were cooked to a higher internal temperature, the difference between the rehydration level in the 72° F. water as contrasted to that in 180° F. water, remained approximately the same. This trend was followed rather closely in samples rehydrated in the same temperatures of water with the addition of 0.5% tripolysodium phosphate as the group above, with the exception that 0.5% tripolysodium phosphate increased the hydratability to a slight degree. Microscopic examinations of the cooked 140°, 160°, and 180° F. samples indicated the variations in morphology due to cooking. The effect of heat on components of muscle tissue per se has been well described in the literature and need not be repeated here, other than to state that the effects of heat were more pronounced in the samples cooked to 180° F. than at 140° F. These effects (hydrolysis of collagen, fat translocation, disruption of muscle fibers) were difficult to quantitate because of the heterogenicity of the material. No correlation could be seen between the amount of heat denaturation and the morphological changes in the tissue, other than that described above.

One theory which may explain minor differences in rehydratability is particle size of protein as related to cooking temperature. During the process of cooking, the extensive unfolding of the protein molecule, exposes side chains, such as aspartic acid and lysine which attract one another and form aggregates. These aggregates reach a size when they no longer remain in solution and thus precipitate. This process of precipitation is the complete form of denaturation and referred to as coagulation. Extractable proteins in meat should be almost completely denatured at a temperature of 80° C. (5). When cooking to an internal temperature of 140° F. or 160° F. the aggregates formed are large. These aggregates begin to break down into smaller particles as the cooking process continues. The larger aggregate structure (140° F. or 160° F.) will tend to prevent water from entering the tissue particularly if this water is at the higher temperature of 180° F. Smaller aggregates formed by longer and higher cooking process should not be affected by the high temperature of the rehydrating water. There is a tendency for those samples cooked to a higher temperature to rehydrate a little better in water at 180° F. but the amount of water regained is still less than those samples rehy-

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drated at 72° F. One would expect to see a change in the histomorphological pattern to effect a change in the tissue response at these two different temperatures, however this was not evident. Another possibility is that the hot water (180° F.) used for rehydration of the 140° F. or 160° F. group of samples, causes further denaturation, manifested by "case hardening," thereby preventing the necessary amount of water from entering the tissues. Organoleptic tests indicate that rehydrating of the 140° F. and 160° F. samples in 180° F. result in a tougher product than those rehydrated at 72° F. In another series of experiments pork loins were roasted to three internal temperatures of 160° F., 180° F. and 200° F. Samples of cooked, freeze-dried and rehydrated pork slices were taken for histological processing. The results of the microscopic analyses will be presented later. On the basis of average per cent moisture regained there appears to be a difference between the two temperatures of rehydrating fluids (72° F. and 180° F.), similar to that found in beef. (Table II) However, as the internal temperature of the pork roast is elevated the rehydratability of the samples improved, especially when compared to samples cooked to a low temperature (140° F.). Ground chuck was cooked in a skillet until uniformly brown, drained, prefrozen and freeze-dried. Ground chuck presented no problems in the freeze-drying process or the rehydrating process. As seen in Table III ground chuck rehydrated more completely than any of the other types of meat.

There seems to be a great deal of controversy as to the effect of freeze-drying on meat. We feel that in precooked samples, freeze-drying has very little to do with protein denaturation. Hamm & Deatherage (6) have mentioned that the undesirable changes in meat during freeze-drying are not due to freeze-drying itself and the changes that do occur are not the same as heat denaturation. Microscopically, freeze-drying decreases muscle fibers, condenses the collagen, and correspondingly increases endomysial spaces and perimysial spaces. There seems to be no adverse effects of ice crystal formation during the pre-freezing stages at -20° F., with the exception of some compression of the muscle fibers into small irregular groups. Maximum compression of the fibers, however, occurs during freeze-drying, following the removal of bound water from the muscle fibers.

In Tables IV and V a comparison of muscle fiber diameters of freeze-dried and cooked meat are presented. As expected, the average muscle fiber diameter has decreased about 25-30% of its original size in the cooked sample. It also appears that a difference in internal temperature of the cooked sample has no significant effect on the muscle fiber diameter until a relative [illegible] temperature is used. Decrease in muscle fiber size merely tells us that water has been extracted during the freeze-drying process and comparisons between fiber diameter measurements of samples rehydrated in water at 72° F. and those in 0.5% tripolysodium phosphate indicate no differences. Although there is an appreciable increase in water pickup, this was not shown by any measurable increase in fiber diameter.

As mentioned earlier, a plate temperature of 160° F. was selected

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for this work. This temperature allows complete dehydration without adverse effect on the samples, however, it has been observed, that, following each cycle a thin layer of fatty residue has been deposited on the sides and front of the freeze-dryer. Evidently the heat is high enough, towards the end of the cycle, to cause some melting of fat and its movement throughout the freeze-dryer due to air currents set up during the removal of moisture. We have found no adverse effects on the samples themselves, but the possibility of the fat depositing on the samples as well as the walls of the freeze-dryer could lead to rehydrating difficulties (especially after storage). There is no apparent affect on rehydratability immediately after removal of the samples from the freeze-dryer.

Following preliminary studies of factors which may affect the rehydratability of precooked meat, time has been spent in rehydration studies to determine the final site of water deposition. Entrance of water into the muscle fiber is evident when sections are examined under the microscope. The muscle fibers enlarge and the striations return to their normal appearance, after rehydration. The reappearance of the striations shows that the muscle proteins, actin and myosin have apparently undergone no change at the microscopic level. Collagen also seems to reabsorb water, returning to its normal cooked appearance. Endomysial and perimysial spaces diminish in size, except in those areas where large spaces are produced by ice crystal formation during the prefreezing process. These spaces apparently allow water to enter the ¼ inch slices and then passing outwardly rehydrating the muscle fibers. The extent of rehydration has been determined by weight gain of the individual slices during a preselected rehydrating time of 15 minutes. Variation of rehydrating fluids, rehydrating methods and rehydration duration have been utilized to determine results on the three types of meat used in this work. In all three types of meat (pork, beef, ground chuck), we have found that rehydration with water at 72° F. results in a higher level of moisture regained than rehydration with water at 180° F. The possible explanation of this effect has been discussed previously. In reviewing the rehydration levels of the meat samples, it becomes clear that the use of 0.5% tripolysodium phosphate solution does not affect the rehydration level to a degree superior to plain water.

In order to decide the minimum amount of time for rehydration, samples of precooked beef and pork were rehydrated at 5 minute time intervals in both water at 72° F. and 180° F. After each five minute interval, the sample was blotted, weighed and placed back into the rehydrating solution. Table VI indicates the average per cent moisture regained in either 72° F. or 180° F. water at 5, 10, and 15 minute time intervals. It is obvious from this data, that practically all rehydration takes place in the first 5 minute period, and certainly no more than a 10 minute period is necessary. It has been our experience that meat containing high levels of interstitial fat rehydrate to a lower level in the first 5 minute period and act in a similar fashion for the ensuing periods as the other samples. This is another indication that the nature of the muscle tissue used for freeze-drying is extremely important for

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consideration of subsequent rehydration. It was our hope at this time to devise an objective method for ascertaining rehydration potentials of freeze-dried samples. In this way, a recording could be made of the smaller increase in weight during the first few seconds of rehydration and this compared to the different processing conditions and final moisture content of the individual samples. However, since the cost of instrumentation was prohibitive, the work was not carried out beyond preliminary tests.

Although considerable work has been done by Luyet (3) and Auerbach (2) on the effect of prefreezing temperatures on the freeze-drying and rehydration of raw meat, little if any work has been conducted on precooked meat. Microscopically our findings are similar to those reported in previous works. Freezing at -150° F. produces small intracellular spaces within the muscle fiber and the fibers do not decrease as much in size during the freeze-drying process, as those samples prefrozen at -20° F. The myofibrils become accentuated as a result of rapid freezing and are separated by small spaces due to ice formation. The intermuscular spaces are not as large nor as numerous as those found in samples prefrozen at -20° F. These characteristics are seen in the photomicrographs accompanying this report. The differences in muscle fiber diameter of the samples subjected to two prefreezing temperatures are tabulated in Table IV. Frozen-dried samples prefrozen at -150° F. show larger fiber diameters and these also tend to be larger following rehydration at 72° F. which in turn corresponds to an increase in the per cent moisture regained (Table VII.) Even though these findings may show a method whereby a more complete rehydration results, it is unfortunate that treatment with liquid nitrogen results in an extremely friable sample. The sudden temperature drop results in fractures of both the muscle fibers and connective tissue components. On a practical basis, there is no advantage in using liquid nitrogen as a prefreezing medium.

It has long been considered that air entrappment is a factor which reduces the level of rehydration of freeze-dried meats. In order to test this theory, a group of samples were rehydrated in the normal way i.e.; the sample placed on the surface of the rehydrating fluid, and another group immersed in the rehydrating fluid for the same period of time (15 minutes). All samples were weighed and rehydration levels computed. The average rehydration level for immersed samples was 91.9% and for the floated samples 94.0%. If air entrappment is a factor in retarding rehydration, then we should expect a significant difference in the rehydration levels of the two groups of samples. A difference of less than 3% does not seem to be significant enough to substantiate this belief. However, we feel that the factors of air entrappment along with all factors so far discussed, aid in the problem of rehydration.

