both the lamb and pork stored at 0 F than at 18 F in 24 weeks. Beef and pork stored for 12 months at −20 F gave lower figures for free fatty acid and peroxide value than when the storage temperature was 0 F. Frozen pork held at 0 F for one year showed a gradual loss of desirable flavor in the fat accompanied by an increase in peroxide value and Kreis number. The pH of the meat has a strong influence on rate of rancidification. Pork sausage was prepared so that the pH ranged from 4.8 to 6.5. At pH values below 6.4, the degree of rancidity increased with decreasing pH.

Clearly, oxygen exclusion should be beneficial in preventing or delaying fat oxidation. It is for this reason that packaging materials with low gas transmission rates are desired. Such films will keep out oxygen and retain a replacement gas when such is needed. Most workers are aware that oxygen exclusion is important, but make no comment to this effect. Protection of the meat from air lengthens its life. In another experiment beef was packed loosely in metal cans, and the cans capped and sealed. Access of differing amounts of air was provided by holes in the lids. The palatability of the meat decreased in proportion to the available oxygen.

If fat oxidation is so important in the flavor breakdown of frozen meats, antioxidants would be expected to improve flavor and possibly keeping quality. When the antioxidant formulations of nordihydroguaiaretic acid (NDGA) or propyl gallate was added to pork sausage, the flavor of the additives themselves was unpleasant, but showed no benefit in preventing flavor change with storage. The same antioxidants and a third one, butylated hydroxyanisol (BHA) were added to precooked beef stew, port stew and Swiss steak before freezing but had little or no effect of the antioxidants in preserving flavor. In a comparison between the freezer stability of raw and cooked ground pork containing BHA, ratings of the stored sausage by a panel showed that the BHA had slightly benefited flavor in that meat which was cooked before freezing, but not in that frozen raw.

It is generally accepted with certain reservations that the peroxide value increases with degree of undesirable flavor as judged by taste panels. No attempt was made to determine specifically if such correlations had been made, but three references on this subject are pertinent.

Ground pork stored at different temperatures and exposed to varying degrees of abuse was sampled for flavor and odor by a taste panel and the results compared with the peroxide values. The organoleptic measures were related to each other but neither was significantly correlated with the peroxide value and, therefore, peroxide value and free fatty acid values not good indications of flavor change. The flavor of frozen pork correlates poorly with peroxide values. However, by using the thiobarbituric acid reagent for measuring fat breakdown, good correlation of these results with panel figures was obtained.

The agent or agents concerned in fat oxidation in meat has been the subject of considerable investigation. Before briefly reviewing this subject another look will be taken at the muscle pigment myoglobin and its related substance hemoglobin. Both are very large molecules consisting of a protein linked to a complex structure called heme. The heme contains an iron atom which oxidizes or reduces reversibly. If the iron is in the ferrous state myoglobin or hemoglobin can form a loose combination with oxygen. Thus reduced myoglobin and oxymyoglobin are ferro compounds. When iron is oxidized (ferric) metmyoglobin or methemoglobin is formed. One other point to mention is that the heme can be separated from the protein and used rather than hemoglobin in some of the experiments discussed. Oxidation of linoleic acid, oleic acid, or the soaps of these acids and of fats by heme or heme compounds has been demonstrated a number of times. When using heme or hemoglobin with linoleate or oleate soaps and heme with linoleates, there is significant oxidation of the fatty acids. Heme was destroyed during the reaction. Likewise in frozen meat, pigment change accompanies development of rancidity. Hemoglobin solution produced oxidation of lard as did also muscle extracts.

Peroxide was produced in ground pork tissue, but one cannot extract an active material from the tissue.

In clear solutions of fatty acids or soaps, action of heme or hemoglobin or heme and muscle extract was negligible, whereas in an emulsion oxidation occurred.

Heat partially or completely inactivates muscle extract. Pork sausage which was heated before freezing did not develop rancidity in storage.

NDGA, propyl gallate, or α-tocophenol inhibit oxidation of linoleate by heme only when present initially. Although the heme content of pork fat tissue is very low, it is sufficiently high to account for the oxidation of fat. The rate of oxidation in this system was slower than that with a plant lipoxidase, but higher than an autocatalytic reaction.