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Storage Studies

Six groups of precooked freeze-dried samples have been stored for 6 months at three different temperatures. Table VIII indicates the nature of the samples, temperature of storage, as well as the length of time in minutes for complete reconstitution. The odor and color was immediately evident upon opening the cans of stored freeze-dried meats. The effect of storage on beef and pork at room (72° F.) and oven (90° F.) temperatures show some differences. Beef, whether sliced or ground, stored at room temperature, has a strong oxidized odor, as compared to pork which is only slightly rancid in odor. These differences are completely reversed in samples stored at 90° F.; beef has a slight oxidation odor and pork is strongly rancid. The pork precooked to 200° F. internal temperature and stored at 90° F. is described as being strongly rancid with an oily or aldehyde component to the odor. Samples stored at refrigerator temperatures are only slightly oxidized in both beef and pork.

Color changes were negligible. The changes were observed mainly in the beef samples which had been precooked to an internal temperature of 140° F. In these samples the central pink portion of the slices retained its pink color with only a slight darkening. Pork samples did not show color changes to the same degree as beef; only very slight browning was observed. Upon opening the cans, all samples were weighed immediately and the residual moisture calculated. In 87-94% of the total samples stored, moisture levels were well below 2%. The sliced samples were rehydrated by floating on the rehydrating fluid (water at 72° F. or 180° F.). Rate of rehydration was calculated as the time it takes for the fluid to completely rehydrate the upper surface of the sample; at this time the slices usually sink unless there is a large amount of collagen or fat. According to the data shown in Table VIII, pork precooked to an internal temperature of 200° F., rehydrated faster in hot water regardless of the storage temperature used. However pork, precooked to 160° F. and stored at 38° F. or 90° F. reacts just the opposite. A possible explanation of this is the spread of fat over the slices which may change in nature during storage. Cold water may be unable to penetrate this layer and hence the increased time for rehydration, whereas hot water will readily melt this fat layer and rapidly enter the tissues. The surface of the hot rehydrating fluid contains a large amount of fat which has come from the rehydrating samples. At the same time, it appears that the water holding capacity of the tissue proteins has been affected by storage. Rehydration in water at room temperature still results in a product that regains more water than that rehydrated in water at 180° F. In all samples that have been stored, the per cent moisture regained of the original moisture content is significantly lower than in the unstored samples (Table IX). The data indicate a general tendency for all samples to decrease in rehydratability as the temperature for storage is increased from 38° F. to 90° F. In the process of rehydration with water at room temperature a brownish material is dissolved out into the rehydrating solution. Pork shows this to a lesser degree than beef. Samples rehydrated in hot water do not

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show this characteristic at all.

Organoleptic Studies

Formal taste studies were conducted on the acceptability of freeze-dried meat products. In all cases the controls consisted of precooked frozen slices of beef, pork and ground beef. The general conclusions are as follows:

Sliced Beef

1. Flavor Flavor was scored on a scale ranging from 9/excellent = pleasing, normal flavor/ to 1/unacceptable = strong off flavors present/. The analysis of variance of the scores shows that the quality of the flavor was similar in samples cooked to 140° F. or 180° F. The treatment given to the meat i.e.: Freeze-dried, reheated; freeze-dried, cool; and frozen, reheated did not influence the quality of the flavor.

2. Initial tenderness The analysis of variance shows that the initial tenderness of the meat was not affected by the degree of doneness (140° or 180° F). Freeze-dried, reheated and frozen, reheated samples were given similar scores by the judges. Rehydrated freeze-dried (cool) samples were significantly more tender than either of the above. This shows that even a short reheating period significantly decreases the tenderness of freeze-dried meat. Any difference in tenderness which may have been present between freeze-dried and frozen samples before reheating were not evident after the samples had been reheated.

3. Residue - Scores for amounts of residue were similar for samples roasted to 140° and 180° F. Treatments differed significantly in their effects on amount of residue. Frozen, reheated samples contained less residue than freeze-dried, reheated pieces. The freeze-drying process adversely affects this characteristic. The freeze-dried cool samples have significantly less residue than the corresponding reheated pieces showing that the reheating process also increases the amount of residue.

4. Initial juiciness Meat roasted to 140° F. was scored significantly higher in initial juiciness than that cooked to 180° F. Frozen, reheated and freeze-dried-reheated samples were not significantly different in this respect. Again any differences in cool samples were masked by the effect of the reheating period. Freeze-dried-cool samples were significantly more juicy than the freeze-dried-reheated ones. The significant internal temperature times treatment interaction shows that these effects are combining to make the

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meat more juicy when cooked to 140° F.

5. Sustained juiciness As with initial juiciness, meat cooked to 140° F. is more juicy than that cooked to 180° F. The freeze-dried process has significantly increased the sustained juiciness of the meat as indicated when the freeze-dried-hot and frozen-hot means are compared. The reheating process has significantly lowered the juiciness of the freeze-dried meat.

Sliced Pork

1. Flavor The treatments given the samples did not influence the quality of the flavor. The judges gave higher scores to meat which was roasted to 200° F. than to samples cooked to 180° F.

2. Initial tenderness Samples cooked to 200° F. internal temperature were more tender than those cooked to a 180° F. end point. Freeze-dried, reheated and frozen, reheated samples were given equivalent scores by the judges. Freeze-dried samples which were not reheated were more tender than either of the other samples. Apparently the reheating process affects the tenderness of the samples markedly, while the dehydration which occurs during freeze-drying has little effect on tenderness.

3. Residue In contrast to the other palatability characteristics, the amount of residue is not affected by the degree of doneness. Freeze-dried, reheated samples had more residue than frozen, reheated samples. The large difference between freeze-dried, reheated and freeze-dried samples which were not reheated shows that reheating adversely affects the amount of residue.

4. Initial juiciness As would be expected, pork cooked to 180° F. received higher initial juiciness scores than that cooked to 200° F. The significant difference among treatment means indicates that the dehydration process and reheating process lower the juiciness of the meat.

5. Sustained juiciness (See comments for initial juiciness).

Ground Beef

1. Flavor The treatment given to ground beef samples did not affect the quality of the flavor.

2. Initial tenderness The reheating process significantly reduced the tenderness of freeze-dried meat. Any differences due to the dehydration process was masked by the effect due to reheating.

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3. Residue The reheating process significantly increased the amount of residue. Differences due to the dehydration process were not significant in this experiment.

4. Initial juiciness The significant difference between freeze-dried, reheated and frozen, reheated shows that the dehydration process lessens the initial juiciness of ground beef. Reheating reduces the juiciness of ground beef more than dehydration.

5. Sustained juiciness The sustained juiciness of the samples was not affected by the dehydration process. Reheating signficantly lowered the scores for this characteristic.

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TABLE I

COMPARISON OF REHYDRATION LEVELS OF BEEF SLICES PRECOOKED TO DIFFERENT TEMPERATURES

Internal Temperature of Cooking 0° F.	Average Per Cent Moisture Regained			
	Water 72° F.	Water 180° F.	Water + 0.5% Tripolysodium phosphate 72° F.	Water + 0.5% Tripolysodium phosphate 180° F.
140	92.2	80.9	94.4	93.9
160	91.9	88.3	97.1	87.8
180	93.6	88.2	94.3	92.4

TABLE II

COMPARISON OF REHYDRATION LEVELS OF PORK SLICES PRECOOKED TO DIFFERENT TEMPERATURES

Internal Temperature of Cooking 0° F.	Average Per Cent Moisture Regained			
	Water 72° F.	Water 180° F.	Water + 0.5% Tripolysodium Phosphate 72° F.	Water + 0.5% Tripolysodium Phosphate 180° F.
140	89.9	78.0		
160	91.8	81.1	90.9	83.4
180	92.4	88.3	90.7	89.3
190	93.9	84.0	85.2	75.0
200	94.5	91.5		

TABLE III

REHYDRATION LEVELS OF GROUND BEEF

Rehydration Temperature	Average per cent moisture regained
72° F.	97.7
180° F.	96.7
72° F. 0.5%+Tripoly-sodium phosphate	99.8
180° F. 0.5% Tripoly-sodium phosphate	100.0

TABLE IV

MUSCLE FIBER DIAMETERS (MICRONS) BEEF

Experiment	Cooking Temperature 0° F.	Raw	Cooked	Pre-frozen -20° F.	Pre-frozen LN_2	Freeze-Drying Cycle (Hrs.) 8	10	12	14	16	Rehydration 72° F.	Rehydration 180°F.	% Moist. Regain to Orig. Moist. 72° F.	% Moist. Regain to Orig. Moist. 180° F.
PV	140	54.6	51.8	x		38.5					51.3	49.3	92.3	80.2
PU	140	58.8	66.1	x		x					52.0	51.9	90.5	79.7
"	"	"	"	x			x				52.1	53.2	91.0	79.5
PP	140	-	47.9	x						36.0	50.4	48.1	93.5	82.7
"	"	-	"		x					43.7	49.9	53.4	96.4	85.5
PS	175	80.8	53.5	x		52.1					60.7	64.3	97.5	83.8
"	"	"	"	"			43.0				65.3	65.2	95.5	88.4
"	"	"	"	"				49.7			56.6	61.5	91.8	82.6
"	"	"	"	"					51.8		60.2	58.1	90.8	91.1
PR	175	88.9	57.0	x		49.0					57.4		55.4	53.4
"	"	"	"	"			41.3				50.4	47.2	61.2	-
"	"	"	"	"				43.0			63.7	55.3	64.6	52.6
"	"	"	"	"					52.1		51.8	60.2	56.4	38.3
PQ	176	61.9	53.5	x						41.3	49.0	57.2	93.6	86.2
"	"	"	"		x					59.1	51.5	49.5	98.6	90.6

TABLE V

MUSCLE FIBER DIAMETER (MICRONS) PORK

Experiment	Cooking Temperature 0° F.	Raw	Cooked	Freeze-Dried 8 Hours	Rehydration 72° F.	Rehydration 180° F.	% Moist Gain to Orig.	
							72° F.	180° F.
PW	140	61.9	60.2	34.6	61.7	59.9	90.7	72.7
AA	160	73.5	75.2	42.3	67.7	60.6	88.8	75.8
PZ	169°	52.1	50.0	42.0	55.3	54.6	90.4	80.2
PX	180°	62.3	61.9	43.7	63.7	61.3	91.2	79.3
AB	191	75.9	69.3	53.2	70.2	68.8	93.0	81.7
PY	192	52.1	48.6	46.2	54.5	50.4	94.9	84.6

TABLE VI

AVERAGE PER CENT MOISTURE REGAINED AT DIFFERENT REHYDRATION TIME INTERVALS

MEAT TYPE	PRECOOKING TEMPERATURE	5 MINUTES		10 MINUTES		15 MINUTES	
	0° F.	72° F.	180° F.	72° F.	180° F.	72° F.	180° F.
BEEF	176	93.3	83.7	94.7	86.1	95.3	87.1
BEEF	140	93.7	80.4	92.8	81.8	93.5	82.7
PORK	170-200	94.0	88.7	94.7	90.1	95.4	91.1
PORK	140	87.9	80.3	88.7	82.6	89.2	83.4

TABLE VII

INFLUENCE OF PREFREEZING TEMPERATURE
ON AVERAGE % MOISTURE REGAINED

PRECOOKING TEMPERATURE 0° F.	PREFREEZING -150° F.		PREFREEZING -20° F.	
	72° F.	180° F.	72° F.	180° F.
140° F.	96.4	85.5	93.5	82.7
175° F.	98.6	90.6	93.6	86.2

TABLE VIII

Average Time in Minutes of Complete Reconstitution of Storage Samples

Sample Type	Precooking Temp.	Rehydrating Solution	STORAGE TEMPERATURE		
			38° F.	72° F.	90° F.
PORK	160° F.	COLD	5.2	11.0	1.6
PORK	200° F.	COLD	12.6	15.0	15.0
BEEF	180° F.	COLD	4.0	30.0	30.0
BEEF	176° F.	COLD	4.5	-	-
PORK	160° F.	HOT	8.0	9.8	5.9
PORK	200° F.	HOT	5.9	2.7	3.5
BEEF	180° F.	HOT	7.5	7.75	6.75
BEEF	176° F.	HOT	2.0	-	-

TABLE IX

Comparison of Per Cent Moisture Regained of Stored and Unstored Freeze-Dried Samples

Sample	Unstored		Stored Samples					
			38° F.		72° F.		90° F.	
	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
Beef 140° F	100.0	82.0	87.5	73.3	90.8	74.6	85.7	71.5
Beef 180° F	93.1	94.2	85.8	76.1	90.7	79.3	89.7	80.8
Pork 160° F	98.2	92.4	87.9	75.0	92.1	73.5	90.8	77.0
Pork 200° F	94.5	91.5	87.1	87.8	91.4	86.4	79.1	83.5
Gr. Beef	95.6	90.0	95.5	91.8	93.5	89.4	94.7	89.3

TABLE X

Beef - residue Anova

SV	df	SS	MS	F
Total	143	430.417		
Animal	3	5.062	1.687	1.928
Int temp	1	0.146	0.146	0.167
Trt	2	26.261	13.131	15.007**
Judge	5	260.075	52.015	59.446**
Ax IT	3	7.193	2.398	3.358*
A x T	6	11.611	1.935	2.211
A x J	15	22.273	1.485	1.697
IT x T	2	4.485	2.243	2.563
IT x J	5	3.113	0.623	0.712
T x J	10	10.596	1.060	1.211
Residual	91	79.602		

* Sig at .05 level
** Sig at .01 level

IT x T Means (diff non-sig)

	FD-hot	FD-cool	F-hot
140	5.8	7.2	6.2
180	5.9	6.6	6.5

T means

FD-hot	FD-cool	F-hot
5.9	6.9	6.3

* P < .05 between bracketed means

TABLE XI

Beef - Initial Juiciness

SV	df	SS	MS	F
Total	143	446.173		
Animal	3	14.489	4.830	6.880**
Internal temp	1	51.600	51.600	73.504**
Treatment	2	104.990	52.495	74.779**
Judge	5	98.131	19.626	27.957**
Ax IT	3	30.984	10.328	14.712**
A x T	6	19.837	3.306	4.709**
A x J	15	33.533	2.236	3.185**
IT x T	2	5.208	2.604	3.709*
IT x J	5	9.192	1.838	2.618*
T x J	10	14.337	1.434	2.043*
Residual	91	63.872	0.702	

* Sig. at .05 level
** Sig. at .01 level

IT x T means (sig at .05 level)

	FD-hot	FD-cool	F-hot
140	5.7	7.8	5.5
180	4.8	6.1	4.5

Mean juiciness scores for ea. trt are higher in meat roasted to 140 rather than 180. Trt & int temp are interacting to increase init. juiciness.

Trt Means

FD-hot	FD-cool	F-hot
5.3 *	6.9 *	5.0

* P< .05 between bracketed means

TABLE XII

Beef - Sustained juiciness

SV	df	SS	MS	F
Total	143	461.230		
Animal	3	18.623	6.204	7.034**
Trt	2	71.971	35.986	40.800**
Internal temp	1	54.760	54.760	62.086**
Judge	5	125.060	25.012	28.358**
A x IT	3	26.296	8.765	9.938**
A x T	6	22.063	3.677	4.169**
A x J	15	40.587	2.706	3.068**
IT x T	2	5.202	2.601	2.949
IT x J	5	10.783	2.157	2.446*
T x J	10	5.649	0.565	0.641
Residual	91	80.236	0.882	

* Sig. at .05 level
** Sig. at .01 level

IT x T means (diff non-sig)

	FD-hot	FD-cool	F-hot
140	5.9	7.6	5.5
180	4.9	5.8	4.6

no interact between IT & T to increase or decrease sust juiciness

Trt Means

FD-hot	FD-cool	F-hot
5.4	6.7	5.0

* $P < .05$ between bracketed means

TABLE XIII

Beef - Flavor Anova F_5

SV	df	SS	MS	F
Total	143	390.237		
Animal (A)	3	9.095	3.032	2.397
Internal temp (IT)	1	3.933	3.933	3.109
Treatment (T)	2	5.821	2.911	2.301
Judge (J)	5	129.062	25.812	20.405**
Ax IT	3	6.993	2.331	1.843
A x T	6	25.798	4.300	3.399**
A x J	15	46.260	3.084	2.438**
IT x T	2	2.108	1.054	0.833
IT x J	5	21.865	4.373	3.457**
T x J	10	24.084	2.408	1.904
Residual	91	115.118	1.265	

** Sig. at .01 level

(IT x T Means) /difference non-sig./

	FD-hot	FD-cool	F-hot
140	5.6	5.3	5.4
180	6.0	5.4	6.1

Treatment Means (differences non-sig.)

FD-hot	FD-cool	F-hot
5.8	5.3	5.8

TABLE XIV

Beef - Initial tenderness - Anova

SV	df	SS	MS	F
Total	143	241.217		
Animal	3	24.353	8.118	9.852**
Int. temp.	1	0.122	0.122	0.148
Treatment	2	34.446	17.223	20.902**
Judge	5	31.916	6.383	7.746**
Ax IT	3	12.017	4.006	4.862**
A x T	6	3.535	0.589	0.715
A x J	15	40.251	2.683	3.256**
IT x T	2	4.507	2.254	2.735
IT x J	5	6.001	1.200	1.456
T x J	10	9.097	0.910	1.104
Residual	91	74.972		

** Sig. at .01 level

IT x T Means (difference non-sig.)