Enzymatic Changes

It is a natural assumption that enzymatic activity is arrested by freezing. Moreover, it can be reasoned that water, the prime necessity for enzyme action, is present in no greater amounts than in a dry product. Unfortunately, reasoning is no more to be relied upon than intuition in this case. The proteolytic enzymes trypsin, chymotrypsin and pepsin all retain some activity even at 0 F. Fortunately, these enzymes are absent from muscle, but a proteolytic enzyme, called cathepsin is present which shows only a fraction of the activity of the other enzymes mentioned even under the most favorable conditions. A recent paper reports activation of muscle cathepsin by freezing and even greater increase in potency by repeated freezing and thawing.

Besides cathepsin, meat tissue contains other enzymes. These were a part of the energy releasing mechanism in the living animal, in utilizing sugar (glycolytic enzymes), and the involved cycle of changes centering around respiration. Succinic acid dehydrogenase and the glycolytic system is stable for a month in chilled beef muscle. The enzyme dehydrogenating succinic acid is the most active one, followed by those converting glycerophosphate or citrate. Freezing for a short time gave better preservation of the principal enzyme than did cooler temperatures. These enzymes are an important factor in bringing about undesirable color changes in fresh meat, and observation will show that on long storage of ground or portioned meat, perceptible activity is evident through such color changes. It is certain that activity is retained even for periods of two years.

Effect of Freezing on Nutritive Values

Although freezing and storage may affect the nutritive qualities of meat, there have been relatively few investigations on the subject. One research paper reports a detailed study of meat which had been kept frozen for 40 years in sealed metal cans. There was nothing unusual in the appearance of the meat except a thin dehydrated layer (*freezer burn*) on the surface. The protein content, coagulable nitrogen, and soluble nitrogen levels were similar to those of freshly frozen beef. Nutritive quality of the protein was not impaired, as shown by rat feeding tests. The rats gained the same weight per gram of food eaten with either stored or fresh beef. Thiamine and niacin contents were slightly lower than in fresh beef, but were within the range reported for beef. Riboflavin level was the same in stored and in fresh beef.

EFFECT OF FREEZING TEMPERATURE ON QUALITY

Two related items of practical importance to producer and consumer are the effect of freezing temperatures on meat quality, and the best storage temperature. Much work has been undertaken to determine what happens to the meat.

Color of Meat

It is clear that freezing temperature and holding temperature influence the color of meat. Meat frozen at −15 F had a brighter color than that frozen at 15 F. Beef frozen in 20 hours, five hours, or one hour showed a significantly better color in meat frozen in the shorter time intervals. Meat frozen and held at 10 F or −30, 10, 0, or −20 F showed color differences favoring the temperatures of 0 F or lower.

Flavor

The freezing temperature or rate of freezing meat has shown no determinable effect on flavor. Beef from carcasses which were chilled, slow frozen, or fast frozen were submitted to taste panels and no significant difference in flavor or juiciness was found. Beef loin steaks frozen in 1½, 7 or 24 hr had similar intensity and desirability of flavor in the lean. The same result was found with pork chops frozen in like fashion.

Structure

Rate of freezing was known to affect drip loss on thawing. Accordingly, muscle has been studied at the cellular level to determine how freezing affects muscle structures. Meat frozen in different ways was sectioned and the size and location of ice crystal masses observed under a microscope. Much larger ice crystals were found in beef and pork which had been frozen slowly. Freezing steaks rapidly produced intrafiber ice crystals, whereas with slow freezing, the crystals are mostly extrafiber. In thawing, the small ice masses within the fibers reabsorb readily, but the larger ice masses outside the fibers are present as free fluid, much of which exudes from the meat. The size of ice crystals and area of ice between fibers decreased with lower freezing temperature. Contrasting extremes in freezing temperatures, at −114 F fibers were split longitudinally, but at 18 F, large interfibrillar ice crystals were present.

Freezing and thawing cause degenerative changes such as breakdown within the muscle fibers and increase intercellular spaces. These changes became progressively worse with repeated freezing and thawing and the drip loss increases.