	FD-hot	FD-cool	F-hot
140	6.5	7.8	6.3
180	6.6	7.4	6.8

Trt Means

FD-hot	FD-cool	F-hot
6.5 *	7.6	* 6.6

* $P < .05$ between bracketed means

TABLE XV

Pork-Flavor Anova

SV	df	SS	MS	F
Total	143	237.377		12.999**
A	3	39.347	13.116	14.436**
IT	1	14.566	14.566	0.364
T	2	0.734	0.367	7.356**
J	5	37.108	7.422	
A x IT	3	0.382	0.127	0.126
A x T	6	3.206	0.534	0.529
A x J	15	27.422	1.828	1.812
IT x T	2	3.202	1.601	1.587
IT x J	5	8.793	1.759	1.743
T x J	10	10.785	1.079	1.069
Residual	91	91.832	1.009	

* Sig. at .05 level
** Sig. at .01 level

IT x T means (diff. not sig.)

	FD-hot	FD-cool	F-hot
180	5.2	5.5	5.3
200	6.1	5.7	6.2

Trt. mean (diff. not sig.)

FD-hot	FD-cool	F-hot
5.6	5.6	5.7

TABLE XVI

Pork-Initial Tenderness Anova

SV	df	SS	MS	F
Total	143	519.413		
A	3	280.580	93.527	97.729**
IT	1	10.133	10.133	10.588**
T	2	47.975	23.988	25.066**
J	5	40.828	8.166	8.533**
A x IT	3	3.669	1.223	1.278
A x T	6	5.288	0.881	0.921
A x J	15	28.881	1.925	2.011*
IT x T	2	2.776	1.388	1.450
IT x J	5	4.897	0.979	1.023
T x J	10	7.272	0.727	0.760
Residual	91	87.114	0.957	

* Sig. at .05 level
** Sig. at .01 level

IT x T means (diff. not sig.)

	FD-hot	FD-cool	F-hot
180	4.9	6.4	4.9
200	5.6	6.6	5.8

T means

FD-hot		FD-cool		F-hot
5.3	*	6.5	*	5.4

* $P < .05$ between bracketed means

TABLE XVII

Pork-Residue Anova

SV	df	SS	MS	F
Total	143	478.636		
A	3	100.475	33.492	38.990**
IT	1	0.765	0.765	0.891
T	2	18.647	9.325	10.856**
J	5	164.099	32.820	38.207**
A x IT	3	2.927	0.976	1.136
A x T	6	7.855	1.309	1.524
A x J	15	73.170	4.878	5.679**
IT x T	2	7.616	3.808	4.433*
IT x J	5	14.486	2.897	3.373**
T x J	10	10.451	1.045	1.217
Residual	91	78.145	0.859	

* Sig. at .05 level
** Sig. at .01 level

IT x T (sig. at .05 level)

	FD-hot	FD-cool	F-hot
180	5.0	6.4	5.4
200	5.5	5.9	5.9

T means

FD-hot	FD-cool	F-hot
5.2	6.1	5.6

* P < .05 between bracketed means

TABLE XVIII

Pork - Initial Juiciness Anova

SV	df	SS	MS	F
Total	143	466.178		
A	3	98.016	32.672	25.585**
IT	1	25.418	25.418	19.904**
T	2	98.899	49.450	38.724**
J	5	58.255	11.651	9.124**
A x IT	3	11.706	3.902	3.056*
A x T	6	4.097	0.683	0.535
A x J	15	32.972	2.198	1.721
IT x T	2	4.765	2.383	1.866
IT x J	5	0.763	0.153	0.120
T x J	10	15.110	1.511	1.183
Residual	91	116.177		

* Sig. at .05 level
** Sig. at .01 level

IT x T means (diff. non-sig.)

	FD-hot	FD-cool	F-hot
180	4.0	6.5	4.9
200	3.5	5.1	4.3

T means

FD-hot	FD-cool	F-hot
3.8	5.8	4.6

* $P < .05$ between bracketed means

TABLE XIX

Pork - Sust. Juiciness

SV	df	SS	MS	F
Total	143	426.952		
A	3	87.496	29.165	22.179**
IT	1	17.920	17.920	13.627**
T	2	71.508	35.754	27.189**
J	5	65.491	13.098	9.960**
A x IT	3	15.765	5.255	3.996*
A x T	6	3.115	0.519	0.395
A x J	15	24.501	1.633	1.242
IT x T	2	8.377	4.189	3.186*
IT x J	5	0.193	0.039	0.030
T x J	10	12.965	1.297	0.986
Residual	91	119.621	1.315	

*Sig. at .05 level
**Sig. at .01 level

IT x T means (sig. at .05 level)

	FD-hot	FD-cool	F-hot
180	4.4	6.6	5.3
200	4.0	5.2	5.0

T means

FD-hot		FD-cool		F-hot
4.2	*	5.9	*	5.1

* P< .05 between bracketed means

TABLE XX

Ground beef - Flavor Anova

SV	df	SS	MS	F
Total	71	103.340		
Lot	3	9.820	3.273	3.641*
T	2	5.160	2.580	2.870
J	5	31.567	6.313	7.022**
L x T	6	7.160	1.193	1.327
L x J	15	13.233	0.882	0.981
T x J	10	9.433	0.943	1.049
Residual	30	26.967	0.899	

* Sig. at .05 level
** Sig. at .01 level

T means (diff. non-sig.)

FD-hot	FD-cool	F-hot
5.3	5.1	5.7

TABLE XXI

Ground beef - Initial tenderness Anova

SV	df	SS	MS	F
Total	71	94.400		
L	3	7.280	2.427	3.011*
T	2	13.720	6.860	8.511**
J	5	23.233	4.647	5.766**
L x T	6	13.000	2.167	2.689*
L x J	15	9.434	0.629	0.780
T x J	10	3.567	0.357	0.443
Residual	30	24.166	0.806	

* Sig. at .05 level
** Sig. at .01 level

T means

FD-hot		FD-cool		F-hot
6.2	*	7.1	*	6.1

* P < .05 between bracketed means

TABLE XXII

Ground beef - Residue Anova

SV	df	SS	MS	F
Total	71	100.440		
L	3	8.642	2.881	4.001*
T	2	13.182	6.591	9.154**
J	5	30.770	6.154	8.547**
L x T	6	5.644	0.941	1.307
L x J	15	16.175	1.078	1.497
T x J	10	4.438	0.444	0.617
Residual	30	21.589	0.720	

*Sig. at .05 level
** Sig. at .01 level

T-means

FD-hot	FD-cool	F-hot
5.5	6.4	5.5

* P < .05 between bracketed means

TABLE XXIII

Ground beef - Initial juiciness Anova

SV	df	SS	MS	F
Total	71	142.380		
L	3	10.780	3.593	7.172**
T	2	68.040	34.020	67.904**
J	5	10.567	2.113	4.218**
L x T	6	21.560	3.593	7.172**
L x J	15	8.766	0.584	1.166
T x J	10	7.633	0.763	1.523
Residual	30	15.034	0.501	

** Sig. at .01 level

T means

FD-hot	FD-cool	F-hot
4.3	6.5	4.7

* P < .05 between bracketed means

TABLE XXIV

Ground beef - Sust. juiciness Anova

SV	df	SS	MS	F
TOTAL	71	141.840		
L	3	12.320	4.107	6.540**
T	2	65.920	32.960	52.484**
J	5	8.233	1.647	2.623*
L x T	6	18.400	3.067	4.884**
L x J	15	8.567	0.571	0.909
T x J	10	9.567	0.957	1.524
Residual	30	18.833	0.628	

*Sig. at .05 level
** Sig. at .01 level

T means

FD-hot	FD-cool	F-hot
4.4 *	6.6 *	4.8

* P < .05 between bracketed means

PLATE I

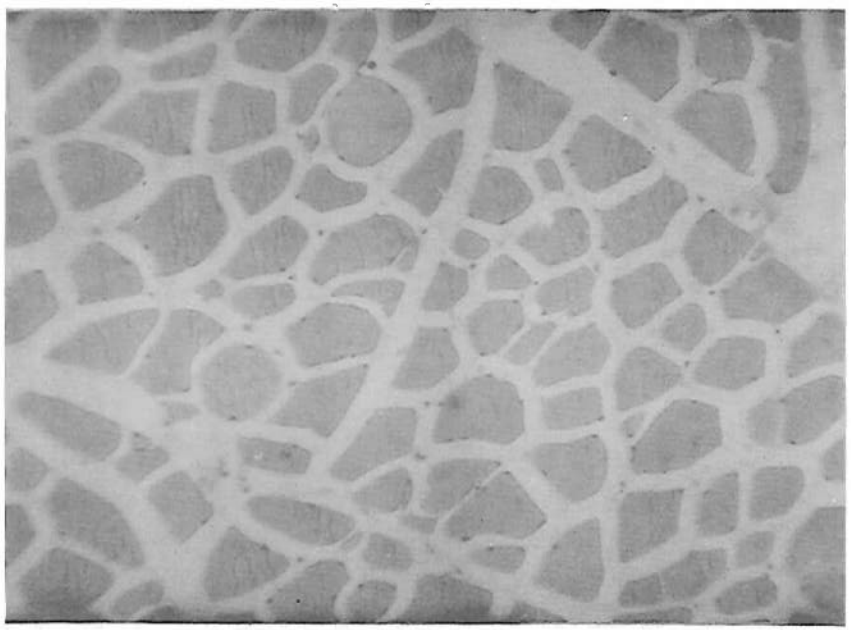
Longitudinal and transverse sections of raw beef and pork longissimus dorsi. Formalin fixed.

Figure 1. Raw beef control. Transverse section.

Figure 2. Raw beef control. Longitudinal section.

Figure 3. Raw pork control. Transverse section. Sacrolemma is pulled away from muscle fibers.

Figure 4. Raw pork control. Longitudinal section.



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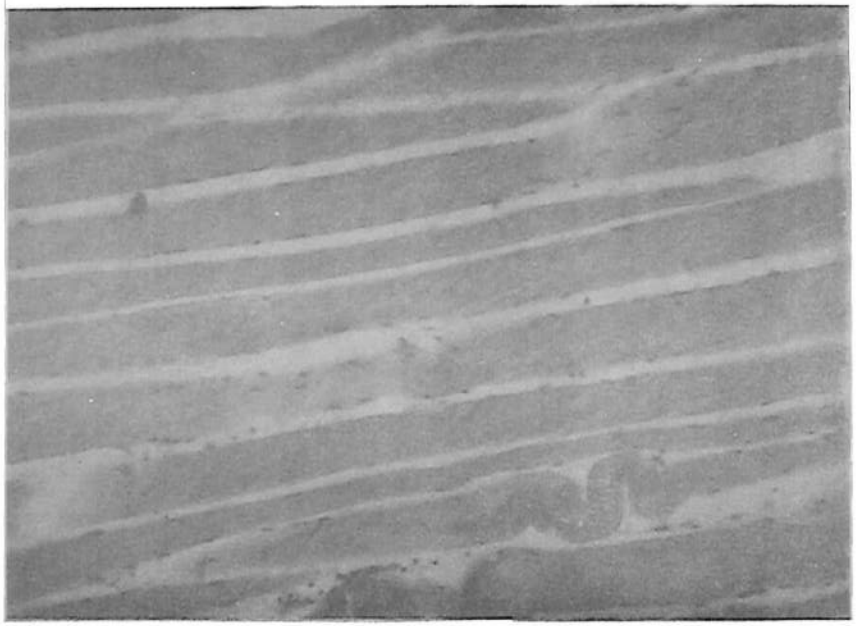

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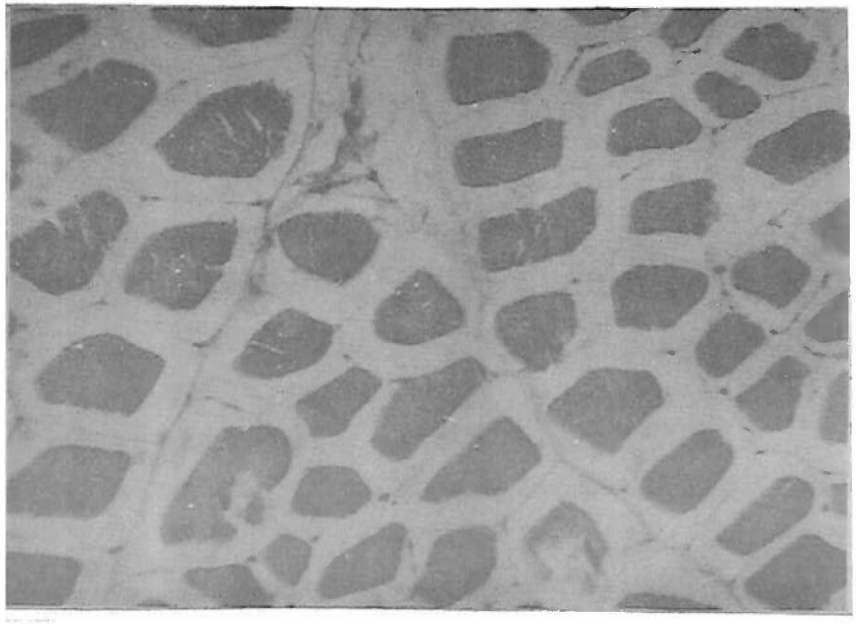

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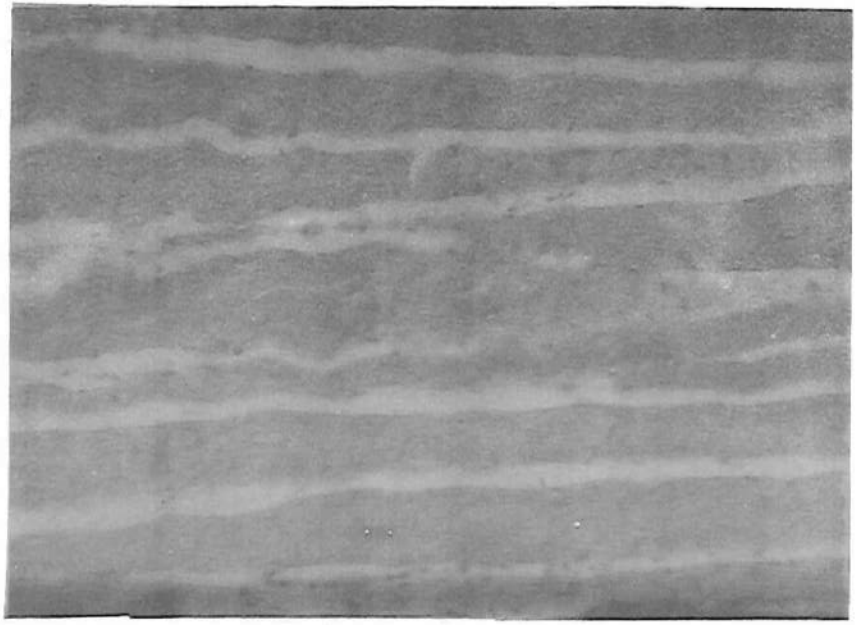


#4 PN 200X

PLATE I

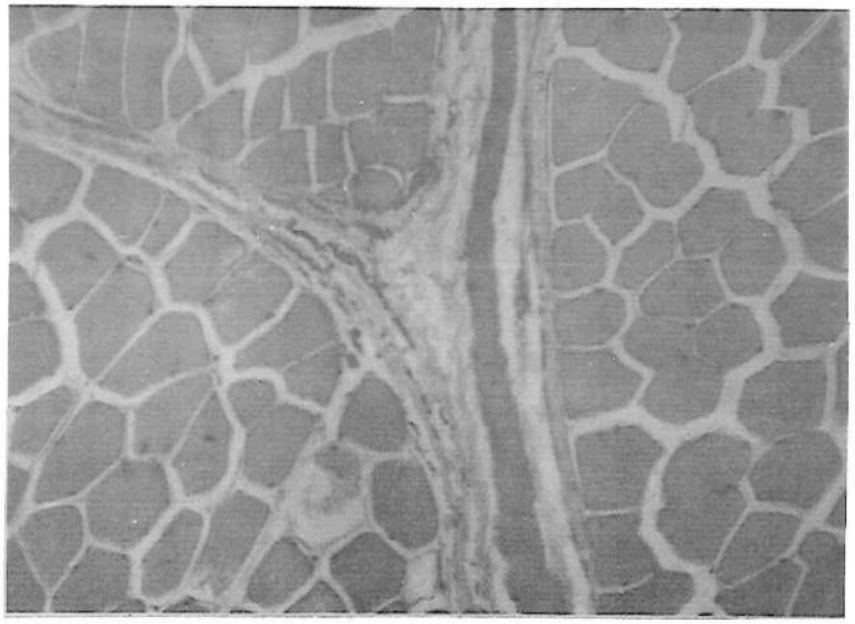
PLATE II

Figure 5. Beef cooked to an internal temperatue of 175° F. Central area of photograph shows collagen degradation. Endomysial spaces have diminished in size.

Figure 6. Longitudinal section of same sample in Figure 5.

Figure 7. Transverse section of pork cooked to an internal temperature of 180° F. showing collagen degradation and diminished size of endomysial spaces.

Figure 8. Longitudinal section of sample in Figure 7.