Tenderness

Although there is strong evidence that freezing does tenderize meat, negative findings by some workers indicate that the question is not yet settled. More work on this subject is needed to find the reason for lack of agreement.

Grade of beef is a factor in response to freezing. Blast freezing beef quarters toughened poorer grades of beef. Size of piece (rate of freezing) also has an effect. Beef frozen as quarters was slightly tougher than corresponding meat cut up into roasts.

Evidence that freezing tenderizes meat resulted from the development of a penetrometer which measures meat tenderness. There was deeper penetration of the instrument in meat when it had been frozen and thawed. Beef short loin steaks were frozen at 20 F, −10 F and −40 F, and then thawed. Compared with unfrozen steaks, the force required to cut across the muscle fibers (Warner-Bratzler shear) increased as follows: −40 F equals −10 F less than 20 F, less than 34 F (unfrozen). Short loins were aged for 5, 15, 25 and 35 days and frozen steaks were cut at these intervals. Shear force necessary for cutting the meat decreased with aging, but at all ages, lower shear force was found after freezing. Freezing temperature, −10 F versus 20 F, affected tenderness in the first experiments with meat up to 15 days of aging, but not beyond. No effect on tenderness was obtained by freezing steaks from loins aged for 32 days. Short loin steaks were frozen at 20, −10 and −40 F and tenderness determined during storage. At the two lower temperatures, shear force values did not change, but in the meat at 20 F, tenderness gradually increased for 112 to 140 days until it was at the same level as the other two. Steaks cut from beef short loins were frozen at 18, −10, −40 still air, −40 blast, −114 F and then thawed and cooked. Toughness decreased gradually with lower temperatures. Based upon our own figures for variability of such results, there is possibly a difference between −114 F and −10 F, but not from −10 to −40 F. Freezing in still air or blast freezing gave the same shear figures. Carcasses of calves, light and heavy steers, heifers and cows were cut up and steaks from seven parts of the animals frozen, thawed cooked and sheared. The meat of calves was not tenderized by freezing, but that from the larger and older cattle was. One cut, the fore shank, was as tough as ever after freezing.

Two research papers report no improvement in tenderness of meat by freezing. Rolled beef rib roasts were frozen at 0 F, then thawed and cooked. The shear figures were not significantly different from those of the unfrozen meat sheared at the beginning of the experiment. Experiments were conducted on the rate of freezing, or the time required to chill steaks to 20 F. Storage was at 0 F. Rate of freezing had no effect on tenderness.

EFFECT OF THAWING ON QUALITY

One characteristic of frozen meat is a loss of fluid when the meat is thawed. It is principally this feature which has caused objection to the frozen product. Extent of the fluid or drip loss depends on the kind of meat and on a number of other factors. Beef will generally show the greatest drip loss, and pork the least, with veal and lamb in intermediate positions.

Factors Influencing Drip Loss

The evidence on the effect of freezing and freezing rates tends to show that some relation exists between location of ice crystal or ice crystal size and amount of drip loss. In general, this is the case. Smaller drip loss was found from steaks frozen at −30 F than from ones frozen at 10 F. In an earlier paper high drip loss was associated with the extrafiber ice formation which occurs with slow freezing. Beef round steaks frozen at −15 F and 0 F and then cooked from both the frozen state or thawed before cooking showed the greatest total loss from cooking and drip in the slow-frozen steaks which were thawed before cooking. Drip loss in beef decreased with lower freezing temperature.

One factor overriding the effect of freezing temperature on drip loss is the surface area of the meat concerned. There is very little drip regardless of freezing temperature from large rib cuts where there is a relatively small surface area to volume. On the other hand with steaks one inch thick, thus having a relatively large area of cut surface to volume, the amount of drip loss increased with higher freezing temperatures. Blast freezing or slow freezing beef quarters affected drip to the same degree. Small pieces of meat cut from the quarters gave smaller loss from those quarters which were blast frozen. An extensive study was made of drip loss from frozen quarters of beef, cuts of beef from the thawed quarters and from small blocks sawed from the frozen meat. The failure to find any means for correlation between the figures for the