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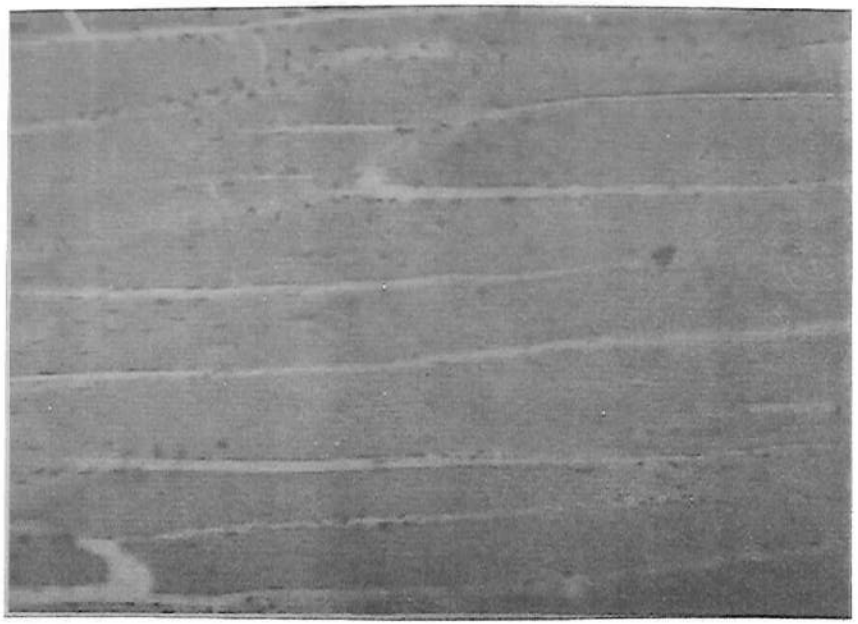

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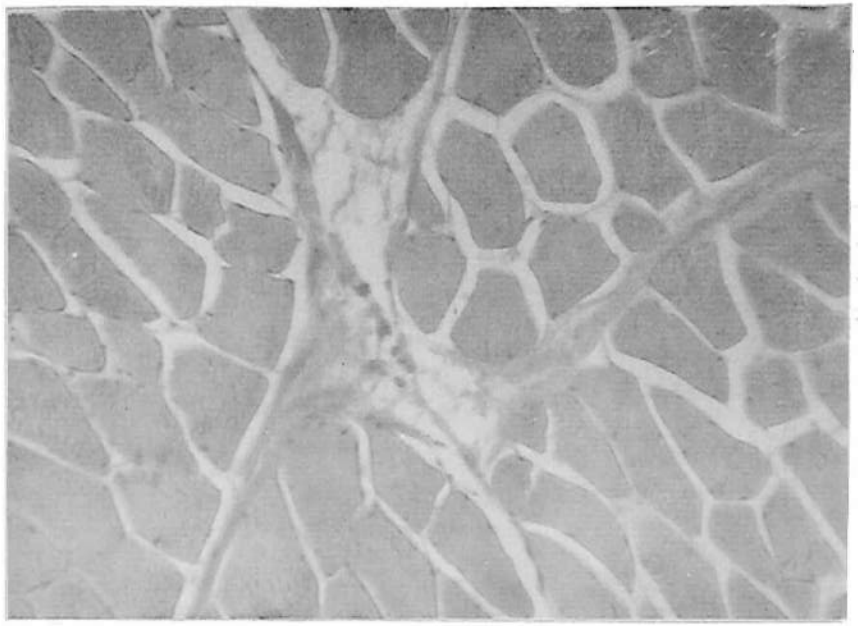

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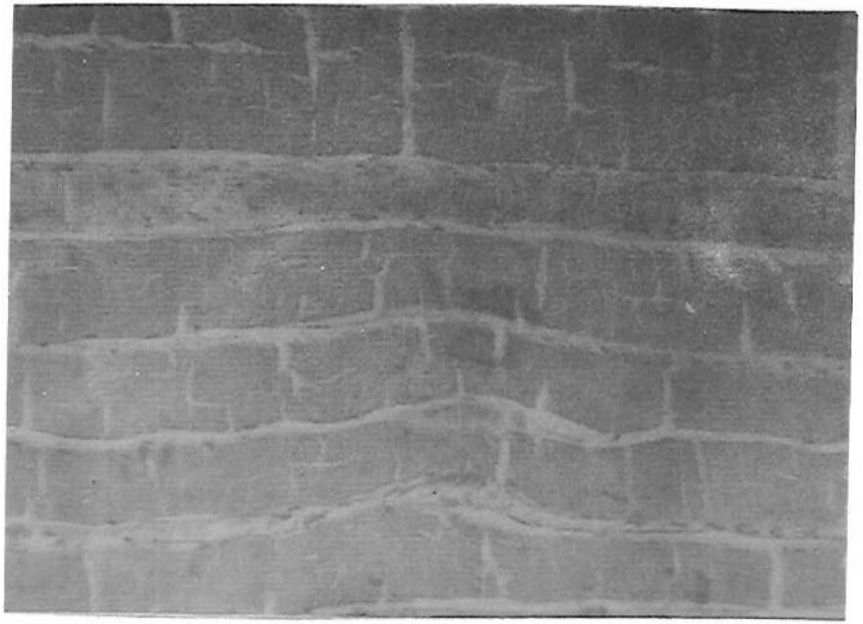


#8 PN 200X

PLATE II

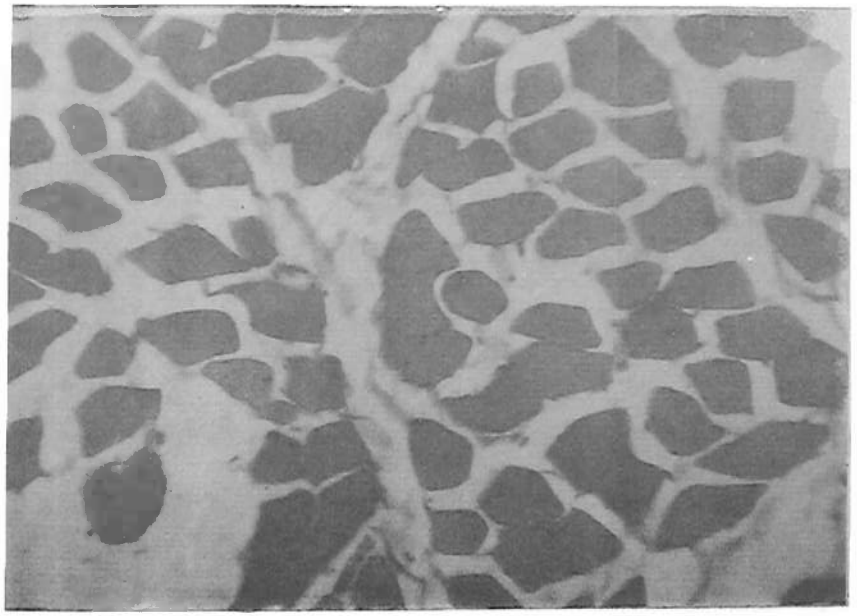
PLATE III

Figure 9. Transverse section. Beef, cooked to 175° F. and freeze-dried for 8 hours. Large space in upper right corner is the result of ice-column formation during pre-freezing. Muscle fibers are fused in some areas and the general uniform appearance of the muscle bundle has been disrupted.

Figure 10. Longitudinal section taken from adjacent area to that in Figure 9. Muscle fibers are grouped together as a result of ice column formation.

Figure 11. Transverse section. Pork, cooked to an internal temperature of 188° F., then freeze-dried for 16 hours. Fibers show an inconsistency in dehydration with the majority of fibers being transluscent as contrasted to Figure 9 and 10 where the fibers are uniformly opaque. There is excessive fragmentation and the sarcolemma appears to be accentuated.

Figure 12. Longitudinal section to show characteristics described in Figure 11.



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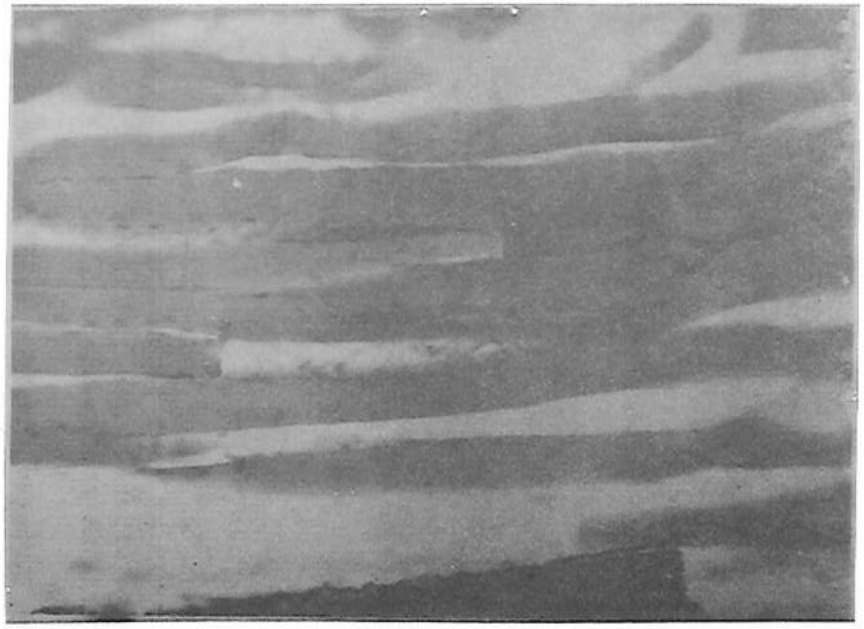

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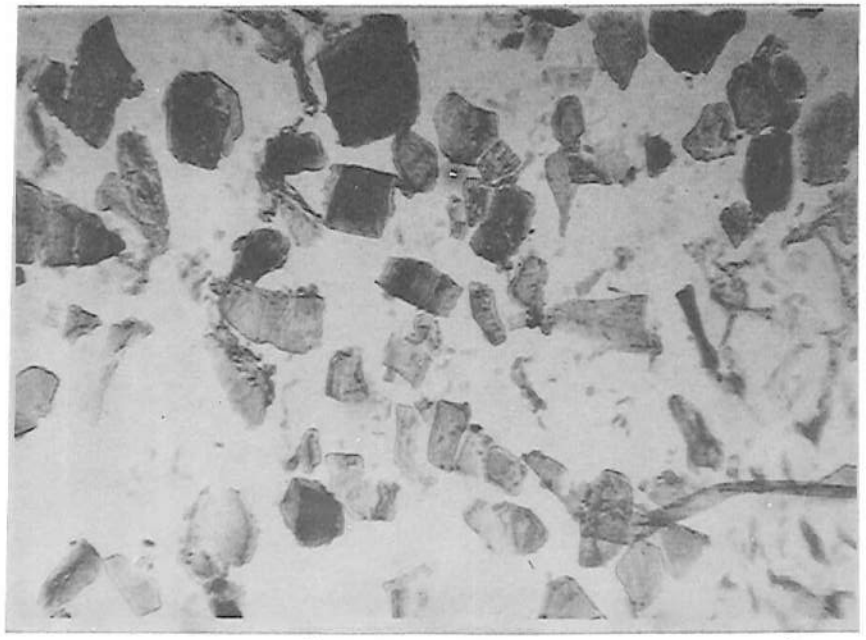
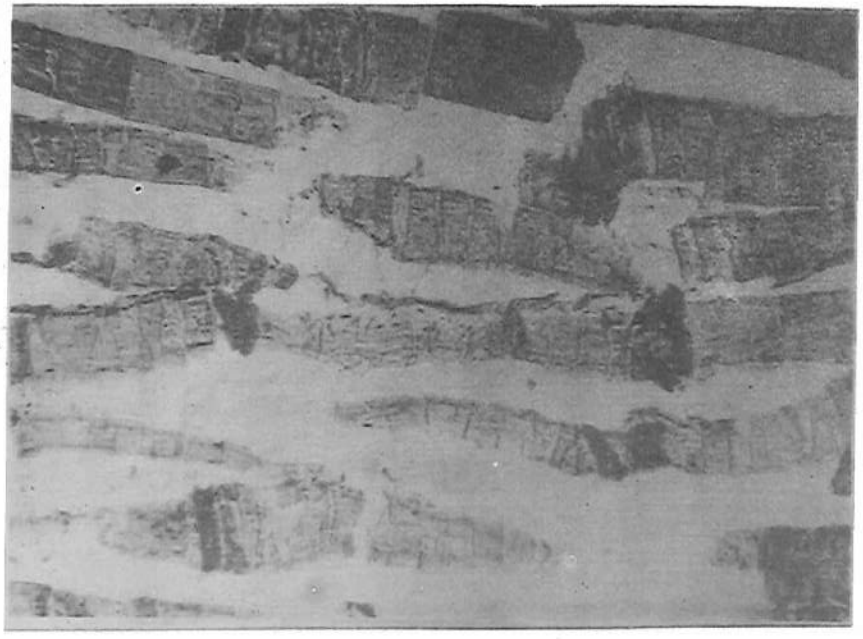


#11 PJ 200X



#12 PJ 200X

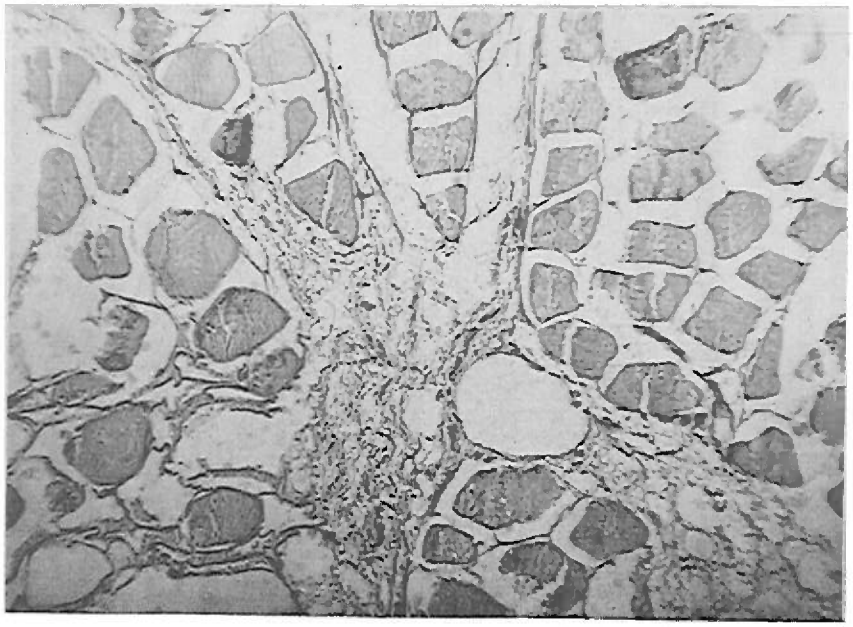
PLATE III

PLATE IV

Figure 13. Transverse section. Pork, cooked to 188° F., freeze-dried 16 hours, then rehydrated in water at room temperature (72° F.). Endomysial spaces are widened, muscle fibers show fragmentation and sacrolemma is accentuated. X200.

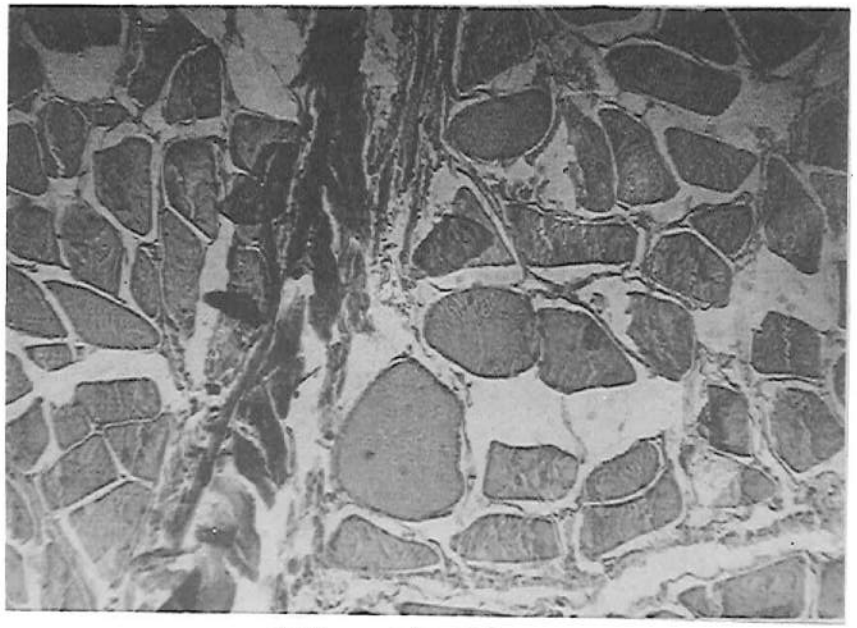
Figure 14. Longitudinal section of samples treated the same as Figure 13. Extensive fragmentation of muscle fibers and accentuation of the sacrcolemma. X200.

Figure 15. Transverse section. Beef, cooked to 175° F., Freeze-dried for 8 hours and rehydrated in water at room temperature. Muscle fibers are enlarged and general appearance tend to be irregular.



#13 PJ 200X

#14 PJ 200X



#15 PS 200X

PLATE IV

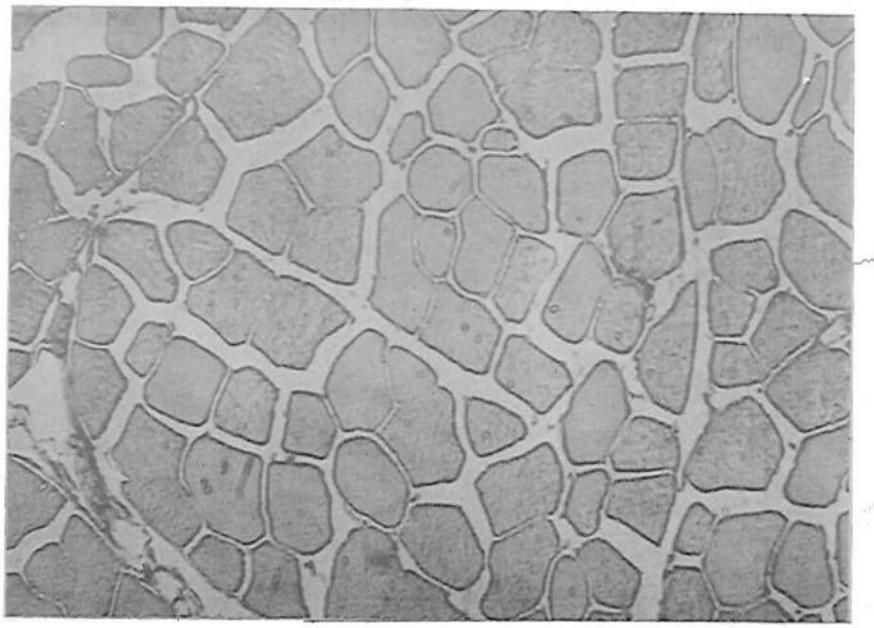
PLATE V

Figure 16. Transverse section. Pork, rehydrated in hot water (180° F.). Muscle fibers tend to remain in groups with some fusion of fibers apparent (upper left). Endomysial spaces are narrower. Sarcolemma is very well defined.

Figure 17. Longitudinal section. Pork, rehydrated in hot water. Muscle fibers are fused but show a normal appearance otherwise.

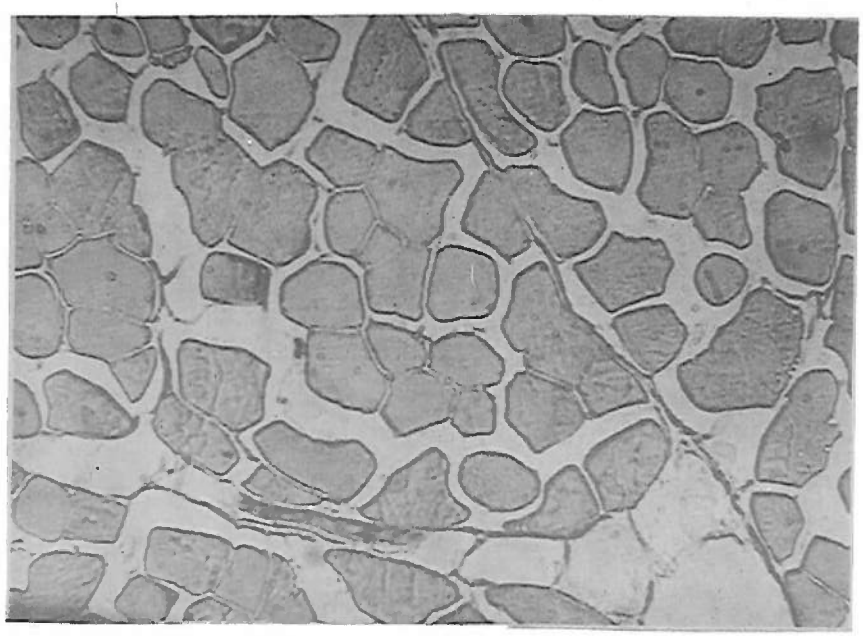
Figure 18. Transverse section. Pork, rehydrated in hot tripolysodium phosphate. There is no apparent difference from the sample in Figure 16.

Figure 19. Longitudinal section. Pork, rehydrated in hot tripolysodium phosphate. Similar to Figure 17 except that the fiber in the center shows the effect of kinking and the large space is the result of ice column formation during freezing.

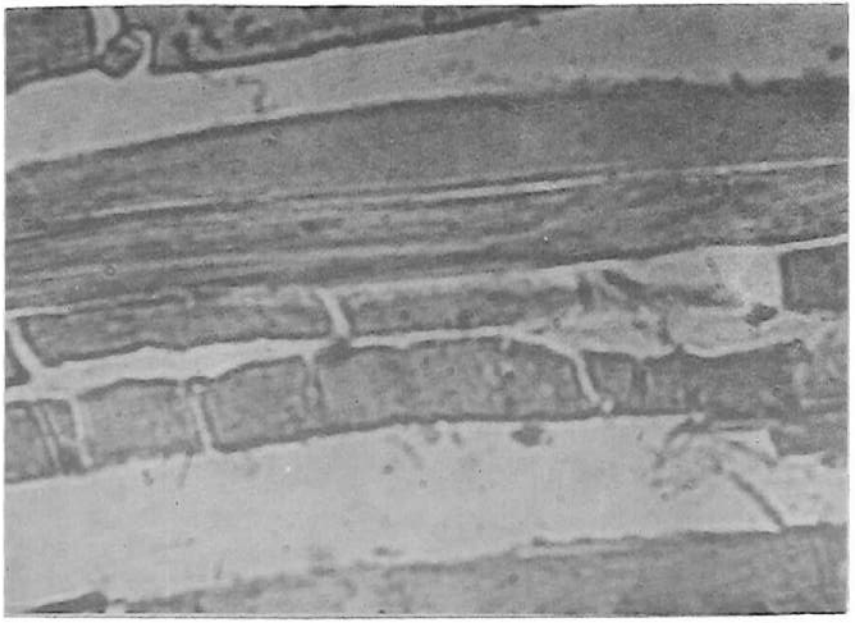


#16 PJ 200X

#17 PJ 200X



#18 PJ 200X



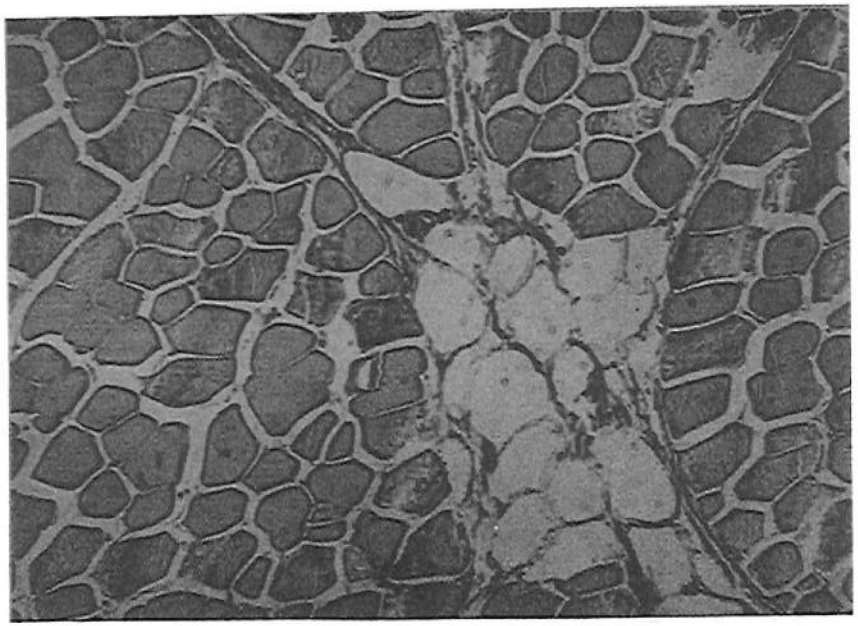
#19 PJ 200X

PLATE V

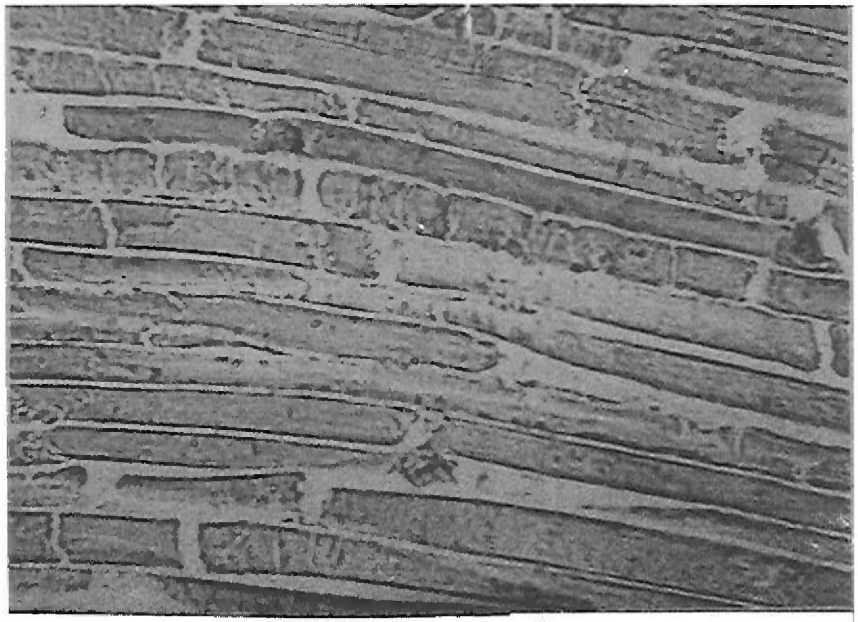
PLATE VI

Figure 20. Transverse section. Beef, cooked to 140° F., freeze-dried 8 hours, and rehydrated in water at 180° F. Photomicrograph shows a non-uniformity in rehydration of muscle fibers with fragmentation of some fibers and fusion of others. A group of fat cells, devoid of fat, is seen centrally.

Figure 21. Longitudinal section of a similar muscle in Figure 20 showing fragmentation and effects of kinking. Borders of individual fibers are accentuated.



#20 PV 200X



#21 PV 200X

PLATE VI